DEPARTMENT OF AGRICULTURE, CEYLON.

BULLETIN No. 68.

YIELD AND GROWTH IN HEVEA BRASILIENSIS.

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DEPARTMENT OF AGRICULTURE, CEYLON.

BULLETIN No. 68.

YIELD AND GROWTH IN HEVEA BRASILIENSIS.

Introduction.

SOME simple method of determining the best yielding trees is generally required by rubber planters. If individual yield records could be kept on estates, the best and worst yielding trees would be known, but the collection of such yield records is not practicable, and such information is, therefore, generally not available. If, however, the yielding capacity of a tree could be accurately gauged by some vegetative character, such as cortex thickness, or girth, which can be measured easily, the detection of the best yielding trees would be facilitated, and their selection thus made easy.

Selection of Hevea trees is made for two purposes, viz. :—

(1) To ascertain the poor yielders in order that they may be removed in thinning; and

(2) To ascertain the highest yielders for the purpose of propagation.

In a previous publication [4] are recorded certain data from a plot at Peradeniya Experiment Station of 161 trees raised from seed of the well-known, high-yielding, Henaratgoda No. 2 tree. These data include measurements of girth, cortex thickness, number of rows of latex vessels in the cortex (made in April, 1921, at the commencement of tapping, when the trees were 10 years old), and the yield for the first 10 months of tapping. Certain relationships were found between yield and girth, cortex thickness, and number of rows of latex vessels. It was considered desirable to repeat the investigation for the second year of tapping to ascertain if any change had occurred in the relationships recorded. At the same time it was decided that the scope of the investigation could usefully be extended to include relationships between other characters.

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With these objects in view, further specimens of cortex were taken, and other data requisite were collected. The specimens of cortex were taken in April, 1923, from the following positions :—

(1) Untapped cortex at 2 feet from ground level, adjacent to the spot from which the 1921 specimen was taken.
(2) Untapped cortex at 16 inches below (1), *i.e.*, at 8 inches above ground level.
(3) Renewing cortex at 2 feet adjacent to (1).

The figure (Fig. 1) illustrates the positions from which the cortex specimens were taken. In many cases large lateral roots have their origin on the stem at a point several inches

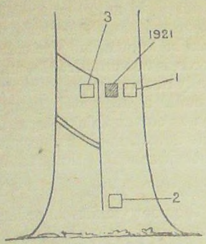

Fig. 1.

above ground level, and for this reason specimens were taken at 8 inches above ground level to ensure that root cortex was not included. From these specimens measurements of cortex thickness and number of latex vessel rows were taken, the methods employed being as described in Bulletin 55.

Girth was measured at 3 feet above ground level, at the same time, to conform with previous girth measurements.

Tapping was continued by the same tapping cooly throughout the year on alternate days, the trees being given no rest period. The same method of coagulation of the latex in the collecting cups was continued.

The yields given in Bulletin 55 [4] were for the first 10 months of tapping only, April 1, 1921, to January 31, 1922; the yields for the first complete year are now given in Table 1.* In this table are also recorded measurements for 1922–23 of the various characters referred to above. All yield figures are given in grammes of dry rubber.

During the course of these investigations six trees (Nos. 11, 22, 76, 85, 88, and 111) have practically ceased to yield latex. Tapping has, however, been continued on these trees. In view of their abnormal condition, data referring to them have not been included in the present investigation, which is therefore based on the remaining 155 trees.

Before proceeding to examine the physiological interrelationships of the various characters, a preliminary study of these characters is desirable to obtain information as to their variability. Such a study has already been made in Bulletin 55, and has been carried on in the present Bulletin in Part I. The investigation then proceeds to the examination of the physiological interrelationships in Part II. The application to estate practice of conclusions reached as a result of the present investigation is discussed in Part III.

PART I.

YIELD.

The yields of the 155 trees for the tapping year, 1921–22, ranged from 1,392 grammes (Tree 118) to 3,693 grammes of dry rubber (Tree 67), the mean yield being 2,249 grammes. It was pointed out in Bulletin 55 [4] that the yields are not evenly distributed throughout the range, but cluster round a point just below the mean. When the frequency distribution (Table 2) is expressed in the form of a graph, a curve is obtained which is approximately "normal." For convenience of comparison the curves for the tapping years, 1921–22 and 1922–23, are given on the same ordinates in Fig. 2. The 1922–23 curve is slightly skewed towards the lower limit of the range, the skewness, however, being considerably less than that in curves of yields of mixed populations (*cf.* Bulletin 55, Fig. 3).

* This table is given at the end of the Bulletin.

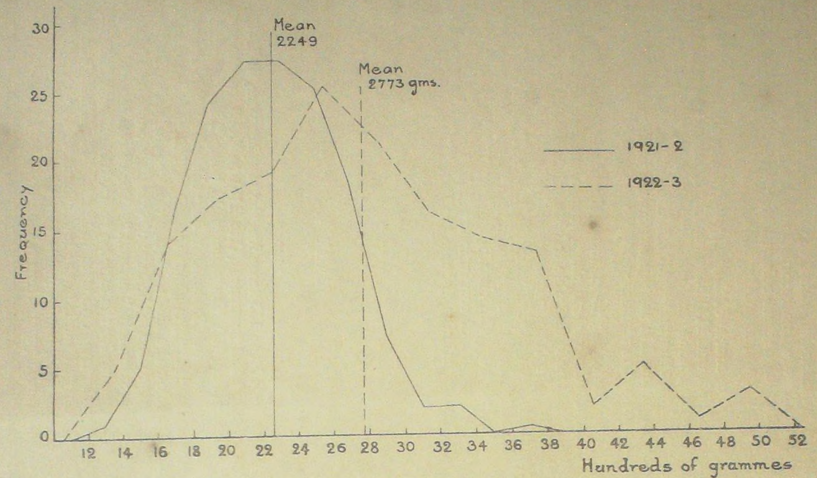

Fig. 2.—Frequency polygons for yield, 1921–22, and 1922–23.

Table 2.

Frequency Distribution of Yield for 1922–23.

Yield. Grammes.	Frequency.	Yield. Grammes.	Frequency.
1,200–1,499 ..	5	3,300–3,599 ..	14
1,500–1,799 ..	14	3,600–3,899 ..	13
1,800–2,099 ..	17	3,900–4,199 ..	2
2,100–2,399 ..	19	4,200–4,499 ..	5
2,400–2,699 ..	25	4,500–4,799 ..	1
2,700–2,999 ..	21	4,800–5,099 ..	3
3,000–3,299 ..	16		

For the tapping year, 1922–23, the yields ranged from 1,330 grammes (Tree 118) to 5,088 grammes (Tree 5), the mean yield being 2,773 grammes. The range, 3,758 grammes, is thus considerably greater than that of the previous year, 2,301 grammes. This indicates a greater variation in yield in the second year. The variability of one year may be readily compared with that of another year by means of the coefficient of variability. The coefficient of variability of the 161 trees for the first 10 months of tapping was given as 19·1 ; for the first 12 months' tapping of the 155 trees it was found to be 18·2 ; and for the second 12 months 29·2. The coefficient for the second year is thus greater than that for the first year, but is still much lower than those given for mixed populations by Whitby [10] and la Rue.[8] (76·19 and 60·32 respectively).

The yield curve for the second year exhibits an increased skewness. The skewness of the curve for the first year has been measured and found to be ·095, whereas for the second year it was ·289. Though the skewness has increased in the second year, it is still not so marked as that for a mixed population, for which Whitby [10] gives a coefficient of skewness of ·575.

Increase in Yield.

The mean yield has risen from 2,249 grammes in 1921–22 to 2,773 grammes in 1922–23, an increase of 23·3 per cent. The increase in yield of each tree has been expressed as a percentage of the first year's yield. It was found that Tree 109 had increased in yield by 70·7 per cent., whereas Tree 100 showed a decrease of 33·6 per cent., between which limits all the other percentage increases or decreases fall.

The frequency distribution of the percentage increase in yield is given in Table 3, and represented graphically in Fig 3.

Table 3.

Frequency Distribution of Percentage Increases in Yield.

Percentage Increase.	Frequency.	Percentage Increase.	Frequency.
— 35 to — 25·1 ..	3	+ 25 to + 34·9 ..	31
— 25 to — 15·1 ..	6	+ 35 to + 44·9 ..	21
— 15 to — 5·1 ..	7	+ 45 to + 54·9 ..	13
— 5 to + 4·9 ..	15	+ 55 to + 64·9 ..	3
+ 5 to + 14·9 ..	24	+ 65 to + 74·9 ..	2
+ 15 to + 24·9 ..	30		

From Fig. 3 it will be seen that the most frequent increase in yield lies between 20 and 30 per cent. The mean percentage increase is 21·29 per cent., and the coefficient of variability has been calculated to be 96. This high coefficient of variability indicates that there is a much greater variability in percentage increase in yield than there is in actual yield.

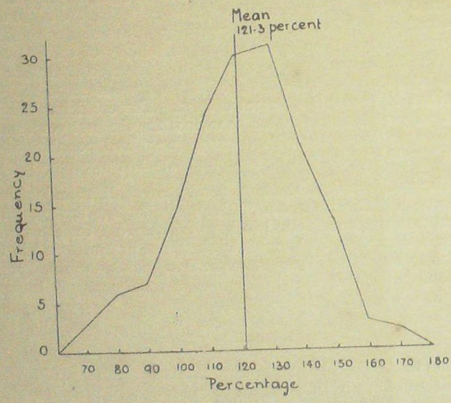

Fig. 3.—Frequency polygon for the percentage increase in yield.

Since increase in yield exhibits great variability, it would appear to be important to determine: (1) whether the trees which gave the highest yields in 1921–22 also gave the highest yields in 1922-23; and (2) whether the highest yielders have given the greatest proportional increases in yield.

Table 4.

Correlation between Yield, 1921–22, and Yield, 1922–23.

Yield, 1922–23, in Grammes.	Yield, 1921–22, in Hundreds of Grammes. 13	15	17	19	21	23	25	27	29	31	33	35	37	Total.
1,250 ..	1	.	.	1	.	.	.	.	.	.	.	.	.	2
1,500 ..	.	2	3	.	.	.	.	.	.	.	.	.	.	5
1,750 ..	.	2	7	5	1	1	1	.	.	.	.	.	.	17
2,000 ..	.	1	3	4	1	2	1	2	.	.	.	.	.	14
2,250 ..	.	.	2	7	6	2	.	.	.	.	.	.	.	17
2,500 ..	.	.	1	4	9	4	1	.	.	.	.	.	.	19
2,750 ..	.	.	.	3	5	5	1	.	.	.	.	.	.	14
3,000 ..	.	.	.	.	5	5	8	3	.	.	.	.	.	21
3,250 ..	.	.	.	.	.	5	5	1	.	.	.	.	.	11
3,500 ..	.	.	.	.	.	3	2	5	1	.	.	.	.	11
3,750 ..	.	.	.	.	.	.	6	3	3	1	.	.	.	13
4,000 ..	.	.	.	.	.	.	.	1	.	.	.	.	.	1
4,250 ..	.	.	.	.	.	.	.	1	2	.	1	.	.	4
4,500 ..	.	.	.	.	.	.	.	1	1	.	.	.	.	2
4,750 ..	.	.	.	.	.	.	.	1	.	.	.	.	.	1
5,000 ..	.	.	.	.	.	.	.	.	.	1	1	.	1	3
Total ..	1	5	16	24	27	27	25	18	7	2	2	0	1	155

Yield, 1922–23.		Yield, 1921–22.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
2,773 gm.	810·1 gm.	2,249 gm.	410·2 gm.

Coefficient of correlation = + ·83 ± ·017.

The degree of relationship existing between the yield in 1921–22 with that of 1922–23 is shown in Table 4. From this table the coefficient of correlation has been calculated to be + ·83 ± ·017. This indicates that a very close relationship exists between the yielding capacity of a tree in one year with its capacity in the succeeding year, and that on the average the high yielders of one year are also high yielders the following year. That the rule is not absolute is shown by the coefficient of correlation being less than unity. Consequently, it is to be expected that a careful examination of the individual yield records will show that some trees, which in the first year might have been termed high yielders, have during the second year of tapping become mediocre or even poor yielders. Such an examination was made, and the fact was revealed that Tree No. 67 which gave the highest yield in 1921–22 had fallen to 3rd place in 1922–23. Tree No. 48 fell from 21st place to 119th, Tree No. 100 from 31st to 143rd, and Tree No. 161 from 13th to 126th, and numerous other changes in the order of merit have occurred. Such changes would be expected owing to the great variability exhibited by increase in yield.

That the highest yielders have on the average made the greatest proportional increase in yield may be seen from Table 5 showing the correlation between yield, 1921–22, and the percentage increase in yield. The coefficient of correlation for these characters has been calculated to be + ·39 ± ·046 which indicates a marked relationship between these characters.

The trees of the plot may conveniently be divided into three groups: (1) high-yielding, (2) medium, and (3) low-yielding. If approximately half the trees are placed in the medium group, the limits of that class can be defined by means of the probable error of a single result.[6] The trees outside this class and at the upper end of the range will then form the high-yielding group, and conversely those at the lower end of the range will form the low-yielding group. This gives a convenient form of classification which will be frequently used in the following pages in connection with other characters. It will be noted that the class limits are obtained by computation, and that they are thus free from any bias due to personal selection.

In 1921–22 the mean yield was 2,249 grammes of dry rubber, and the probable error of a single result ± 276 grammes. The medium class will, therefore, include all trees with yields lying

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Table 5.

Correlation between Yield, 1921–22, and Percentage Increase in Yield, 1921–23.

Yield, 1921–22, in Grammes.	Percentage Increase in Yield. —30	—20	—10	0	10	20	30	40	50	60	70	Total.
1,300 ..	.	.	.	1	.	.	.	.	.	.	.	.. 1
1,500 ..	.	.	1	1	2	1	.	.	.	.	.	.. 5
1,700 ..	.	2	1	5	2	2	2	1	1	.	.	.. 16
1,900 ..	1	.	3	3	7	5	2	3	.	.	.	.. 24
2,100 ..	.	1	.	3	6	7	3	5	2	.	.	.. 27
2,300 ..	.	1	2	2	3	4	8	2	5	.	.	.. 27
2,500 ..	1	1	.	.	2	8	4	6	3	.	.	.. 25
2,700 ..	1	1	.	.	2	2	6	3	.	2	1	.. 18
2,900 ..	.	.	.	.	.	1	3	1	1	1	.	.. 7
3,100 ..	.	.	.	.	.	.	1	.	.	.	1	.. 2
3,300 ..	.	.	.	.	.	.	1	.	1	.	.	.. 2
3,500 ..	.	.	.	.	.	.	.	.	.	.	.	.. 0
3,700 ..	.	.	.	.	.	.	1	.	.	.	.	.. 1
Total ..	3	6	7	15	24	30	31	21	13	3	2	155

Yield, 1921–22. Mean.	Yield, 1921–22. Standard Deviation.	Percentage Increase in Yield. Mean.	Percentage Increase in Yield. Standard Deviation.
2,249 gm.	410·2 gm.	21·3 per cent.	20·4 per cent.

Coefficient of correlation = + ·39 ± ·046.

between 1,973 grammes and 2,525 grammes, the trees forming the low-yielding group are those with yields of less than 1,973 grammes, and the high-yielding group those having yields greater than 2,525 grammes. From an examination of Table 1 it can be ascertained that there were in 1921–22, 43 trees in the low-yielding group and 39 in the high-yielding group. A comparison of the mean yield records of these two groups is given in Table 6.

Table 6.

Comparison of Low-yielding Group with High-yielding Group.

	Number of Trees in Group.	Mean Yield. 1921–22.	Mean Yield. 1922–23.	Increase of Mean.	Mean Increase as Percentage of 1921–22 Yield.
		Grammes.	Grammes.	Grammes.	Grammes.
Low Group ..	43 ..	1,778 ..	1,945 ..	167 ..	$9 \cdot 3 \pm 1 \cdot 74$
High Group..	39 ..	2,779 ..	3,647 ..	868 ..	$30 \cdot 8 \pm 2 \cdot 42$

It will be seen from the foregoing table that the mean yield of the High Group in 1922–23 has increased by a greater amount than has the mean of the Low Group. Moreover, the mean increase, in proportion to the 1921–22 yields, is greater in the High than in the Low-yielding Group. The difference between the percentage increase in yield of the High and Low Groups is $21 \cdot 5 \pm 2 \cdot 98$ per cent. This difference is statistically significant, and indicates that the difference is real, and is not due merely to the variation of the percentage increases used in obtaining the averages. It may, therefore, be definitely concluded that, on the average, the trees which had the highest yields in 1921–22 have shown the greatest increases in yield during the following year. The increases are greater, not only in nett amount, but also in proportion to the initial yields.

GIRTH.

The frequency distribution of girth measurements made in 1923 is given in Table 7, and is given in graph form in Fig. 4. Here, as in the case of yield, the girth curves for 1921 and 1923 are given on the same ordinates. It will be noticed that the distribution for 1923 resembles closely that for 1921.

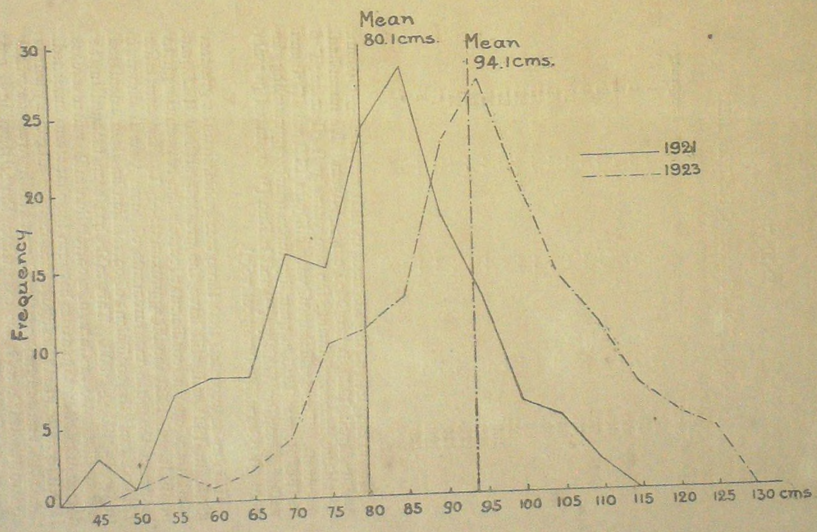

Fig. 4.—Frequency polygons for girth, 1921 and 1923.

Table 7.

Frequency Distribution of Girth for 1923.

Girth. cm.	Frequency.
50	1
55	2
60	1
65	2
70	4
75	10
80	11
85	13
90	23
95	27
100	20
105	14
110	11
115	7
120	5
125	4

The mean girth of the 155 trees in 1921 was 80·1 ± ·74 cm., and in April, 1923, it was 94·1 cm. ± ·79 cm. The mean had, therefore, increased during the two years by 14·1 cm. or 17·5 per cent. The coefficient of variability in 1921 was 17·0, and in 1923 it was 15·5, a quantity more nearly approaching the values given by Whitby (10) and la Rue (8) for mixed populations (14·8 and 14·0 respectively).

It is to be expected that those trees which had the greatest girth in 1921 will still have the greatest girth in 1923, and that, therefore, the coefficient of correlation between the girths of 1921 and 1923 should approximate + 1. The correlation between the girth measurements of these years is shown in Table 8, and the coefficient of correlation has been calculated to be + ·96 ± ·006. This table has been included in the text to illustrate the form of a correlation table, where a close degree of relationship exists between the characters concerned. It will be noted that the figures are arranged diagonally across the table, and are not scattered sporadically over the whole area of the table as is the case where the relationship is not marked, *cf.* Table 38.

Table 8.

Correlation Girth, 1921, and Girth, 1923.

Girth, 1921, in Centimetres.	Girth, 1923, in Centimetres. 50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	Total.
45 ..	1	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
50 ..	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1
55 ..	.	.	1	2	1	2	1	.	.	.	.	.	.	.	.	.	7
60 ..	.	.	.	.	.	5	2	1	.	.	.	.	.	.	.	.	8
65 ..	.	.	.	.	2	2	2	1	1	.	.	.	.	.	.	.	8
70 ..	.	.	.	.	.	1	5	5	4	1	.	.	.	.	.	.	16
75 ..	.	.	.	.	.	.	1	6	4	4	.	.	.	.	.	.	15
80 ..	.	.	.	.	.	.	.	.	13	9	2	.	.	.	.	.	24
85 ..	.	.	.	.	.	.	.	.	1	12	11	2	1	1	.	.	28
90 ..	.	.	.	.	.	.	.	.	.	1	7	8	1	1	.	.	18
95 ..	.	.	.	.	.	.	.	.	.	.	.	4	7	2	.	.	13
100 ..	.	.	.	.	.	.	.	.	.	.	.	.	2	2	3	.	7
105 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	1	2	2	5
110 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	2
Total ..	1	2	1	2	4	10	11	13	23	27	20	14	11	7	5	4	155

Girth, 1921.		Girth, 1923.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
80·1 cm.	13·69 cm.	94·10 cm.	14·56 cm.

Coefficient of correlation = + ·95 ± ·006.

Increase in Girth.

The increase in the girth has been calculated as a percentage of the 1921 girth. It was found that Tree 136 shows the smallest increase in girth, namely, 3·5 per cent., and that Tree 14 shows the greatest, 42·6 per cent. The frequency distribution is given in Table 9, and the frequency curve in Fig. 5.

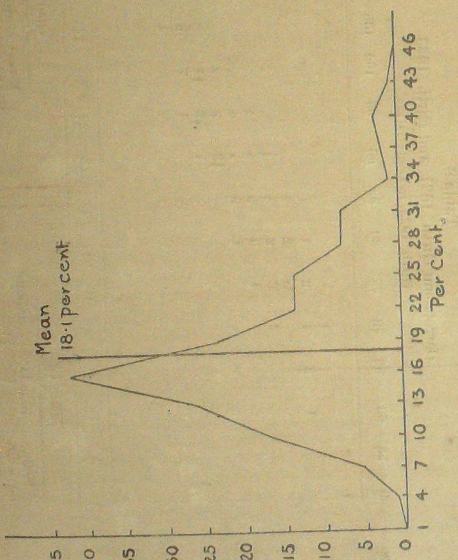

Fig. 5.—Frequency polygon for percentage increase in girth.

Table 9.

Frequency Distribution of Percentage Increases in Girth.

Percentage Increase.	Frequency.	Percentage Increase.	Frequency.
2·5 – 5·4 ..	1	23·5 – 26·4 ..	10
5·5 – 8·4 ..	5	26·5 – 29·4 ..	7
8·5 – 11·4 ..	17	29·5 – 32·4 ..	7
11·5 – 14·4 ..	26	32·5 – 35·4 ..	1
14·5 – 17·4 ..	42	35·5 – 38·4 ..	2
17·5 – 20·4 ..	23	38·5 – 41·4 ..	3
20·5 – 23·4 ..	10	41·5 – 44·4 ..	1

The mean value of these percentage increases in girth is 18·1 ± ·397, and the coefficient of variability is 40·5. The percentage increase in girth, therefore, shows greater variability than does the actual girth. The relationship between these two characters in this respect resembles the relationship existing between yield and yield increase.

It was shown in the previous Bulletin [4] that no correlation exists between the initial girth and the actual increase in girth. The coefficient of correlation for these characters for the first ten months of the experiment was found to be – ·001 ± ·053, which is practically zero. The relationship between the same characters for the two years covered by this investigation is represented by a coefficient of correlation of + ·08 ± ·054 which also closely approximates zero. It may therefore be concluded that the actual increases in girth of the smallest trees are, on the average, equal to the actual increases shown by the largest trees. This indicates a tendency towards an "evening up" in the size of the trees. This tendency is further demonstrated by the fact that the coefficient of variability for the 1923 girths is smaller than that for the 1921 girths (15·5 and 17·0 respectively).

It would appear that, if on the average the smaller trees show actual increases in girth equal to those of the initially larger trees, then the smaller trees must be growing at a proportionately greater rate. This conclusion may be reached by a study of the measurements of girth and percentage increase in girth given by Petch in a paper [7] on "Girth Increment of Hevea brasiliensis," where he records poor growth in the initially largest tree and rapid growth in the initially small trees. The degree of relationship between the size of the trees and the proportional rate of growth may be represented by the coefficient of correlation for the characters girth (in 1921) and the percentage increase in girth (for the two years under

Table 10.

Correlation between Girth, 1921, and Percentage Increase in Girth, 1921–23.

Girth, 1921, in Centimetres.		Percentage Increase in Girth. 4	7	10	13	16	19	22	25	28	31	34	37	40	43		Total.
45	..	.	.	.	.	1	1	.	.	.	.	1	.	.	.	..	3
50	..	.	.	.	.	.	.	.	.	.	1	.	.	.	.	..	1
55	..	.	.	2	.	1	.	.	1	.	.	.	1	2	.	..	7
60	..	.	.	.	.	.	.	2	1	1	2	.	.	1	1	..	8
65	..	1	1	.	.	2	.	1	1	1	.	.	1	.	.	..	8
70	..	.	.	2	1	4	1	1	2	3	2	.	.	.	.	..	16
75	..	.	1	1	3	3	2	1	3	1	.	.	.	.	.	..	15
80	..	.	.	4	6	9	3	2	.	.	.	.	.	.	.	..	24
85	..	.	.	3	8	7	7	1	1	.	1	.	.	.	.	..	28
90	..	.	3	2	2	7	3	.	.	.	1	.	.	.	.	..	18
95	..	.	.	1	4	3	3	1	.	1	.	.	.	.	.	..	13
100	..	.	.	1	1	2	2	1	.	.	.	.	.	.	.	..	7
105	..	.	.	1	1	2	.	.	1	.	.	.	.	.	.	..	5
110	..	.	.	.	.	1	1	.	.	.	.	.	.	.	.		2
Total	..	1	5	17	26	42	23	10	10	7	7	1	2	3	1		155

Girth, Increase. Mean.	Girth, Increase. Standard Deviation.	Girth, 1921. Mean.	Girth, 1921. Standard Deviation.
18·12 per cent.	7·32 per cent.	80·1 cm.	13·69 cm.

Coefficient of correlation = — ·40 ± 0·46.

observation). The correlation table for these characters is given in Table 10, from which the coefficient of correlation has been calculated to be — ·40 ± ·046. This indicates that the trees which had the *smallest* girth in April, 1921, have made on the average the *greatest* increase in girth in proportion to their initial size, and, conversely, the largest trees have made the smallest proportional increase. These facts may be further illustrated by a classification of the trees into three groups, viz., high, medium, and low, the same principle being employed as for yield. The low group, consisting of trees with girths of less than 70·9 cm. in April, 1921, contains 38 trees; the high group, consisting of trees with girths greater than 89·3 cm. in the same year, contains 37 trees. For purposes of comparison the data concerning these two groups are given in Table 11.

Table 11.

Comparison of Girth Low Group with Girth High Group.

	Number of Trees in Group.	Mean Girth. 1921. cm.	Mean Girth. 1923 cm.	Increase of Mean. cm.	Increase as percentage of 1921 Girth.
Low Group ..	38 ..	61·7 ..	76·2 ..	14·5 ..	23·4 ± 1·01
High Group..	37 ..	96·4 ..	111·2 ..	14·8 ..	15·4 ± ·49

From the foregoing table it is apparent that the mean increase in girth of the large trees is only 0·3 cm. greater than that of the small trees. In proportion, however, to their initial size, the small trees have increased their mean girth measurement by 23·4 per cent. against 15·4 per cent. of the large trees. The difference, 8·0 ± 1·12 per cent., is statistically significant, which indicates that the difference is real, and not due solely to the variable measurements from which the result has been obtained.

This conclusion should at once be compared with that reached for yield and percentage increase in yield in the preceding section.

Latex Vessel Rows.

In determining the number of rows of latex vessels in the various specimens of cortex, difficulties were frequently encountered owing to the presence of interrupted or ill-defined rows, to the branching or anastomosing of rows, and to the variations in visibility of rows in different specimens. Such difficulties in measurements, into which the personal element enters to a large extent, give rise to errors, commonly known as personal errors. Such characters as girth, cortex thickness, and yield are capable of exact measurement by instruments, and these measurements are consequently not liable to personal errors of a magnitude as great as the error in the determination of the number of latex vessel rows. Precautions were therefore taken to eliminate this error as far as possible; three sections of each specimen of cortex were examined by each of the authors, and the average of the readings was taken as the correct determination of the number of rows of latex vessels present.

Despite the precautions taken, it is improbable that the personal error was eliminated, but it may reasonably be concluded that it was considerably reduced. The presence of this error must be borne in mind when conclusions based on these determinations are considered. At the same time, from the nature of the precautions taken, the conclusions arrived at should not be vitiated to any great extent by the personal error.

In the case of Tree No. 41 an actual error was discovered in the number of latex vessel rows recorded for 1921. Instead of 8 rows, as previously stated, the number is 15. This corrected figure has been applied in all calculations based on data for the 12 months, 1921–22, and the results obtained do not materially differ from those published in Bulletin 55.

In Cortex at 2 Feet.

The mean number of latex vessel rows in the cortex of the 155 trees at 2 feet in 1921 was 11·3 ± ·158. In 1923 the mean number had increased to 19·7 ± ·257. The frequency distribution of the numbers of rows in 1923 is given in Table 12. During the two years the mean number of rows had increased by 8·4 ± ·302, *i.e.*, by 75 per cent. It has previously been pointed out [4] that the frequency curve in 1921 was approximately symmetrical and departed from the normal curve to a smaller extent than did the curve given by Bobilioff [2] for this character. In 1923 the curve is again approximately normal, and differs but slightly from the 1921 curve (see Fig. 6). It has been calculated that the skewness for the 1921 curve was — ·112 ± ·066, and for the 1923 curve + ·114 ± ·066. The curve, in each case, can therefore be considered as normal. From the data given by Bobilioff [2] the skewness of his curve has been calculated to be ·69 ± ·04, which shows a considerable difference from the results obtained from the present plot

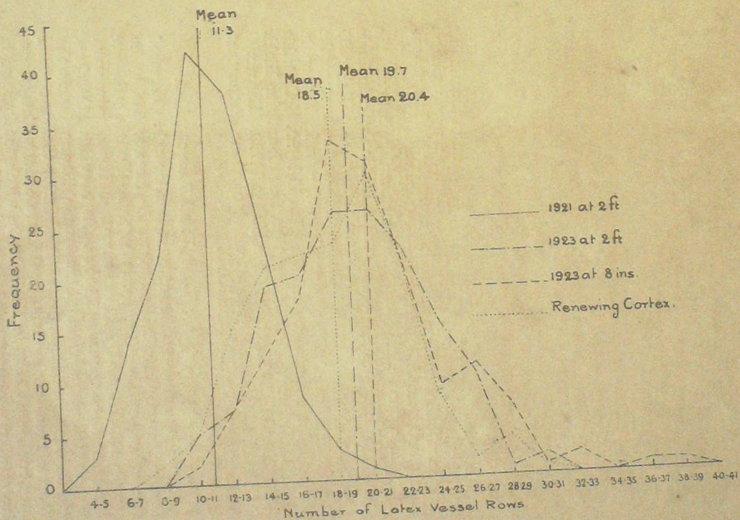

Fig. 6.—Frequency polygons for number of latex vessel rows at 2 feet, 1921 and 1923, at 8 inches, 1923, and in renewing cortex.

Table 12.

Frequency Distribution of Number of Latex Vessel Rows at 2 Feet in 1923.

Number of Rows.	Frequency.
10–11	5
12–13	7
14–15	19
16–17	20
18–19	26
20–21	26
22–23	22
24–25	15
26–27	10
28–29	1
30–31	2
32–33	0
34–35	0
36–37	1
38–39	1

There is a possibility of an annual variation in the number of latex vessel rows in the cortex. If there is a great variation in the rate of formation of new latex vessel rows, it is not unlikely that trees with few rows in one year may have numerous rows in a succeeding year. The relationship between the numbers of rows present in 1921 and in 1923 is shown in Table 13, from which a coefficient of correlation of $+ \cdot 54 \pm \cdot 039$ has been obtained. This indicates that on the average the trees which had the largest numbers of rows in 1921 again have the largest numbers in 1923. It will be noted that this coefficient of correlation is less than those found for Yield, 1921–22 and 1922–23, and for Girth, 1921 and 1923. This would indicate that the number of latex vessel rows is not so constant a character as are Girth and Yield.

Increase in Number of Latex Vessel Rows at 2 Feet.

Though the mean number of latex vessel rows has increased during the two years under review, the increase has, by no means, been uniform throughout the plot. No tree had fewer rows in 1923 than in 1921, though two trees showed no increase. The greatest increase was 23 rows. It is evident, therefore, that the trees have exhibited great variability as regards the number of rows which they have added during these two years. The variation which occurs in the rate of formation of new rows is clearly shown in Table 14, in which the increase is expressed as a percentage of the number of rows present in 1921. This table is represented graphically in Fig. 7.

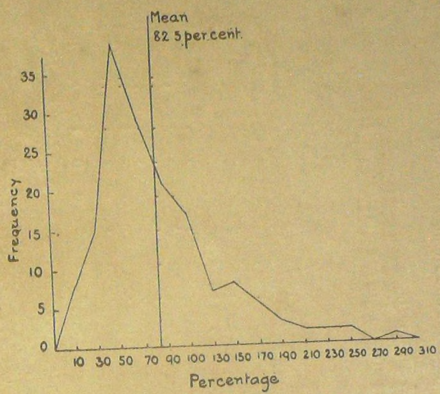

Fig. 7.—Frequency polygon for percentage increase in number of latex vessel rows at 2 feet.

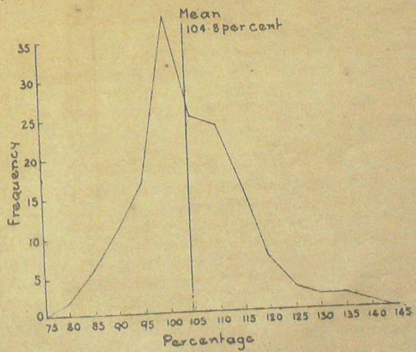

Fig. 8.—Frequency polygon for number of latex vessel rows at 8 inches as a percentage of the number at 2 feet.

Table 13.

Correlation between Number of Latex Vessel Rows in 1921 and Number of Latex Vessel Rows in 1923 at 2 Feet.

Number of Latex Vessel Rows, 1923.	Number of Latex Vessel Rows, 1921.																	Total.
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
10–11 ..	.	1	2	.	1	.	1	.	.	.	.	.	.	.	.	.	.	5
12–13 ..	.	.	.	.	3	1	2	1	.	.	.	.	.	.	.	.	.	7
14–15 ..	2	1	2	3	3	5	2	.	.	1	.	.	.	.	.	.	.	19
16–17 ..	.	.	1	2	2	2	3	6	3	.	1	.	.	.	.	.	.	20
18–19 ..	1	.	1	.	4	6	3	6	2	2	.	1	.	.	.	.	.	26
20–21 ..	.	1	1	.	.	3	4	7	.	5	4	.	.	1	.	.	.	26
22–23 ..	.	.	2	2	2	4	1	5	.	2	1	3	.	.	.	.	.	22
24–25 ..	.	.	2	.	.	3	2	1	4	.	1	1	.	1	.	.	.	15
26–27 ..	.	.	.	.	.	.	.	.	2	1	4	1	2	.	.	.	.	10
28–29 ..	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	1
30–31 ..	.	.	.	.	.	.	.	.	.	1	.	.	.	1	.	.	.	2
32–33 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
34–35 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
36–37 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1
38–39 ..	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1
Total ..	3	3	11	7	15	24	18	27	11	12	12	6	2	3	0	0	1	155

Number of Latex Vessel Rows, 1921.		Number of Latex Vessel Rows, 1923.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
11·3 rows	2·91 rows	19·7 rows	4·74 rows

Coefficient of correlation = + ·54 ± ·039.

Table 14.

Frequency Distribution of Percentage Increases in Number of Latex Vessel Rows at 2 Feet.

Percentage Increase.	Frequency.
0– 19	8
20– 39	15
40– 59	39
60– 79	29
80– 99	21
100–119	17
120–139	7
140–159	8
160–179	1
180–199	3
200–219	2
220–239	2
240–259	2
260–279	0
280–299	1

It will be seen from Fig. 7 that more trees fall into the 50 per cent. group than in any other. The mean percentage increase may be calculated from Table 14 to be $82 \cdot 5 \pm 2 \cdot 80$ per cent. The curve is therefore skewed towards the lower end of the range (skewness $= + \cdot 73$).

Since there is a considerable variation in the rate of increase in the number of latex vessel rows, it is necessary to determine whether the trees which had the largest number of rows in 1921 have shown the greatest increase, *i.e.*, whether there is any relationship existing between the initial number of rows and the rate of increase. In Table 15 is shown the relationship between the number of rows of latex vessels in 1921 and the percentage increase in the number of latex vessel rows during the two years. The coefficient of correlation for these characters has been calculated to be $- \cdot 51 \pm \cdot 04$. From this coefficient it is evident that on the average the trees which had the *smallest* number of rows in 1921 have made the *greatest* proportional increase, and those trees which had the largest number of rows initially have made the smallest increases.

This fact may be further demonstrated by dividing the trees into three groups as was done for yield. Trees which in 1921 had less than 10 rows constitute the Low Group, and those with more than 13 rows form the High Group. A comparison of these groups, consisting of 39 and 36 trees, respectively, is given in Table 16.

Table 15.

Correlation between Number of Latex Vessel Rows in 1921 and Percentage Increase in Number of Latex Vessel Rows, 1921–23, at 2 Feet.

Number of Latex Vessel Rows, 1921.	Percentage Increase in Number of Latex Vessel Rows. 10	30	50	70	90	110	130	150	170	190	210	230	250	270	290	Total.
5 ..	.	.	.	.	.	.	.	.	.	1	1	.	.	.	1	3
6 ..	.	.	.	1	.	.	1	.	.	.	.	1	.	.	.	3
7 ..	.	.	2	.	.	2	1	1	.	1	1	1	2	.	.	11
8 ..	.	.	.	3	.	2	.	.	1	1	.	.	.	.	.	7
9 ..	.	1	3	5	.	4	.	2	.	.	.	.	.	.	.	15
10 ..	.	1	5	2	6	3	4	3	.	.	.	.	.	.	.	24
11 ..	3	2	3	3	4	2	1	.	.	.	.	.	.	.	.	18
12 ..	1	3	9	7	5	1	.	1	.	.	.	.	.	.	.	27
13 ..	.	3	2	.	4	2	.	.	.	.	.	.	.	.	.	11
14 ..	1	2	6	1	1	1	.	.	.	.	.	.	.	.	.	12
15 ..	1	1	4	4	1	.	.	1	.	.	.	.	.	.	.	12
16 ..	1	1	3	1	.	.	.	.	.	.	.	.	.	.	.	6
17 ..	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	2
18 ..	1	1	.	1	.	.	.	.	.	.	.	.	.	.	.	3
19 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
20 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
21 ..	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1
Total ..	8	15	39	29	21	17	7	8	1	3	2	2	2	0	1	155

Number of Latex Vessel Rows, 1921.		Percentage Increase in Number of Latex Vessel Rows.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
11·28	2·91 rows	82·5	51·6 rows

Coefficient of correlation = — ·51 ± ·04.

Table 16.

Comparison of Latex Vessel Row Low Group with Latex Vessel Row High Group.

	Number of Trees in Group.	Mean Number of Latex Vessel Rows. 1921.	1923.	Increase of Mean.	Mean Increase as Percentage of 1921 Number.
Low Group ..	39 ..	7·7 ..	16·9 ..	9·2 ..	126 ± 7·36
High Group..	36 ..	15·4 ..	23·5 ..	8·1 ..	53 ± 3·16

From the above table it is evident that the mean number of latex vessel rows of the Low Group has increased by 9·2, whereas that of the High Group has increased by 8·1. The difference here is very small. The mean percentage increase of the Low Group is, however, 126 ± 7·36 and that of the High Group 53 ± 3·16. This difference 73 ± 8·01 per cent. is large, and should be taken as significant. Consequently, trees in the Low Group have produced proportionately more latex vessel rows than trees of the High Group.

Here then, as in girth, the Low Group shows a greater percentage increase than the High Group, and in this, both these characters differ from yield.

Number of Latex Vessel Rows at 8 Inches.

The frequency distribution of the number of latex vessel rows in the cortex at 8 inches from the ground is given in Table 17, and represented graphically in Fig. 6.

Table 17.

Frequency Distribution of Number of Latex Vessel Rows at 8 Inches in 1923.

Rows.	Frequency.	Rows.	Frequency.
10–11 ..	2	26–27 ..	11
12–13 ..	7	28–29 ..	7
14–15 ..	11	30–31 ..	1
16–17 ..	18	32–33 ..	2
18–19 ..	33	34–35 ..	0
20–21 ..	31	36–37 ..	1
22–23 ..	21	38–39 ..	1
24–25 ..	9		

The mean number of latex vessel rows in the cortex at 8 inches was found to be 20·4 ± ·258. This number is greater than that found for the cortex at 2 feet by ·7 ± ·36, a quantity which is statistically insignificant. In some trees there were more rows in the cortex at 8 inches than at 2 feet, the greatest increase being 8 rows; other trees showed fewer rows at 8 inches than at 2 feet, the greatest decrease being 4 rows. The relative values of these differences are best shown when the number of latex vessel rows at 8 inches is expressed as a percentage of the number at 2 feet. (Table 18 and Fig. 8.)

Table 18.

Frequency Distribution of Number of Latex Vessel Rows at 8 Inches as a Percentage of the Number at 2 Feet.

Percentage.	Frequency.	Percentage.	Frequency.
77·5– 82·4	2	117·5–122·4	7
82·5– 87·4	6	122·5–127·4	3
87·5– 92·4	11	127·5–132·4	2
92·5– 97·4	17	132·5–137·4	2
97·5–102·4	38	137·5–142·4	1
102·5–107·4	25	....	
107·5–112·4	24	....	
112·5–117·4	16	177·5–182·4	1

It will be seen from the above table that the greatest number of trees fall into the group 97·5 — 102·4 per cent., the mid point of which is 100. This class contains all the trees in which the number of rows in the cortex at 8 inches does not differ from the number in the cortex at 2 feet by more than 2½ per cent. The mean percentage has been calculated to be 104·8 ± ·67.

It is evident, therefore, that the mean number of latex vessel rows in the cortex at 2 feet and at 8 inches above ground level is approximately the same. Any increase in yield obtained as the tapping cut descends the tree cannot, therefore, be ascribed solely to the presence of an increasing number of latex vessel rows on descending. This will again be referred to in Part III.

Cortex Thickness.

The frequency distribution of cortex thickness in 1923 at 2 feet from ground level is given in Table 19, and represented graphically in Fig. 9.

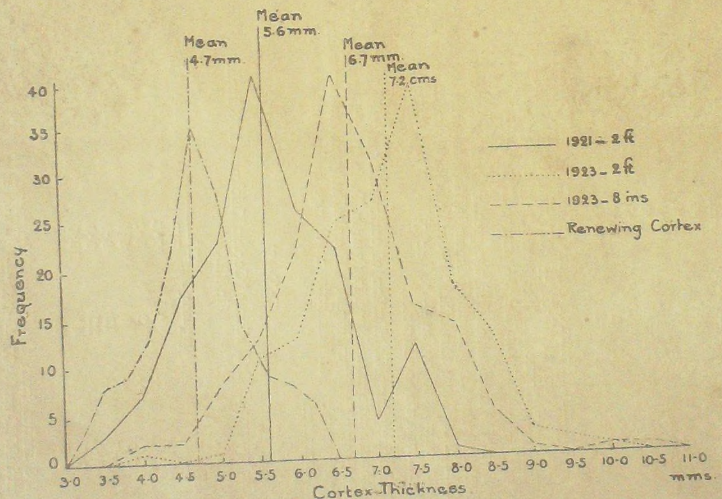

Fig. 9.—Frequency polygon for cortex thickness at 2 feet, 1921 and 1923, at 8 inches, 1923, and in renewing cortex.

Table 19.

Frequency Distribution of Cortex Thickness at 2 Feet in 1923.

Thickness. mm.		Frequency.	Thickness. mm.		Frequency.
4·0	..	1	7·5	..	39
4·5	..	0	8·0	..	18
5·0	..	1	8·5	..	13
5·5	..	11	9·0	..	3
6·0	..	13	9·5	..	2
6·5	..	25	10·0	..	1
7·0	..	27	10·5	..	1

The mean thickness of the cortex at 2 feet from the ground of the 155 trees was 5·64 ± ·051 mm. in April, 1921. In April, 1923, the mean thickness was 7·18 ± ·054 mm., which represents an increase of 1·54 mm. or 27·3 per cent.

That the trees which had the greatest cortex thickness in 1921 had also the greatest thickness in 1923 may be seen from Table 20. From this table the coefficient of correlation has been calculated to be + ·86 ± ·014. Cortex thickness is therefore a stable character.

The frequency distribution of cortex thickness in 1923 at 8 inches above ground level is given in Table 21, and is represented graphically in Fig. 9. The similarity of the curves in Fig. 9 is marked, and indicates no change in the variability of the character.

Table 21.

Frequency Distribution of Cortex Thickness at 8 Inches in 1923.

Thickness. mm.		Frequency.	Thickness. mm.		Frequency.
4·0	..	2	7·5	..	16
4·5	..	2	8·0	..	14
5·0	..	8	8·5	..	5
5·5	..	13	9·0	..	1
6·0	..	22	9·5	..	0
6·5	..	40	10·0	...	1
7·0	..	31			

At 8 inches from the ground the mean thickness of the cortex in 1923 was 6·65 ± ·053 mm., which is ·63 ± ·076 mm., or 8·8 per cent. less than that at 2 feet. The difference

Table 20.

Correlation between Cortex Thickness, 1921, and Cortex Thickness, 1923, at 2 Feet.

Cortex Thickness, 1923, in Millimetres.	Cortex Thickness, 1921, in Millimetres. 3·5	4·0	4·5	5·0	5·5	6·0	6·5	7·0	7·5	8·0	Total.
4·0 ..	1	.	.	.	.	.	.	.	.	.	.. 1
4·5 ..	.	.	.	.	.	.	.	.	.	.	.. 0
5·0 ..	1	.	.	.	.	.	.	.	.	.	.. 1
5·5 ..	1	4	5	1	.	.	.	.	.	.	.. 11
6·0 ..	.	1	5	6	1	.	.	.	.	.	.. 13
6·5 ..	.	2	6	8	7	2	.	.	.	.	.. 25
7·0 ..	.	.	1	4	14	7	1	.	.	.	.. 27
7·5 ..	.	.	.	4	17	11	6	1	.	.	.. 39
8·0 ..	.	.	.	.	1	6	9	.	2	.	.. 18
8·5 ..	.	.	.	.	.	.	5	2	6	.	.. 13
9·0 ..	.	.	.	.	.	.	1	1	.	1	.. 3
9·5 ..	.	.	.	.	.	.	.	.	2	.	.. 2
10·0 ..	.	.	.	.	.	.	.	.	1	.	.. 1
10·5 ..	.	.	.	.	.	.	.	.	1	.	.. 1
Total ..	3	7	17	23	40	26	22	4	12	1	155

Thickness Cortex, 2 Feet, 1923.		Thickness Cortex, 2 Feet, 1921.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
7·18 mm.	1·00 mm.	5·64 mm.	·947 mm.

Coefficient of correlation = $+ \cdot 86 \pm \cdot 014$.

·63 mm. is more than 8 times as great as its probable error, and may be considered to be significant. On the average, therefore, the thickness of the cortex is greater at 2 feet than at 8 inches. All measurements refer to the thickness of the living cortex excluding the dead bark scales. It is possible, therefore, that the greater thickness at 2 feet is due to the more rapid scaling of the bark at 8 inches. At the same time it should be pointed out that the root cortex is thinner than the stem cortex, and the influence of the root system on the lower portions of the stem would, therefore, tend toward the formation of thinner cortex in this region.

Increase in Cortex Thickness.

The increase in cortex thickness at 2 feet is best considered when expressed as a percentage of the initial thickness in 1921. An increase in cortex thickness (say, 1 mm.) made by a thin cortex represents a proportionately greater increase than does the same amount made by a thick cortex. The proprotional increase in cortex thickness has been calculated for each tree, and the frequency distribution is given in Table 22, and represented graphically in Fig. 10.

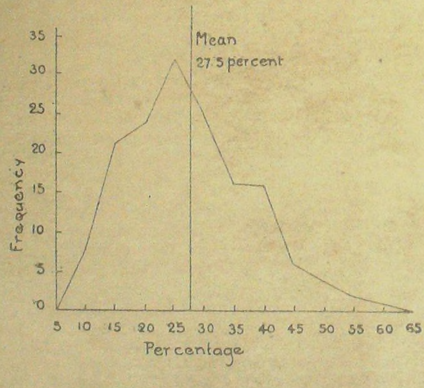

Fig. 10.—Frequency polygon for percentage increase in cortex thickness at 2 feet.

Table 22.

Frequency Distribution of Percentage Increases in Cortex Thickness.

Percentage Increase.	Frequency.
7·5–12·4	8
12·5–17·4	21
17·5–22·4	24
22·5–27·4	32
27·5–32·4	25
32·5–37·4	16
37·5–42·4	16
42·5–47·4	6
47·5–52·4	4
52·5–57·4	2
57·5–62·4	1

It may be calculated from Table 22 that the mean increase in cortex thickness is 27·5 ± ·572 per cent. From Fig. 10 it will be seen that the approximate mode is at 25 per cent., *i.e.*, less than the mean, and consequently the curve is skewed slightly towards the lower limit of the range.

The coefficient of variation for the percentage increase in cortex thickness is 38·4, whereas the coefficient of variation for actual cortex thickness at 2 feet is 13·9. The variation in increase of cortex thickness is greater than the variation shown in the actual measurements of thickness itself.

Is there any relationship between the initial cortex thickness and the percentage increase of cortex thickness? Have those trees, which originally had the thickest cortex at 2 feet, increased by the largest amount in proportion to their initial thickness? These questions may be answered by means of the coefficient of correlation for these characters, for which the correlation table is given in Table 23. The coefficient of correlation has been calculated to be — ·47 ± ·042. This indicates that, on the average, the cortices which were thickest in 1921 have increased by smaller amounts, in proportion to their initial thickness, than have the initially thinner cortices.

If the trees are divided into three classes according to the thickness of their cortex in 1921, it will be found that 39 trees had cortices thicker than 6·2 mm., and 36 trees, cortices thinner than 5·0 mm. The remaining trees have cortex thickness approximating the mean measurement for the plot. The mean measurements for the two extreme classes are given in able 24.

Table 23.

Correlation between Cortex Thickness, 1921, and Percentage Increase in Cortex Thickness, 1921–23, at 2 Feet.

Cortex Thickness. mm.	Percentage Increase in Cortex Thickness. 10	15	20	25	30	35	40	45	50	55	60	Total.
3·5	.	1	.	.	.	1	.	1	.	.	.	3
4·0	.	.	.	.	2	.	1	1	1	1	1	7
4·5	.	2	1	1	1	5	2	3	1	1	.	17
5·0	.	1	3	6	2	3	5	1	2	.	.	23
5·5	.	4	5	10	10	6	5	.	.	.	.	40
6·0	2	5	5	7	5	1	1	.	.	.	.	26
6·5	2	4	7	5	3	.	1	.	.	.	.	22
7·0	1	.	.	2	1	.	.	.	.	.	.	4
7·5	3	3	3	1	1	.	1	.	.	.	.	12
8·0	.	1	.	.	.	.	.	.	.	.	.	1
Total	8	21	24	32	25	16	16	6	4	2	1	155

Cortex Thickness, 1921.

Mean. 5·64 mm. Standard Deviation. ·947 mm.

Percentage Increase in Cortex Thickness, 1921–23, 2 Feet.

Mean. 27·52 per cent. Standard Deviation. 10·55 per cent.

Coefficient of correlation = — ·47 ± ·042.

Table 24.

Comparison of Cortex Thickness Low Group with Cortex Thickness High Group.

	Mean Cortex Thickness.		Difference.	Mean Percentage Increase in Thickness.
	1921.	1923.		
	mm.	mm.	mm.	
Low Group ..	4·4 ..	6·0 ..	1·6 ..	36·2 ± 1·24
High Group ..	6·9 ..	8·3 ..	1·4 ..	20·9 ± ·79

Though the mean cortex thickness of both groups had increased by approximately the same amount, the trees with the thinner cortex have increased their measurements by 36·2 ± 1·24 per cent., whereas the increase of the trees with the thicker cortex is 20·9 ± ·79 per cent. The difference 15·3 ± 1·47 per cent. is 10·4 times as large as its probable error, and is consequently significant.

It should be noted that the relationship between cortex thickness and percentage increase in cortex thickness is similar to that between girth and percentage increase of girth, and to that between number of latex vessel rows and percentage increase.

RENEWING CORTEX.

In estate practice tapping is begun at a height of 2 feet, and is continued down to the base of the tree. From this point the cut is changed to the other side of the tree, and again is continued down to the base. When there is no untapped cortex left in this region, tapping has to be carried out on cortex which has been previously tapped, and naturally the cut is placed on that portion of the cortex which has had the longest time for regeneration. This regenerated cortex is in practice termed "renewing cortex," and on its character will depend the future yield of the tree. The period allowed for this regeneration is usually 8 to 10 years, and depends on the system of tapping adopted. The time necessary for complete regeneration has been arrived at empirically, generally on estate experience of the rate of increase in thickness of the renewing cortex, or of the yields obtained from renewing cortex of various ages. Exact information is therefore desirable as to the rate of renewal, the character of the renewing cortex, its similarity to the untapped cortex, and its yield as compared with that of the untapped cortex preceding it. This last point cannot yet be dealt with in the present experiment, as tapping will not be commenced on the renewing cortex till about 1929. The other points, however, are discussed below. The specimens of renewing cortex examined here had had two years for regeneration.

Thickness.

The frequency distribution of the measurements of the thickness of the renewing cortex at 2 feet in April, 1923, are given in Table 25, and represented graphically in Fig. 9.

Table 25.

Frequency Distribution of Renewing Cortex Thickness Measurements.

Thickness mm.	Frequency.	Thickness. mm.	Frequency.
3·10–3·39 ..	3	4·90–5·19 ..	28
3·40–3·69 ..	8	5·20–5·49 ..	14
3·70–3·99 ..	9	5·50–5·79 ..	9
4·00–4·29 ..	13	5·80–6·09 ..	8
4·30–4·59 ..	22	6·10–6·39 ..	6
4·60–4·89 ..	35		

The mean thickness of the renewing cortex was 4·74 ± ·037 mm., the greatest thickness being 6·3 mm., and the least 3·2 mm. The coefficient of variability (14·3) is similar in magnitude to that of the untapped cortex at 2 feet (13·9). In Fig. 9 the resemblance between the frequency polygon for the renewing cortex and those for the untapped cortex at 2 feet and at 8 inches will be noticed. It will also be seen that the renewing cortex has not yet attained the thickness of the untapped cortex for 1921.

The renewing cortex thickness expressed as a percentage of untapped cortex at 2 feet in 1923 is given in Table 26. From this it will be seen that the lowest nine trees have renewing cortex of half the thickness of their untapped cortex, and the highest tree has the former approximately equal to the latter.

Table 26.

Frequency Distribution of Renewing Cortex Thickness as a Percentage of Untapped Cortex Thickness.

Percentage.	Frequency.	Percentage.	Frequency.
47·5–52·4 ..	9	72·5–77·4 ..	16
52·5–57·4 ..	20	77·5–82·4 ..	10
57·5–62·4 ..	26	82·5–87·4 ..	7
62·5–67·4 ..	33	87·5–92·4 ..	5
67·5–72·4 ..	28	92·5–97·4 ..	1

The mean of the foregoing frequency distribution is 66·8 ± ·54 per cent., and this indicates that on the average the renewing cortex, after two years' growth, has attained two-thirds of the thickness of the adjacent untapped cortex.

Table 27.

Correlation between Untapped Cortex Thickness, 1923, and Renewing Cortex Thickness, 1923, at 2 Feet.

Thickness of Renewing Cortex in Millimetres.	Untapped Cortex Thickness in Millimetres. 4·0	4·5	5·0	5·5	6·0	6·5	7·0	7·5	8·0	8·5	9·0	9·5	10·0	10·5	Total.
3·2 ..	.	.	.	2	1	.	.	.	.	.	.	.	.	.	3
3·5 ..	1	.	.	2	3	1	1	.	.	.	.	.	.	.	8
3·8 ..	.	.	1	1	.	2	1	3	1	.	.	.	.	.	9
4·1 ..	.	.	.	2	2	3	.	3	3	.	.	.	.	.	13
4·4 ..	.	.	.	1	1	4	5	6	3	2	.	.	.	.	22
4·7 ..	.	.	.	2	2	7	7	10	2	3	1	.	1	.	35
5·0 ..	.	.	.	1	3	3	8	8	3	.	.	2	.	.	28
5·3 ..	.	.	.	.	1	2	1	3	3	2	2	.	.	.	14
5·6 ..	.	.	.	.	.	1	.	4	1	3	.	.	.	.	9
5·9 ..	.	.	.	.	.	1	2	.	2	2	.	.	.	1	8
6·2 ..	.	.	.	.	.	1	2	2	.	1	.	.	.	.	6
Total ..	1	0	1	11	13	25	27	39	18	13	3	2	1	1	155

Thickness, Renewing Cortex.		Thickness, Untapped Cortex at 2 Feet, 1923.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
4·74 mm.	·681 mm.	7·18 mm.	1·00 mm.

Coefficient of correlation = + ·42 ± ·045.

The relationship between the thickness of untapped cortex and of renewing cortex is shown in Table 27, from which a coefficient or correlation of $+ \cdot 42 \pm \cdot 045$ was obtained. This indicates that the trees with thick untapped cortex tend to produce a thick renewing cortex. This is somewhat to be expected, as it has already been shown that those trees which had the thickest cortices in 1921 had on the average the thickest cortices in 1923. It would appear evident, therefore, that thickness of cortex is an inherent character, which determines not only the thickness of the untapped cortex, but also that of the renewing cortex.

Number of Latex Vessel Rows.

The number of latex vessel rows found in the renewing cortex of each tree is given in Table 1. The frequency distribution for this character is given in Table 28, and represented graphically in Fig. 6.

Table 28.

Frequency Distribution of the Number of Latex Vessel Rows in Renewing Cortex.

Number of Latex Vessel Rows.		Frequency.	Number of Latex Vessel Rows.		Frequency.
8–9	..	2	24–25	..	8
10–11	..	5	26–27	..	2
12–13	..	15	28–29	..	4
14–15	..	21	30–31	..	1
16–17	..	22	....		
18–19	..	23	....		
20–21	..	30			
22–23	..	21	40–41	..	1

It will be noticed that there is one outstanding tree (Tree No. 41) with 41 rows. This tree has 10 rows more than the next best tree, and 22 more than the average (the mean being $18 \cdot 6 \pm \cdot 249$ rows). The polygon representing the frequency distribution (Fig. 6) closely resembles those for the number of rows at 2 feet and at 8 inches in the untapped cortex.

The mean number of rows of latex vessels in the untapped cortex at 2 feet in 1923 was $19 \cdot 7 \pm \cdot 257$, which is only $1 \cdot 1 \pm \cdot 36$ greater than the mean number in the renewing cortex. This quantity, however, is not statistically significant, and it may, therefore, be concluded that the mean number of latex vessel rows in the renewing cortex, after two years' regeneration, is equal to that of the untapped cortex.

The process of renewal may, however, result in the formation of a renewed cortex differing considerably from the untapped cortex, and any change would probably affect the number of latex vessel rows present. It is therefore of interest to determine whether those trees which had the greatest number of latex vessel rows in the untapped cortex maintain this position in regard to their renewing cortex. The coefficient of correlation between the number of latex vessel rows in the untapped cortex at 2 feet, and in the renewing cortex at 2 feet in 1923 (Table 29), is $+ \cdot 69 \pm \cdot 028$ which indicates a decided relationship between these characters. The trees, which on the average have the greatest number of latex vessel rows in the untapped cortex, also have the greatest number in the renewing cortex.

Evidently, the number of latex vessel rows is an inherent character. Those trees which had the greatest number in 1921 have the greatest number in 1923 and also have the greatest number in the renewing cortex, the number being determined by the character.

PART II.

It has already been shown that considerable variation exists in the yielding capacity of the trees under investigation. Further those trees, which gave the highest yields during the first year of tapping, have on the average given the highest yields during the second year, and similarly with girth, cortex thickness, and number of latex vessel rows in the cortex at 2 feet above ground level. It has also been established for the first year of tapping that the trees giving the highest yields are also those with the greatest girth, most numerous latex vessel rows, and thickest cortex. In other words the character yield is interrelated with the characters—girth, number of latex vessel rows, and cortex thickness. The question naturally arises as to whether the relationships established for the first year of tapping still hold good for the second year.

It has also been shown that during the two years of tapping some trees have increased in cortex thickness, girth, &c., by proportionately greater amounts than have other trees. Have those trees which have shown the greatest proportionate increase in girth, cortex thickness, &c., also shown the greatest proportionate increase in yield ?

Table 29.

Correlation between Number of Latex Vessel Rows in Untapped Cortex and Number of Latex Vessel Rows in Renewing Cortex at 2 Feet in 1923.

Number of Latex Vessel Rows in Untapped Cortex.	Number of Latex Vessel Rows in Renewing Cortex. 9–10	11–12	13–14	15–16	17–18	19–20	21–22	23–24	25–26	27–28	29–30	31–32	33–34	35–36	37–38	39–40	41–42	Total.
10–11 ..	.	3	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5
12–13 ..	1	2	1	2	1	.	.	.	.	.	.	.	.	.	.	.	.	7
14–15 ..	2	1	2	8	3	3	.	.	.	.	.	.	.	.	.	.	.	19
16–17 ..	.	.	5	4	2	5	3	.	1	.	.	.	.	.	.	.	.	20
18–19 ..	.	.	4	6	6	7	2	1	.	.	.	.	.	.	.	.	.	26
20–21 ..	.	2	1	3	7	1	10	1	.	1	.	.	.	.	.	.	.	26
22–23 ..	.	1	1	1	4	7	4	3	1	.	.	.	.	.	.	.	.	22
24–25 ..	.	.	.	.	3	1	5	4	1	.	1	.	.	.	.	.	.	15
26–27 ..	.	.	.	.	.	3	.	3	.	4	.	.	.	.	.	.	.	10
28–29 ..	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1
30–31 ..	.	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	2
32–33 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0
34–35 ..	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	0
36–37 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1
38–39 ..	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Total ..	3	9	16	24	26	29	24	13	3	5	1	1	0	0	0	0	1	155

Number of Latex Vessel Rows in Untapped Cortex, 2 Feet, 1923.		Number of Latex Vessel Rows in Renewing Cortex.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
19·7 rows	4·74 rows.	18·6 rows	4·59 rows

Coefficient of correlation = + ·69 ± ·028.

The following pages are devoted to the elucidation of such problems. Definite information on these points will be of value in the selection of best yielding trees, and may have some influence on general estate practice.

Yield.

The coefficient of correlation between yield for 1921–22 and yield for 1922–23 is + ·83 ± ·017. This indicates that generally the high-yielding trees of 1921–22 are also the high-yielding trees of 1922–23, and the low-yielding trees continue to give low yields. In so far as yield may be termed a physiological function of the tree—it is, indeed, a response to the stimulus of wounding—it may be treated as a character of the tree, and the constancy exhibited by it for the two years under review is good evidence as to its inherent nature.

Certain relationships were established between yield and other characters in 1921–22 in a previous publication [4], and for convenience these are tabulated below, and may be compared with the corresponding relationships determined for 1922–23:—

Table 30.

Coefficients of Correlation between Yield, 1922–23, and Other Characters.

Other Characters.	Coefficients, 1921–22.	Coefficients, 1922–23.
Yield, 1921–22 ..	—	.. + ·83 ± ·017
Girth, 1923 ..	+ ·58 ± ·035	.. + ·56 ± ·037
Cortex thickness, 2 feet, 1923	+ ·42 ± ·044	.. + ·36 ± ·047
Number of latex vessel rows, 2 feet, 1923 ..	+ ·46 ± ·042	.. + ·38 ± ·046
Number of latex vessel rows, renewing cortex ..	—	.. + ·36 ± ·047
Thickness, renewing cortex..	—	.. + ·34 ± ·048

The relationships between the characters in the foregoing table have, as will be seen, remained practically constant for the two years. It should be noted that the coefficient of correlation with girth is higher, and remains more nearly constant than do the coefficients for cortex thickness and number of latex vessel rows. Accordingly, as an indirect measure of yield, girth is a more accurate and reliable character than are cortex thickness and number of latex vessel rows. The differences between the coefficients for 1921–22 and 1922–23 are: girth ·02 ± ·051, cortex thickness ·06 ± ·064, latex vessel rows ·08 ± ·057; none of which is significant.

Table 31.

Correlation between Yield, 1922–23, and Renewing Cortex Thickness, 1923.

Yields, 1922–23. Grammes.	Renewing Cortex Thickness in Millimeters. 3·2	3·5	3·8	4·1	4·4	4·7	5·0	5·3	5·6	5·9	6·2	Total.
1,250 ..	.	.	.	.	.	.	2	.	.	.	.	2
1,500 ..	.	1	1	3	.	.	.	.	.	.	.	5
1,750 ..	1	2	3	1	2	5	.	.	.	2	1	17
2,000 ..	1	.	2	.	1	2	5	2	1	.	.	14
2,250 ..	.	.	1	3	4	2	5	2	.	.	.	17
2,500 ..	1	2	.	2	4	4	3	1	2	.	.	19
2,750 ..	.	1	.	.	2	5	1	2	1	1	1	14
3,000 ..	.	1	2	1	4	5	4	2	1	1	.	21
3,250 ..	.	.	.	1	1	4	3	1	.	.	1	11
3,500 ..	.	.	.	1	2	3	2	2	.	.	1	11
3,750 ..	.	1	.	.	2	3	2	1	2	1	1	13
4,000 ..	.	.	.	1	.	.	.	.	.	.	.	1
4,250 ..	.	.	.	.	.	.	1	1	.	2	.	4
4,500 ..	.	.	.	.	.	1	.	.	1	.	.	2
4,750 ..	.	.	.	.	.	1	.	.	.	.	.	1
5,000 ..	.	.	.	.	.	.	.	.	1	1	1	3
Total ..	3	8	9	13	22	35	28	14	9	8	6	155

Yield, 1922–23.		Renewing Cortex Thickness, 1923.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
2,773 gm.	810·1 gm.	4·74 mm.	·681 mm.

Coefficient of correlation + ·34 ± ·048.

Table 32.

Correlation between Yield, 1922–23, and Number of Latex Vessel Rows in Renewing Cortex, 1923.

Yield. Grammes.		Number of Latex Vessel Rows in Renewing Cortex. 9–10	11–12	13–14	15–16	17–18	19–20	21–22	23–24	25–26	27–28	29–30	31–32	33–34	35–36	37–38	39–40	41–42		Total.
1,250	..	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	..	2
1,500	..	1	1	.	1	.	.	2	.	.	.	.	.	.	.	.	.	.	..	5
1,750	..	1	2	3	5	3	2	.	1	.	.	.	.	.	.	.	.	.	..	17
2,000	..	.	.	2	1	3	4	3	.	.	1	.	.	.	.	.	.	.	..	14
2,250	..	.	1	2	5	2	3	2	.	2	.	.	.	.	.	.	.	.	..	17
2,500	..	1	3	3	1	3	5	1	1	.	1	.	.	.	.	.	.	.	..	19
2,750	..	.	1	1	4	1	2	2	3	.	.	.	.	.	.	.	.	.	..	14
3,000	..	.	.	2	4	4	5	3	1	1	1	.	.	.	.	.	.	.	..	21
3,250	..	.	.	.	.	4	3	3	1	.	.	.	.	.	.	.	.	.	..	11
3,500	..	.	.	1	.	1	3	1	3	.	1	.	1	.	.	.	.	.	..	11
3,750	..	.	1	.	1	3	1	3	2	.	1	.	.	.	.	.	.	1	..	13
4,000	..	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	..	1
4,250	..	.	.	.	1	.	1	2	.	.	.	.	.	.	.	.	.	.	..	4
4,500	..	.	.	.	.	1	.	1	.	.	.	.	.	.	.	.	.	.	..	2
4,750	..	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	..	1
5,000	..	.	.	.	.	.	.	1	1	.	.	1	.	.	.	.	.	.	..	3
Total	..	3	9	16	24	26	29	24	13	3	5	1	1	0	0	0	0	1		155

Yield, 1922–23.		Number of Latex Vessel Rows in Renewing Cortex.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
2,773 gm.	810·1 gm.	18·6 rows	4·59 rows

Coefficient of correlation + ·365 ± ·047.

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The coefficients of correlation between yield and the new characters—thickness and number of latex vessel rows of renewing cortex—have been calculated (Tables 31 and 32 respectively), and are given in Table 30. It is noteworthy that the relationship between yield and number of latex vessel rows in the renewing cortex is as close as that existing between yield and number of latex vessel rows in untapped cortex. A similar relationship exists between yield and thickness of untapped cortex and yield and thickness of renewing cortex. The relationships, therefore, between yield and characters of untapped cortex are not altered in degree in the succeeding renewing cortex.

GIRTH.

It was shown in a former Bulletin[4] that the character girth was interrelated, not only with yield, but also with the characters, cortex thickness and number of latex vessel rows. The coefficients of correlation for these characters, obtained from measurements made in 1921, are repeated in Table 33 to facilitate comparison with the coefficients obtained from the 1923 measurements.

Table 33.

Coefficients of Correlation between Girth, 1923, and Other Characters.

Other Characters.	Coefficients. 1921–22.	Coefficients. 1922–23.
Girth, 1921 ..	—	+ ·95 ± ·006
Yield, 1922–23 ..	+ ·58 ± ·035	+ ·56 ± ·037
Cortex thickness, 2 feet, 1923	+ ·63 ± ·032	+ ·56 ± ·037
Number of latex vessel rows, 2 feet, 1923 ..	+ ·40 ± ·046	+ ·11 ± ·054

From the above table it will be seen that, though in 1921 there was a decided relationship between girth and number of latex vessel rows, the same relationship is not shown by the 1923 measurements. The relationship between girth and cortex thickness has, however, remained constant.

LATEX VESSEL ROWS.

The correlation table for number of latex vessel rows at 2 feet in 1921 and in 1923 gives a coefficient of + ·53 ± ·039, and this indicates that those trees which had most latex vessel rows in the first year still have most in the second year. The mean number of rows per tree at 2 feet from the ground rose from 11·3 rows to 19·7 rows in the period under review. How then have these various increases in the individual trees of the plot affected the degree of relationship of this character with other characters as compared with the previous year? For ready comparison the coefficients of correlation between number of latex vessel rows and other characters for the years 1921 and 1923 are set down side by side in the following table :—

Table 34.

Coefficients of Correlation between Number of Latex Vessel Rows, 1923, and Other Characters.

Other Characters.	Coefficients.	
	1921–22.	1922–23.
Number of latex vessel rows, 2 feet, 1921 ..	—	.. + ·54 ± ·039
Yield, 1922–23 ..	+ ·46 ± ·042	.. + ·38 ± ·046
Girth, 1923 ..	+ ·40 ± ·046	.. + ·11 ± ·054
Cortex thickness, 2 feet, 1923	+ ·34 ± ·047	.. + ·14 ± ·053

The coefficient of correlation between number of latex vessel rows and yield has dropped slightly in 1923, but remains of the same order of magnitude as in 1921, and the relationship of these two characters is, therefore, unchanged.

In the cases, however, of girth and cortex thickness, there is a decided drop in 1923 in each coefficient. While in 1921 these coefficients indicated a small but definite correlation between these characters and the number of latex vessel rows, in 1923 these coefficients do not indicate any decided relationship.

Cortex Thickness.

The relationships of cortex thickness with other characters have been discussed in the preceding paragraphs under the characters concerned. The following table brings together the various coefficients of correlation to facilitate comparison :—

Table 35.

Coefficients of Correlation between Cortex Thickness, 1923, and Other Characters.

Other Characters.	Coefficients.	
	1921–22.	1922–23.
Cortex thickness, 1921 ..	—	.. + ·86 ± ·014
Yield, 1922–23 ..	+ ·46 ± ·044	.. + ·36 ± ·047
Girth, 1923 ..	+ ·63 ± ·032	.. + ·56 ± ·037
Number of latex vessel rows, 2 feet, 1923 ..	+ ·34 ± ·047	.. + ·14 ± ·053

RENEWING CORTEX.

It has already been shown that those trees, which had the thickest untapped cortex, have on the average produced the thickest renewing cortex. Also those trees which had the largest number of latex vessel rows in the untapped cortex have on the average the largest number in the renewing cortex. The coefficients of correlation for these characters are for convenience given in the following table, together with the coefficients for other relationships of the characters of the renewing cortex :—

Table 36.

Coefficients of Correlation between Characters of Renewing Cortex and Other Characters.

Other Characters.	Renewing Cortex.	Coefficients.
Yield, 1922–23	Thickness	+ ·34 ± ·048
Do.	Number of latex vessel rows	+ ·36 ± ·049
Cortex thickness, 2 feet, 1923	Thickness	+ ·42 ± ·045
Number of latex vessel rows, 2 feet, 1923	Number of latex vessel rows	+ ·69 ± ·028
Renewing cortex thickness	do.	+ ·41 ± ·045

From the foregoing table it will be seen that the relationship between the thickness of the renewing cortex and yield is the same as that between thickness of untapped cortex and yield (+ ·36 ± ·047). The relationship between the number of rows of latex vessels in renewing cortex and yield also is similar to that between number of latex vessel rows in untapped cortex and yield (+ ·38 ± ·047). These facts are additional proof of the statement already recorded, that the renewing cortex does not differ in character from the untapped cortex which preceded it. The coefficient of correlation between number of latex vessel rows in renewing cortex and in untapped cortex is considerably higher than that between thickness of renewing and untapped cortex, and indicates a correspondingly closer resemblance. Cortex thickness measurements would be affected by the rate of exfoliation of dead bark scales, a factor which would not affect a count of latex vessel rows to the same extent. At the same time it would appear not unlikely that latex vessel rows are laid down at fairly definite intervals, the total number present in the cortex being dependent on the character of the cortex concerned. In other words the number of latex vessel rows in the cortex is an inherent character exhibited by both renewing and untapped cortex.

Table 37.

Correlation between Thickness and Number of Latex Vessel Rows in Renewing Cortex, 1923.

Thickness, mm.	Number of Latex Vessel Rows. 9–10	11–12	13–14	15–16	17–18	19–20	21–22	23–24	25–26	27–28	29–30	31–32	33–34	35–36	37–38	39–40	41–42	Total.
3·2	.	1	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	3
3·5	1	2	1	.	.	2	2	.	.	.	.	.	.	.	.	.	.	8
3·8	.	1	1	3	3	.	1	.	.	.	.	.	.	.	.	.	.	9
4·1	1	.	3	6	1	.	2	.	.	.	.	.	.	.	.	.	.	13
4·4	1	.	.	3	9	6	.	2	.	1	.	.	.	.	.	.	.	22
4·7	.	3	5	4	6	6	4	4	2	1	.	.	.	.	.	.	.	35
5·0	.	.	4	2	3	11	4	2	1	1	.	.	.	.	.	.	.	28
5·3	.	.	1	3	2	2	3	3	.	.	.	.	.	.	.	.	.	14
5·6	.	1	.	.	1	1	3	1	.	2	.	.	.	.	.	.	.	9
5·9	.	1	.	2	.	1	3	.	.	.	1	.	.	.	.	.	.	8
6·2	.	.	.	.	1	.	2	1	.	.	.	1	.	.	.	.	1	6
Total ..	3	9	16	24	26	29	24	13	3	5	1	1	0	0	0	0	1	155

Thickness in Renewing Cortex.		Number of Latex Vessel Rows in Renewing Cortex.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
4·74 mm.	·681 mm.	18·6 rows	4·59 rows

Coefficient of correlation + ·41 ± .045.

The relationship between the thickness of the renewing cortex and the number of latex vessel rows which it contains (Table 37) corresponds to that determined for these characters in untapped cortex in 1921 (+ ·34 ± ·047). It differs, however, considerably from the relationship in untapped cortex in 1923. It should be noted here that the latex vessel rows in the renewing cortex are much more distinct than in untapped cortex, and a count is, therefore, not liable to such a great personal error.

Relationship between the Proportional Increases in Yield and in Other Characters.

It has already been shown that high yield is interrelated with big girth, numerous latex vessel rows, and thick cortex. It has also been indicated that there is considerable variation, not only in the actual quantities by which the yield of individual trees have increased during the second year of tapping, but also in the proportion that quantity bears to the first year's yield. In the second year the yield of some trees increased by more than 50 per cent. of their first year's yield, others have shown decreases, and some have remained constant. Variations have also occurred in the proportional increases in girth, number of latex vessel rows, and cortex thickness.

It would appear to be of some importance, therefore, to determine whether a change in yield has been accompanied by a corresponding change in girth, number of latex vessel rows, or cortex thickness. If a change in one character results in a corresponding change in another, it indicates that these characters are closely interlinked, and that any factor affecting one character will affect the others by a corresponding amount owing to the interlinking.

The true value of a change in a character is best measured by representing the increase or decrease as a percentage of the initial measurement. It is possible, therefore, by correlating percentage increase in yield with percentage increases in other characters, to determine whether yield is interlinked—and the extent of the interlinking—with these characters, and whether any relationship found between yield and other characters may be due to conditions other than the close interlinking of the characters.

In Table 38 the proportional increase in yield is correlated with the proportional increase in girth, and a coefficient of correlation of + ·03 ± ·054 has been obtained. This indicates that a change in yield, on the average, is *not* accompanied by a corresponding change in girth.

Table 38.

Correlation between Percentage Increase in Yield and Percentage Increase in Girth.

Percentage Increase in Girth.	Percentage Increase in Yield. —30	—20	—10	0	10	20	30	40	50	60	70	Total.
4 ..	.	.	.	.	.	1	.	.	.	.	.	.. 1
7 ..	.	.	1	2	1	.	1	.	.	.	.	.. 5
10 ..	.	.	2	3	3	5	3	.	.	.	1	.. 17
13 ..	.	1	.	2	5	5	4	5	3	1	.	.. 26
16 ..	1	2	.	1	8	9	11	6	4	.	.	.. 42
19 ..	1	3	1	3	1	4	4	3	1	1	1	.. 23
22 ..	1	.	.	1	2	2	2	1	.	1	.	.. 10
25 ..	.	.	.	1	2	2	2	1	2	.	.	.. 10
28 ..	.	.	.	.	.	1	1	2	3	.	.	.. 7
31 ..	.	.	1	1	.	1	2	2	.	.	.	.. 7
34 ..	.	.	.	1	.	.	.	.	.	.	.	.. 1
37 ..	.	.	1	.	.	.	.	1	.	.	.	.. 2
40 ..	.	.	1	.	1	.	1	.	.	.	.	.. 3
43 ..	.	.	.	.	1	.	.	.	.	.	.	.. 1
Total ..	3	6	7	15	24	30	31	21	13	3	2	155

Percentage Increase in Girth.		Percentage Increase in Yield.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
18·13 per cent.	7·32 per cent.	21·3 per cent.	20·4 per cent.

Coefficient of correlation + ·03 ± ·054.

Table 39.

Correlation between Percentage Increase in Yield and Percentage Increase in Number of Latex Vessel Rows at 2 Feet, 1921–23.

Percentage Increase in Yield.	Percentage Increase in Number of Latex Vessel Rows. 10	30	50	70	90	110	130	150	170	190	210	230	250	270	290	Total
— 30 ..	.	1	.	1	1	.	.	.	.	.	.	.	.	.	.	3
— 20 ..	.	1	2	1	1	.	.	.	.	.	.	.	.	.	.	5
— 10 ..	1	.	1	1	1	1	.	.	.	2	.	.	.	.	.	7
0 ..	.	2	6	2	2	1	.	1	.	1	.	.	.	.	.	15
+ 10 ..	1	4	10	4	1	2	.	.	.	.	1	1	.	.	.	24
20 ..	2	2	7	9	1	3	4	2	.	.	.	1	.	.	.	31
30 ..	2	3	8	6	4	3	2	2	.	.	.	.	1	.	.	31
40 ..	2	1	4	2	3	4	1	2	.	.	1	.	.	.	1	21
50 ..	.	1	1	2	5	1	.	1	1	.	.	.	1	.	.	13
60 ..	.	.	.	1	2	.	.	.	.	.	.	.	.	.	.	3
70 ..	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	2
Total ..	8	15	39	29	21	17	7	8	1	3	2	2	2	0	1	155

Percentage Increase in Yield.		Percentage Increase in Number of Latex Vessel Rows.	
Mean.	Standard Deviation.	Mean.	Standard Deviation.
21·3 per cent.	20·4 per cent.	82·5 per cent.	51·6 per cent.

Coefficient of correlation + ·15 ± ·053.

Chapters	Description	Pages
17.	FORMWORK	409
	Requirements of formwork ; Footing forms ; Column forms ; Wall forms ; Beam and slab forms ; Other types of formwork ; Steel formwork ; Form linings ; Removal of forms.	
18.	PLASTERING AND POINTING ...	421
	Terms used ; Tools used in plastering ; Materials for plastering ; Design considerations for plastering ; Background for plastering ; Application of plaster ; Defects in plastering ; External finishes ; Pointing.	
19.	PAINTING, DISTEMPERING AND WHITE WASHING ...	441
	Painting—types of paints ; process of painting ; Painting woodwork, iron, steel and other metals : Painting brickwork ; floors and other concrete surfaces ; Distempering ; White and colour washing.	
20.	THERMAL INSULATION ...	453
	Heat transference ; Type of insulating materials ; Their methods of application ; Insulation of roofs, air spaces and cavities ; Economics of insulation ; Condensation ; Thermal treatments in tropical and sub-tropical regions ; Treatment of different units in a building.	
21.	VENTILATION AND AIR-CONDITIONING OF BUILDINGS ...	465
	Requirements of ventilation system ; Types of ventilation—natural and mechanical ventilation ; Airconditioning ; System of air-conditioning ; Air-circulation ; Cleaning of air ; Method of removing excessive heat from air ; Dehumidifying air ; Humidification.	
22.	ACOUSTICS AND SOUND INSULATION ...	483
	General principles ; Sound absorbing materials ; Optimum time of reverberation ; Acoustical correction ; Acoustical design of Auditorium ; Broadcasting rooms ; Class rooms ; Library ; Sound Insulation of walls, floors.	
23.	SHORING, UNDERPINNING, SCAFFOLDING, ETC. ...	501
	Shoring—raking shores ; horizontal shores ; dead or vertical shores ; Under-pinning ; Scaffolding ; Steel centering and scaffolding ; Earthquake resisting buildings—General recommendations, treatment of foundations ; Fire protection, development of fire, Classification of buildings for fire-resistance, fire-proofing walls ; Fire-proofing of structural steel, Fire resistance of wooden joist floors.	
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1

SOILS AND THEIR INVESTIGATION

The materials supporting a building may be broadly classified into two categories, namely, soils and rocks. Soil is a natural aggregate of mineral grains which can be separated by easy mechanical means like agitation in water. Rock, on the other hand, is a natural aggregate of cemented minerals.

Rocks are of three classes according to their mode of formation. These are igneous, sedimentary and metamorphic rocks. Igneous rocks are formed from the solidification of molten matter called *magma*. This solidification may occur in the surface of earth or above it. Sedimentary rocks are the result of the accumulation of weathered deposits of igneous rocks. Metamorphic rocks are either igneous or sedimentary rocks whose physical or chemical properties have been altered by the action of intense pressure or heat. Rocks, if encountered as a layer, on which a building is to be constructed, ensure a good support for the building. Rocks can take heavy loads without causing significant settlement or failure. Investigation of rock surfaces is restricted to the determination of any cracks and soft layers underneath. However, even this is only necessary when multi-storeyed buildings have to be constructed. Although rock would provide an ideal surface for constructing a building, yet it is not met with in abundance at building sites.

Rocks are subjected to weathering agencies of wind, water, temperature, frost, waves, etc. These forces of nature weaken the rock considerably and subsequently disintegration takes place. The products of rock weathering located at the place of their origin are termed as residual soils. If they get transported to a different place and deposited there, they are called transported soils. Residual soils are of more uniform character than the alluvial soils. The construction of buildings on alluvial soils needs more detailed investigations to be conducted. Constructional problems also occur in some residual soils, *e.g.*, black cotton soils.

Types of Soils

Soils may be broadly classified as under :

(1) **Gravel** : This consists of particles of coarser material resulting from the disintegration of rocks These particles are often transported by water from their original source.

As a result of transportation, these particles are worn out and have a rounded shape. Particles in size from 4·7 mm. to 8 cm. are classified as gravels and those greater than 8 cm. are called pebbles. Gravel deposits neither swell when moisture penetrates into them nor they shrink when dried from a moist condition. Any water which collects at their surface is drained off rapidly. They have high strength to bear the loads coming over them. Buildings built on gravel do not show any signs of settlement. Gravel deposits form the second best foundation surface for a building.

(2) **Sands** : Natural sands consist of coarse particles of silica derived from the disintegration of rocks. The particles are visible to the naked eye and have rough surfaces. Clean sand particles will fall apart when collected in a dry state. Their size varies from 0·06 mm.to about 4·7 mm. Pure sand deposits are not affected by the action of frost. They do not swell in size whenever water penetrates into them. No shrinkage occurs when they are dried from a moist condition. Coarse sands do not allow water to rise through capillary action and are very permeable. Pure sands in a dense state provide a good foundation surface for buildings and there are no settlement problems associated with them.

(3) **Silt** : This is a finer variety of soil. The particles are usually equi-dimensional in size, ranging from 0·002 mm. to 0·06 mm. Silt particles have a smooth texture. Silt is relatively impervious. It may also exhibit a slight tendency towards swelling or shrinkage. Silt deposits may contain some organic matters. If the silt layers are in lower density due to looseness in structure they can bear stresses of small magnitude. The settlements on account of the loading may also be significant.

(4) **Clays** : Particles which are less than 0·002 mm. in size are termed clays. They have a smooth and flaky appearance. Clays are formed during excessive weathering of the coarser particles of the rock. The elongated shape of clay particles causes a plastic mixture to be formed in wet state. There is very small space between the individual particles of clays and hence water cannot be drained off easily. This keeps the clays in a damp condition for a considerable period after water has penetrated into them. Whenever loads are applied to a clayey soil, settlement takes place gradually and may last even for many years. Buildings constructed on clayey soils are thus liable to a gradual settlement. Clays also show the property of shrinkage if dried. The capacity of wet clays to bear loads is very less. A high capillary rise of moisture is prevalent in clays. It is difficult to construct buildings on a surface of a pure clayey soil.

Soil Investigation

The object of soil investigation is to get information regarding :

(*i*) the nature, thickness and variation of soil strata at a place,

(*ii*) physical properties of the soil strata encountered, and

(*iii*) the seasonal variations in ground water table and its effect on the soil strata met.

The first step in soil investigation is to carry out a preliminary survey of the site. Information can be collected from the residents of the area regarding the type of soils available at different levels and also the location of water table from season to season. A study of any building nearby will give a fair idea of the behaviour of the soil at the site. In case a good soil is met with, further investigation may not be necessary. However, for high buildings and where the character of soil is doubtful, it is essential to carry out a thorough investigation of the soil available at the site.

The methods used for further study are:

(1) Open test pits.

(2) Borings.

(3) Sub-surface soundings.

(4) Geo-physical methods.

A brief description of these follows :

(1) **Open test pits.** A rectangular pit is excavated at the site and sample of soils collected at different levels. Further idea about the nature of soil layers can be obtained by examining the sides of the pit (*see* Fig. 1). This method is, however, limited to depths of 3 metre and cannot be used below ground water table. Moreover, for areas where rock or boulders are encountered after some excavation, this method is unsuitable.

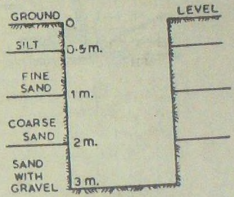

Fig. 1. A typical section of a test pit.

The spacing of these test pits depends on the nature of building, the variation in soils met with and the time available for investigations. At least one test pit should be excavated for a 15 × 15 metres area. In case the sides of the test pit do not stand vertically, the measurement of different layers should be taken carefully.

(2) **Borings.** The types of borings usually adopted are :

(*a*) Small type (tube)

(*b*) Wash borings

(*c*) Auger borings

(*d*) Mechanised drilling.

Small type (tube) : This method is used for small jobs. A tube about 2 metre in length with a cutting edge and a flap valve at the lower end is used for taking out the soil sample. It is raised by a rope passing over a pulley which in turn is suspended by a tripod stand. The tube is allowed to fall under gravity inside a casing-pipe. The thick mixture formed near the cutting edge enters the tube and is taken out as the tube is raised. The casing is driven as the depth of

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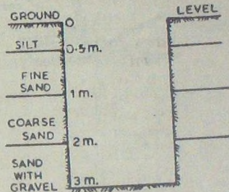

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Wash borings : This method is suitable for investigations to deeper depths. The equipment usually consists of a 6 cm. dia pipe in 1/2 metre length and is called casing. This serves to support the sides of the hole. Suitable weights are used for driving the casing. A derrick is used for driving casing and handling the weight. A

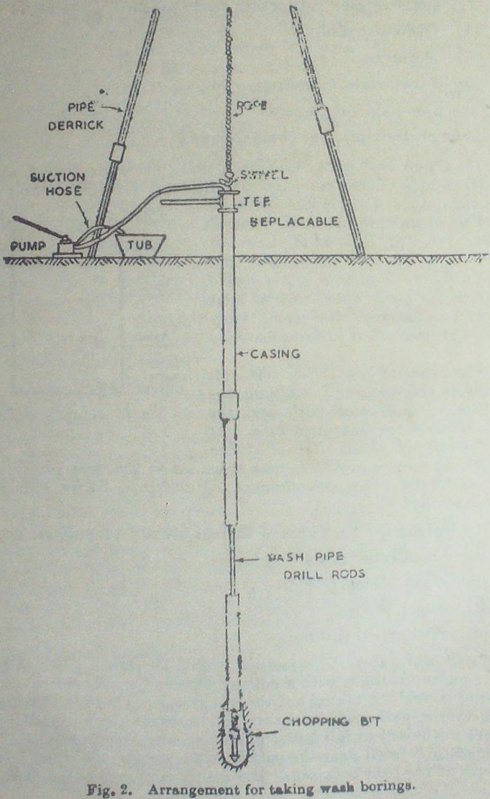


Fig. 2. Arrangement for taking wash borings.

wash pipe 3 cm. in dia (usually a thick walled pipe called drill rods) and 1½ to 3 metre in length is used for injecting water and this is connected to a pump through a hose pipe. For boring, the derrick is erected and the casing is driven about 1 metre into the ground. A T-junction is attached to the top of the casing and a short length of pipe connected to it. The wash pipe is introduced into the casing. Water is injected under pressure through the wash pipe and rises through the annular space between the wash pipe and the casing (Fig. 2). As the water circulates, the wash pipe is rotated to make the soil loose. The soil comes out in the form of a thin slurry and gives only a rough indication of the soil layers. However, sample tubes can be inserted and samples taken out after certain intervals, *e.g.*, when the colour of the soil slurry changes, the wash pipe is first lifted out from the hole.

These samples can be taken by attaching a sampling tube to the bottom of the wash pipe instead of the cutting edge. This is driven gradually and lightly into the soil to obtain a sample and is removed after being filled with the soil.

Special tubes are available for taking samples of the soil in such a manner that the structure of the soil is not disturbed. Undisturbed soil samples are absolutely essential for getting a correct picture of the behaviour of the soil in a strata.

Laboratory tests are run on samples collected. Generally 5 to 10 kg. of soil is needed for carrying out the various laboratory tests. The samples are suitably preserved and are arranged serially according to the depth at which they are met. A full record of the borings is kept and a chart is prepared showing the character of the soil met with at different depths (*see* Fig. 3).

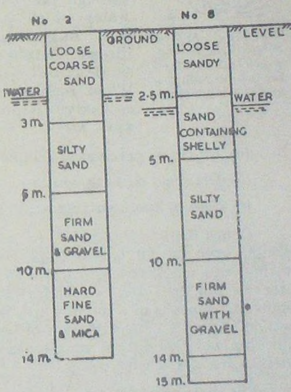


Fig. 3. Details of borings

Auger Borings : These are sometimes preferred to wash borings as the information obtained from wash borings is not always sufficient and correct. Various types of augers are used for taking out the samples. The bore is made by turning the auger into the soil for a short distance and withdrawing it along with the soil which sticks to it. The soil thus taken out is examined to determine its properties. The auger is again driven and taken out. The process is repeated till a complete record of the soil layers at various depths is obtained. If the sides of the holes do not stand vertically, a casing of some pipe can be used. This casing should be of a slightly larger diameter than the auger. Augers cannot be used in sandy silts below water table. It is difficult to drive augers through gravels. Generally 10 to 12 cm. diameter holes are driven with augers. Augers can conveniently be used for depths of 6 to 8 metre.

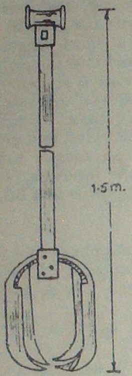


Fig. 4. A typical Auger. Additional pipes can be fitted for taking samples at deeper depths.

Mechanised Drilling : Soil investigations can be conducted rapidly if machines are used for making bore holes. Several types of machines are available. The rotatory types are preferred. Briefly, the process consists of a cutting tool to the end of a series of drill rods. These drill rods are then coupled whith the machine and rotated at a convenient speed and simultaneously pushed into the soil. The bits of soil which get cut from time to time are removed through the bore holes with the help of wash water which is continuously being fed into the soil. As soon as a particular depth is reached, the sample tubes are inserted in the same manner as described earlier and soil samples obtained. When rock is encountered, drilling becomes a necessity. Drilling through rock is done in three ways, *viz* :

(*a*) Churn or percussion drilling,

(*b*) Diamond drilling, and

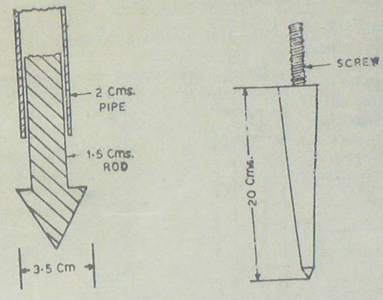
(*c*) Shot or tooth cutting drilling.

Churn drilling is similar to wash boring except that water, enough only to fill the bottom portion of the hole, is used. The cuttings become mixed with water as the churning proceeds and at intervals, the drill stem is withdrawn. The cuttings and water are removed by means of a pump which is lowered into the hole. This method is used for investigation of boulders and rock. The samples thus obtained give only a rough idea of the soil encountered as the cuttings are mixed with water.

The diamond drill consists of a hollow thick steel tube with cheap diamonds set on its outside and inside edges at the bottom so as to form a cutting bit. The diamonds are set in such a manner that the hole driven is of a slightly greater diameter than that of the tube and also a core is cut which is of a slightly smaller diameter than the inner diameter of the tube. The drill rods are rotated into the rock, water is forced down through the drill rods to the bottom of the hole so as to keep the cutting edge cool and also to take out the rock chippings. After some time, a solid core of rock is formed inside and can be withdrawn by a jerky motion. A continuous record of cores is kept to get a correct idea of the rock strata underneath.

Shot drilling is also used for getting cores out of the rock. A shot-drill consists of a hollow cylinder which is rotated by a drill rod. The cutting action is provided by feeding steel shots which come directly under the rotating edge. Thus a core of rock is formed. Water is fed to take out small chippings. Whenever cavities or open spaces are met with, a cement-water mixture is forced first so that the shots do not get away from the cutting edge. Drilling is resumed only after this mixture has considerably set.

(3) **Sub-surface soundings** : These are used for investigation of soil layers which have a varying nature. They are also used to make sure that the sub-soil does not contain exceptionally soft spots.

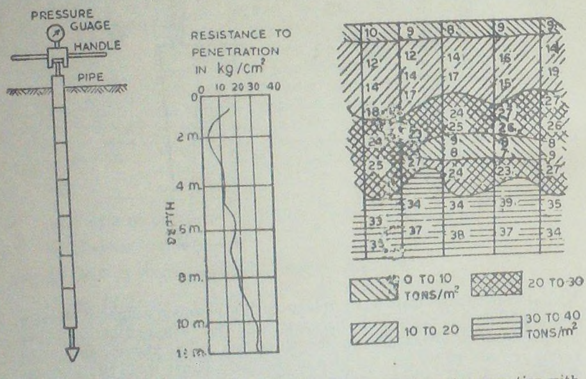


Figs. 5-6. Typical penetrometers.

In olden methods, rails were driven with a hammer weighing about a tonne and falling through a distance of 80 cm. The number of blows needed to drive about 30 cm. length of this rail at various elevations below ground would give an idea of the surface met with. Static sounding methods have been developed and these are called penetrometers. They consist of rods of various shapes in standard lengths. After they sink into the soil under their own weight, they are loaded at suitable intervals or else are driven at a steady rate into the soil. The rate of penetration in the first case or the load in the second case will give an idea of the soil type.

The static cone penetrometer is very commonly used nowadays. This consists of a cone having an area of 10sq cm. This is driven with the help of a hydraulic jack system using a set of rods. The pressure required to drive the cone is recorded at intervals as the cone penetrates into the soil. The information can also be collected separately for the driven resistance of the cone and the side sleeves used. Typical profile of penetration resistance with depth is shown in Fig. 8 and contours of bearing capacity are worked out in Fig. 9.

The dynamic method which is known as 'Standard Penetration Test' has become very common and is now an accepted standard procedure. This consists of a thick walled tube having an outer diameter of 5 cm. and inner diameter of 3.5 cm. and a length of about 60 cm. This thick walled tube can be split into two parts longitudinally so as to facilitate the removal of the soil samples which gets collected inside. The cutting edge is provided at one end and the tube can be screwed to the drill rod at its other end. This tube is driven into the ground with the help of 63 kg. weight falling to a distance of 75 cm. The number of blows required to drive this tube through a distance of 60 cm. into the ground are recorded and are designated as the Standard Penetration Resistance. Several relationships have been derived between the standard penetration resistance and the load carrying capacity of a soil.



Figs. 7-9. Diagrams showing the set-up for a penetrometer operation with typical results plotted graphically and contours of bearing capacity values wprked out.

(4) **Geo-physical methods :** These methods are used where only a rough indication of the soils is needed and also where speed of investigation is of primary importance. Two methods are generally used.

The seismic method (*see* Fig. 10) depends upon the fact that sound waves travel faster in rocks than in soils. Similarly soune waves travel faster in solid rocks than in shattered rocks Thesd waves are created artificially by explosions and get reflected from a stronger layer below. The time of travel can be measured and hence the thickness of strata determined.

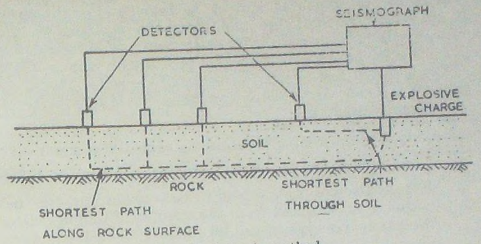


Fig. 10. Seismic method.

In the resistivity method (Fig. 11) two electrodes are driven into the ground. They are spaced apart a distance of about three times the depth of information needed. Two more electrodes are set in the ground between them and a current is passed through the ground from the outer electrodes. Part of the current is passed through the intermediate electrodes and the resistance of the circuit can be measured by means of a potentiometer. The spacing of these electrodes can be changed till a significant change in resistance is caused. The spacing of inner electrodes will indicate the depth of the layer causing this change.

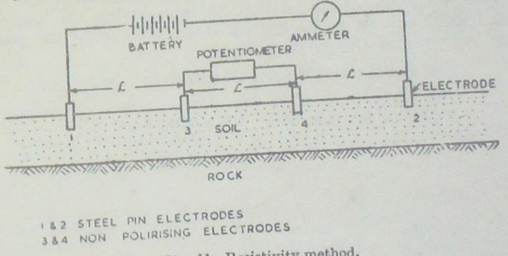


Fig. 11. Resistivity method.

Bearing Capacity of Soils

The preliminary and the detailed investigations described above will enable the engineer incharge to know the following points about the site :

1. The depth of bed rock, if any.
2. Character of soil, *i.e.*, gravel, sand, silt, clay, etc.
3. Presence of boulders or other obstructions, if any.

4. Elevation of the ground water table.

The next thing to determine is the type of foundation to be used, the depth to which it should be taken and its dimensions so that it can safely transmit the load from the building to the soil without any failure or significant settlement. For their determination, a knowledge of the safe allowable pressure on the soil is necessary. This is called the bearing capacity of the soil. The maximum load which a soil can carry just at the time of failure is termed as ultimate bearing capacity.

Methods of determining the bearing capacity of a soil are :

a. Local experience in the construction of a similar building.

b. Examination of the soil and using a value for the bearing capacity as obtained from the standard building codes for the particular type of soil met with.

c. Laboratory and field tests for the determination of bearing capacity.

In the first method information is collected about the values of safe bearing capacities assumed in the design of structures nearby and their condition at site is examined. This will lead us to a very approximate value of the bearing capacity and should be used with great caution. This method may be used for small buildings.

The second method consists in identifying and classifying the soil into the various groups. After the identification of the soil, standard tables can be referred to determine the value of the bearing capacity to be used. These tables are available in the standard building codes of the locality. A table giving the maximum safe bearing capacity for foundations at one metre below the ground level is given below for guidance.

PRESUMPTIVE SAFE BEARING CAPACITY

Sl. No.	*Types of Rocks and Soils*	*Presumptive safe bearing capacity kg./cm²*	*Remarks*
1	2	3	4
	(a) Rocks.		
1.	Rocks (hard) without lamination and defects, for example, granite, trap and diorite.	33	—
2.	Laminated rocks, for example, sandstone and limestone in sound condition.	16·5	—
3.	Residual deposits of shattered and broken bed rock and hard shale, cemented material.	9·0	—
4.	Soft rock.	4·5	—

1	2	3	4
	(b) Non-cohesive Soils.		
5.	Gravel sand and gravel, compact and offering high resistance to penetration when excavated by tools.	4·5	See Note 1
6.	Coarse sand, compact and dry.	4·5	Dry means that the ground water level is at a depth not less than the width of foundation below the base of the foundation.
7.	Medium sand, compact and dry.	2·5	—
8.	Fine sand, silt (dry lumps easily pulverized by the fingers).	1·5	—
9.	Loose gravel or sand gravel mixture, loose coarse to medium sand, dry.	2·5	See Note 1
10.	Fine sand, loose and dry.	1·0	—
	(c) Cohesive Soils.		
11.	Soft shale, hard or stiff clay in deep bed, dry.	4·5	This ground is susceptible to long term consolidation and settlement.
12.	Medium clay, readily indented with a thumb nail.	2·5	—
13.	Moist clay and sand clay mixture which can be indented with strong thumb pressure.	1·5	—
14.	Soft clay indented with moderate thumb pressure.	1·0	—
15.	Very soft clay which can be penetrated several centimetres with the thumb.	0·5	—
16.	Black cotton soil or other shrinkable or expansive clay in dry condition (50 per cent saturation).	—	See Note 2. To be determined after investigation.
	(d) Peat.		
17.	Peat	—	See Notes 2 and 3. To be determined after investigation.
	(e) Made-UP Ground.		
18.	Fills or made-up ground.	—	See Notes 1 and 4. To be determined after investigation.

Note 1. Compactness or looseness of non-cohesive materials may be determined by driving a wooden picket of dimensions 5 cm. x 70 cm. with a sharp point. The picket shall be pushed vertically into the soil by the full weight of a person and if the penetration of the picket exceeds 20 cm. the loose state shall be assumed to exist.

Note 2. No generalized values for presumptive safe bearing capacitites can be given for these types of soils. In such area, adequate site investigation shall be carried out and expert advice shall be sought.

Note 3. Peat may occur in a very soft spongy condition or may be quite firm and compact. While ultimate bearing capacity may be high in the compact cases, very large consolidation and settlements occur even under small pressures and the movements continue for decades.

Note 4. The strength of made-up ground depends on the nature of the material, its depth and age, and the methods used for consolidating it.

Note 5. The presumptive safe bearing values may be increased by an amount equal to weight of the material (virgin soil) removed from above the bearing level, that is, the base of the foundation.

Note 6. For non-cohesive soils, the presumptive safe bearing value shall be reduced by 50 percent if the water table is above or near the bearing surface of the soil. If the water table is below the bearing surface of the soil at a distance at least equal to the width of the foundation, no such reduction shall apply. For intermediate depths of the water table, proportional reduction of the presumptive safe bearing vaule may be made.

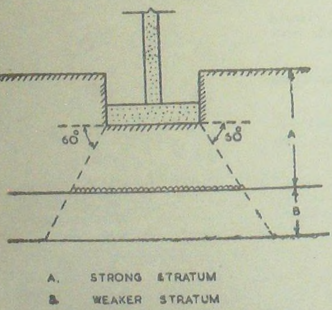


Fig. 12. Practical assumption of pressure distribution through various strata.

Any tabulated values of permissible loads should be used very cautiously. In addition to the soil type, the bearing capacity of a soil depends on many factors such as the degree of compaction, moisture content, size of the foundation below the ground level and the type of foundation used. Some building codes specify the increments in allowable bearing capacities for greater depths below the ground surface. Similarly adjustments for the increased widths and rigidity or flexibility of the foundation are incorporated. Certain building codes are very comprehensive and directions are given to account for a weak strata which underlies a strong strata, *e.g.*, in Boston Building Code it is specified that the bearing capacity of the weak strata below is to be taken into account and the pressure should not exceed the allowable capacity of the strata. The pressure gets distributed from the base of the foundation downwards into the soil at a specified rate which is at 60 degrees to the horizontal in the code referred to (*see* Fig. 12). The load at the top of the weak strata is considered to be uniformly distributed within the inclined lines shown in the figure. Similarly provision has been made in the said code for an inward flow of water and it is specified that the allowable capacity should be reduced to a value used for the material in a loose condition. But in spite of all these limitations, the values taken from the building codes are highty approximate and should be used for ordinary buildings where thorough investigation is not feasible.

For multi-storeyed and important buildings it is necessary to carry out a field test or laboratory tests on the soil. The simplest type of field test is called 'Plate Bearing Test' and is described below :

Plate Bearing Test: A pit equal to five times the width of the test plate is dug up to the required foundation depth. The test plate is made to rest in the centre of the pit in a depression which is of the same area as that of the test plate. The depth of the depression is such that the ratio of depth over width of this loaded area is the same as that for the actual foundation. The test plate is generally of mild steel 2·5 cm. in thickness and 30 cm. square in area for sandy or gravely soils whereas for clayey soils a plate 60 cm. square in area is used. A loading platform is built which consists of a wooden column with the suitable horizontal platform at the top. The sides of the pit may be lined with sheetings if the soil is soft. Adequate supports are provided to prevent the overturning of the vertical column. For loading, sand bags or lead bars are used. These are placed on the top of the horizontal platform.

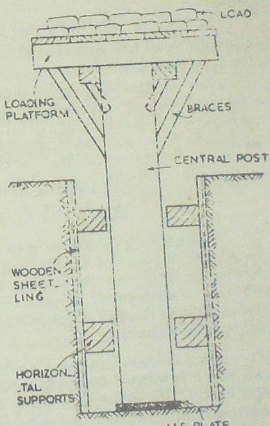


Fig. 13. A simple arrangement for carrying out bearing capacity test. Readings of settlement can be taken by fixing gauges. A water proof compound is to be used to prevent leakage into the pit at the base.

The load is increased in regular increments of 250 kg. or $\frac{1}{5}$th of the approximate ultimate bearing capacity whichever is less. Each loading increment is kept in position till no further measurable settlement occurs. Settlements are read with the aid of gauges fitted suitably. At least two gauges should be used to take care of any differential settlement that may occur. For an approximate work, readings of settlement can be taken with a dumpy level. The settlement readings should be taken to at least 0·025 mm. accuracy. Settlement should be noted at regular intervals between the loading increments.

A graph is plotted between the settlement and the load. For initial readings a straight line is obtained whereas after the soil starts losing bearing power, the plot becomes curved. The change point between the straight line and the curve will give the value of the bearing capacity. If a straight line is not obtained at all, bearing capacity is considered to be maximum when the settlement is 1·25 cm.

For sandy and gravely soils, the ultimate capacity is proportional to the width of the loaded area and can be estimated by extrapolation of the results of two or three different sized test plates.

The ratio of settlement between the plate as determined by the standard load test and that of the footing shall be as calculated by the following formulae :

$$\left[\frac{B_2\,(B_1+30{\cdot}48)}{B_1\,(B_2+30{\cdot}48)}\right]^2 \text{ for sandy soils,}$$

and

$$\frac{B_2}{B_1} \text{ for clayey soils}$$

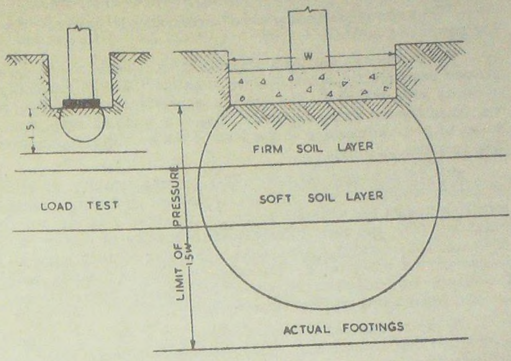
where B_2 = Width of the test plate in cm. and

B_1 = Width of the footing in cm.

The above expressions give a fair idea of the variation in settlement with the size of the footing. But the results may be made more reliable by repeating the loading tests with plates of two or three different sizes, namely, 30,45 and 60 cm. square, and settlements corresponding to the full width of the footing for particular load intensities extrapolated.

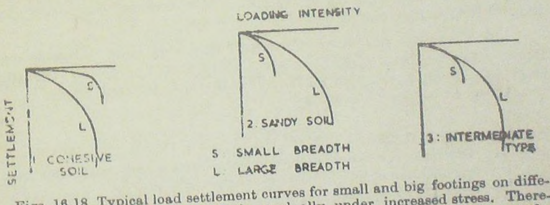
The load test has great limitations as it gives an idea of the soil which is located within a depth less than twice the width of the test plate. However, a building is normally constructed on greater widths and influence of pressure in the actual construction penetrates to deeper depths. Hence any soft strata lying within the influence of pressure created by the actual building are liable to settlement. Hence if any weak strata is encountered, it should be ensured that the pressure coming on to that strata is less than its allowable safe bearing pressure.

It should be noted that for a clayey soil, the ultimate bearing capacity is constant and is independent of the width of the building.



Figs. 14-15. Pressure distribution for a load test and actual footings.

However, the ratio of the load and the settlement, *i.e.*, the coefficient of settlement is inversely proportional to the breadth of the footing. For sandy soils, as stated earlier, the bearing capacity is proportional to the width of the building, the coefficient of settlement is slightly dependent on the width. The typical load settlement curves for clayey, sandy and mixed soils are shown below.



Figs. 16-18. Typical load settlement curves for small and big footings on different soils. Clays settle gradually under increased stress. Therefore, buildings constructed over clay soils may continue to settle for many years after construction.

Laboratory tests: Whenever load tests are not feasible, approximate values of bearing capacity can be calculated by testing the samples of the soils in the laboratory. Various tests are specified for sandy and clayey soils. The values of bearing capacities can be calculated after determining the physical properties of these soils. Charts are used to help in the calculations. A reference may be made to a standard book on Soil Mechanics for details of laboratory tests.

Methods to improve the bearing capacity of a soil :

The various methods generally employed to increase the bearing power of a soil are:

(1) *Increasing the depth of foundation* : Usually soils have got greater bearing capacity at deeper depths. This is especially true of sandy soils, for which the bearing capacity increases due to the weight of the overlying material. But this method may not prove to be of great advantage as the load of the building foundation will also increase with depth.

(2) *By draining the soil* : The bearing capacity of every soil decreases when its water content increases. Submergence of a soil strata decreases the ultimate bearing capacity of a sandy soil by as much as fifty per cent. The bearing capacity of clayey soil also decreases considerably by an increase in water content, may be by a rise in ground water table. Cohesionless soils, *i.e.*, sandy soils and gravels can be drained easily, either by gravity pipe drainage system or by installing shallow tube wells.

(3) *By compacting the soil.* Compaction of the soil reduces the open space between the individual particles and hence they are less liable to displacement, thereby increasing the bearing capacity. By driving piles or by packing boulders, compaction to a certain extent can be attained particularly in sandy soils of a loose nature.

(4) *By confining the soils*: Sheet piles are driven to form an enclosure, thereby confining the movement of the soil. This can help in increasing the bearing power.

(5) *By grouting*: Cement grout can be injected under pressure in the foundation to seal off any cracks or fissures which otherwise reduce the bearing capacity of the soil. This method is mostly employed for fissured cracks.

(6) *Chemical treatment*: Chemical solutions like silicates are injected under pressure into the soil. They form a gel and thereby unite to develop a compact mass. This method is very costly and is adopted in exceptional cases.

QUESTIONS

1. Describe the various investigations you would make for the examination of soils for the construction of buildings.
2. Name the types of soils generally encountered in the construction of a building and briefly describe their properties stating clearly their suitability over each other.
3. Describe briefly the various methods of soil investigations with the aid of borings for ordinary soils.
4. Write short notes on :
   (*i*) Wash borings
   (*ii*) Churn drilling
   (*iii*) Penetrometers
   (*iv*) Geo-physical method of soil investigation.

5. What is meant by the term 'Bearing Capacity' of a soil ? Describe briefly how the bearing capacity of a sandy soil is determined with the help of plate bearing test.

6. Describe a method to test the bearing capacity of a soil. What are the values of the bearing capacity generally allowed for :

(*i*) Black cotton soil,

(*ii*) Gravel,

(*iii*) Moorum,

(*iv*) Trap rock.

7. What are the methods normally used to increase the bearing capacity of a soil ?

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2

FOUNDATIONS

Foundation is that part of a building whose exclusive function is to distribute the loads to the soil supporting the building. Foundations are normally placed below the ground surface. The function of a foundation is to distribute the load over a larger area at a uniform rate so that the pressure on the soil below does not exceed its allowable bearing capacity. Foundations increase the stability of a building and, moreover, enable the construction to be carried out systematically.

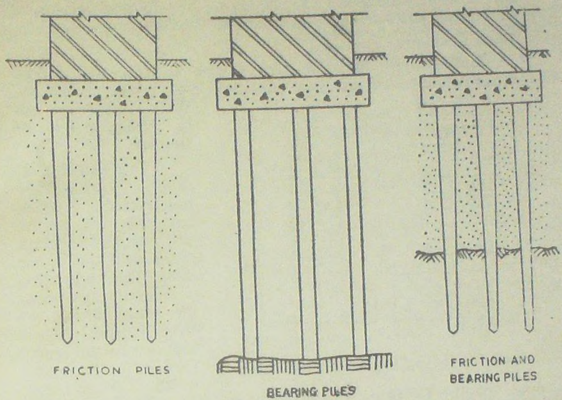
Foundation can be built in various types of material. Generally bricks, stones, concrete, steel, etc., are used in differeut forms for constructing the foundation of a building. However, the type of building which is supported on a particular foundation has a great bearing on the selection of the material, *e.g.*, the use of R.C.C. foundation for reinforced concrete building.

Types of Foundations

The various types of foundation commonly used are :

(1) **Spread foundations :** These types of foundation spread the load over a greater area so that the load transmitted to the soil supporting the building is less than its allowable bearing capacity, thereby preventing excessive settlement of the building. The width of the wall is made wider at the base in a series of steps. The different types of spread foundation are described in the following pages.

(2) **Pile foundations** : The load is transmitted to the soil by driving long vertical members of either timber or concrete or steel called piles. Loads are supported in two ways, *i.e.*, either by the effect of friction between the pile and the surrounding soil or by resting the pile on a very hard stratum. The number of piles used will depend on the type of pile and also on the load coming from the building. A group of piles, if used, is connected at the top by a



Figs. 19-21. Types of piles.

layer of concrete which distributes the load uniformly from the walls to the piles.

(3) **Pier Foundations**. These are rarely used for buildings and consist in carrying down through the soil a huge masonry cylinder which in turn may be supported on a solid rock or by the frictional force between its exterior surface and the soil around it.

Spread Foundations

These foundations include all those types which are designed to spread the loads. The various types are :

(1) Wall footings
(2) Isolated footings
(3) Combined footings
(4) Inverted Arches
(5) Cantilever footings
(6) Continuous footings
(7) Raft foundation

Spread footings are classified into further groups which are based on the type of construction. They are :

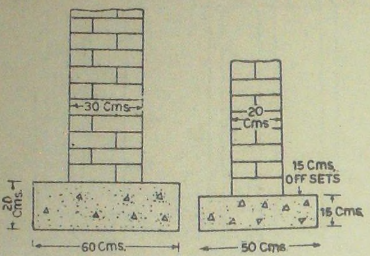
(*i*) *Simple footings* : These project only a few cm. beyond the edges of the walls or other structures supported by them. These foundations are used when only light loads come on the wall, *e.g.*, a wall surrounding a garden has simple footing.

(*ii*) *Stepped footings* : These are necessary when a wider distribution of the load is to be ensured and also a uniform spreading from the top of the footing to the bottom is desired. The footing consists of layers which increase in widths as the depth of foundation increases.

(*iii*) *Grillage foundation* : In this type, the footing consists of steel or wooden joists arranged in a stepped manner.

(1) **Wall footings**

A footing may have a base course of concrete or may be entirely built up of one material, *e.g.*, bricks or stones. Wall footings can be either simple or stepped.



Figs. 22-23. Footing for small walls.

For light loads, simple footings are constructed which have only one projection beyond the width of the wall, on either side. This projection is generally not greater than 15 cm. on either side. As a thumb rule for small footings the base width of concrete bedding should be twice the width of the wall. The depth of the concrete bedding is at least twice the projections.

In another type no base concrete is provided. In that case it is necessary to increase the width of the wall in steps so that the load can be transmitted safely. This is done by projecting bricks regularly to a distance not greater than one-fourth of a brick beyond the edge of the wall. These layers are built in cement mortar and the mix of the mortar should be richer than that used above the foundations. This type of foundation is not used nowadays as the first type is more economical.

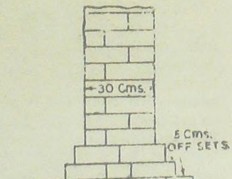


Fig. 24. Stepped footings for a brick wall.

When it is necessary to increase the width of the foundation considerably, either the base concrete has to be finished in steps or the bricks are projected and concrete bed is kept level. Projections in concrete are not economical as the construction becomes difficult and hence the bricks are stepped by giving 5 cm. offsets. The concrete projections are at least 20 cm. on either side so as to provide a proper working space inside the trench. (*see* Table)

Width of Excavation for Foundations

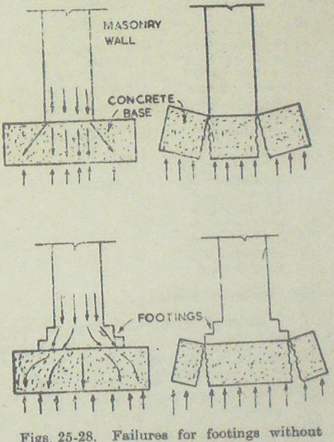
Description	*Width of excavation*
(*i*) **Depth about 0.3 m.**	Width of concrete footing.
(*ii*) **Depth about 0.6 m.**	Width of concrete footing or thickness of wall plus 40 cm. whichever is greater.

(iii) Shallow depth, from 0.6 to 0.9 m.	10 cm. more than for case (ii) at top, the increased width being obtained by giving batter on both the sides.
(iv) Medium depth, from 0.9 to 1.2 m.	Width of concrete footing or thickness of wall plus 65 cm, whichever is greater at bottom and 15 cm. more at top, sides being battered.
(v) Medium depth, from 1.2 to 1.5 m.	Width of concrete footing or thickness of wall plus 80 cm. whichever is greater at bottom and 15 cm. more at top, sides being battered.
(vi) Depth greater than 1.5 m.	Clear working space of 40 cm. on either side of wall at bottom, and space of 55 cm. at top, sides being battered.

NOTE 1. Batters are not necessary in trenches in hard soil, such as moorum, gravel and in disintegrated rock, if depth of excavation is not more than 1.2 to 1.5 m.

NOTE 2. Where shoring of the sides of the trench is found necessary, extra width shall be appropriately provided for excavation.

It should be noted that the number of projections equals the number of half bricks in the thickness of the wall. Furthei the width of the bottom brick course is equal to twice the thickness of the wall. It is desirable to construct footing courses of as many headers as possible so as to get maximum strength. For breaking the bond at least 5 cm. offsets are essential. The arrangement of these steps can, however, be altered to suit a particular depth of the foundation. A proper design of the steps is essential. The load from the wall is distributed over a greater width of the steps and is further distributed through the concrete bedding. The upward forces of soil try to break the concrete bed as shown in the figures 25 and 28 and hence the thickness of this bed must be adequate to resist the tendency of cracking.



Figs. 25-28. Failures for footings without steps and with steps.

The thickness of a concrete bed is given by

$$D = P\sqrt{W/fc}$$

D = The thickness or depth of concrete in cm.

P = Offset of masonry or concrete in cm.

W = Load coming on the soil in kgm. per square cm.

fc = 0.03 × ultimate crushing strength of concrete after 28 days in kgm. per square cm.

However, it should be ensured that a proper value of *fc* is used in the design because concrete will gain full strength after about a month and if the footings are built during this period, there is a danger of failure.

The concrete normally used in footings consists of coarse aggregates of either bricks or stones passing 4 cm. screen. The fine aggregate is sand or surkhi and the cementing material may be Portland cement or lime (*see* Table).

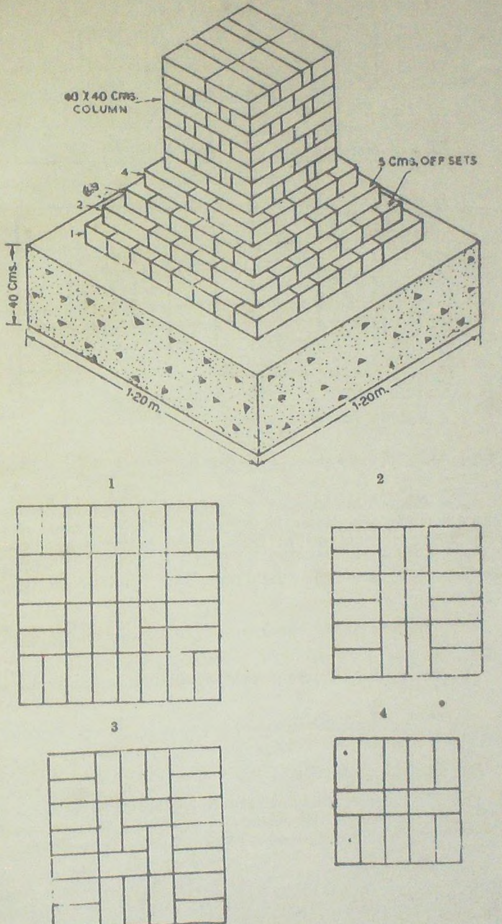
Mortars for Foundation Concrete

S. No.	*Situation*	*Type of mortar (All Proportions by Volume)*	*Class of Lime*	*Remarks*
1.	Drysub-grade, with subsoil water level never within 1.5 m. (or5 ft.) of the foundation level	1. 1 lime, 2 sand	A	Normally suitabe for buildings not more than three storeys high. The quantity of mortar to be used will depend on the grade of aggregate. The corresponding concrete mix shall be 1 : 5 : 10
		2. 1 lime, 1 surkhi and 1 sand	B or A	
		3. 1 lime, 2 surkhi	B or A	
		4. 1 cement, 3 lime and 12 sand	B	
		5. 1 cement, 5 sand		
2.	Moist sub-grade with high subsoil water usually 1.5 m. (or 5ft.) or less below foundation level	1 cement, 4 sand		The corresponding concrete mix will be 1 : 4 : 8 unless otherwise found necessary by special conditions, such as in the case of excessive subsoil water.

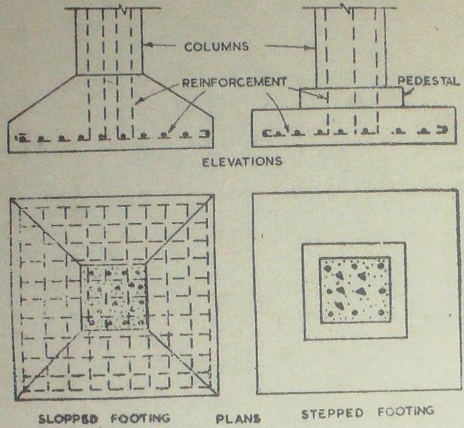
(2) . Isolated footings

Isolated footings are used to support the individual columns. Column footings are either of stepped type or have projections in the base concrete. Since column loads are heavy, reinforcement is provided by placing steel bars at the base of the footings. If columns are made with bricks, these are stepped down on all sides in regular layers giving 5 cm. offset (Figs. 29-33). The concrete bedding offsets are at least 15 cm. on all sides.

For concrete columns, it is essential to have concrete footings. Slab type, stepped or sloped footing bases can be used. The reinforcements are placed in both directions.



Figs. 29-33.
Footing details for an isolated brick column with plans of brick courses.



Figs. 34-37. Sloped and stepped footings for isolated R.C.C. columns.

Steel columns can have either concrete footings or footings of steel. Generally the latter type is used. They consist of steel beams arranged in layers at right angles to one another and are embedded in concrete. Further, the beams are connected with each other by bolts so as to form a rigid unit. This is known as 'Grillage footing'.

The following points about steel grillage should be kept in view :

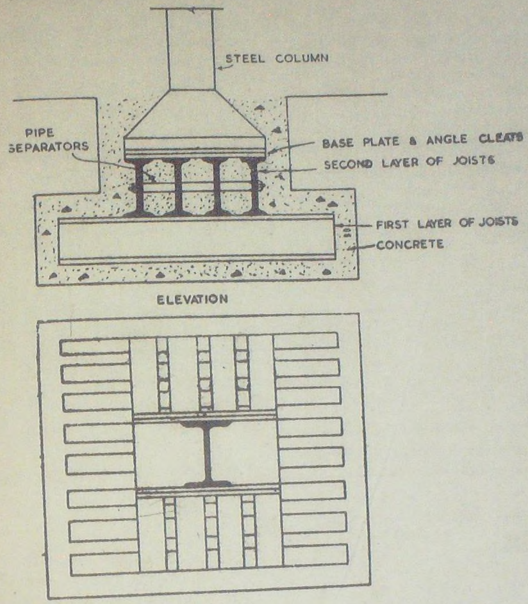
(*i*) The pressure from the footing is uniformly distributed over the soil.

(*ii*) The pressure of one tier of beams is uniformly distributed on the tier below.

(*iii*) Each tier acts independently of all other tiers.

(*iv*) The concrete filling in between the beams does not carry any load but only keeps the beams in position and prevents the corrosion of the beams. At least a cover of 10 cm. is necessary.

Timber columns have a grillage foundation built of timber beams in a manner similar to the steel grillage (Fig. 40). No concrete embedment is necessary. Timber grillage foundations are used for temporary structures and steel grillage foundations are used for very heavy loads.



Figs. 38-39. Typical grillage footing for steel columns.

(3) Combined footings

Combined footings are essential whenever the projections of columns are not possible on one side due to limited available space. In such a case, the footing of the exterior column can be combined with the footing of the interior column. This enables very small projections to be provided for the footing of the exterior column. Combined footings are proportioned in a manner that the centre of gravity of the resultant area is in line with the centre of gravity of the loads. Hence these footings have a trapezoided shape. Footings of two or three columns may be combined with the exterior column. These can also have rectangular shape if the load on the interior column is heavier than the other and the inward projection of the footings can be adjusted. Combined

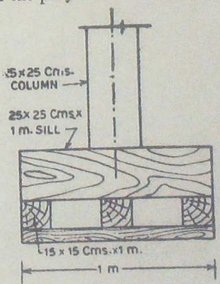
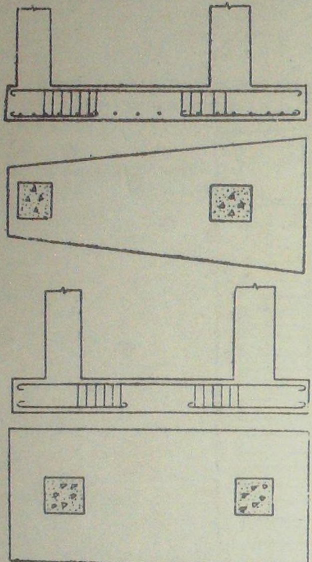
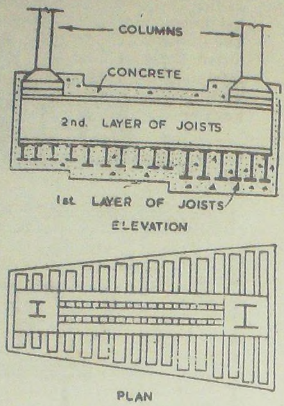


Fig. 40. Timber grillage footing.

footings are built of reinforced concrete. However, steel grillage combined footings are also used.



Figs. 41-44. Combined R.C.C. footings.



Figs. 45-46. Combined Steel footings.

(4) Inverted Arches

An arch consists of brick or stone units arranged in such a manner so as to form a curved surface. This type of

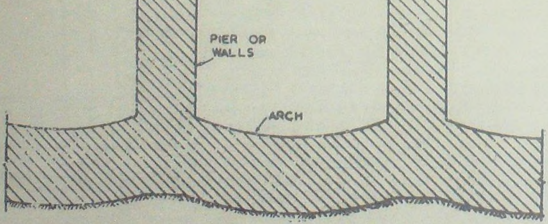


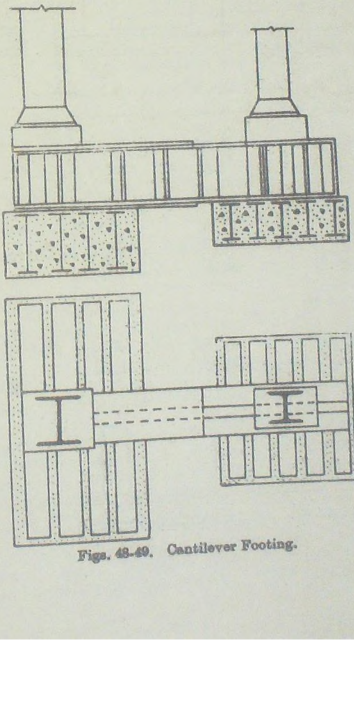
Fig. 47. Inverted Arch Footing.

construction is used to transmit loads above an opening to the supporting walls. When they are built with the curved surface having the concave face upwards, an inverted arch is formed. Inverted arches can be constructed between the two walls at the base. The load which is transmitted to the soil through these arches gets distributed over a wider area and hence the soil can bear the pressure safely. The disadvantage with this type of footing is that the end walls have to be made sufficiently strong so as to withstand the outward pressure which is caused by the arch action.

They are especially suitable when the bearing capacity of the soil below is very low and it is desired to distribute the loads over a large area. Further advantage of this type of construction is that the depth of foundation is quite less.

(5) **Cantilever Footings**

This type of foundation is useful when it is impossible to place a footing directly beneath a column or other load because of limitations of adjacent buildings or eccentric loading conditions. A load from the outer column is balanced by the load from the inner column acting about a fulcrum. The product of the load in the interior column multiplied by its corresponding lever arm should be at least 50% greater than the load on the exterior



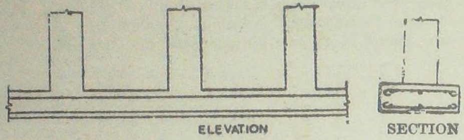
Figs. 48-49. Cantilever Footing.

column multiplied by its lever arm under all types of loading conditions. In case the interior column load is not available, a suitable huge concrete block can be built to act as an anchorage. The foundation of the interior column has to be built as strong as possible and must have suitable connecting reinforcement with its base.

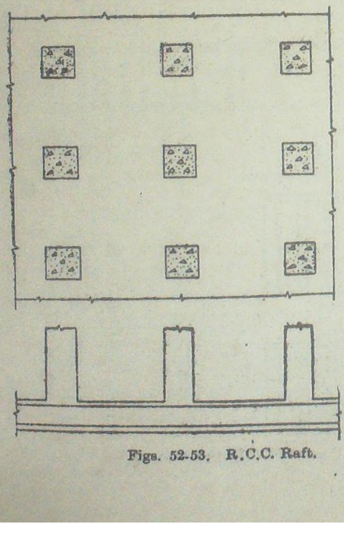
In practice, however, point shaped fulcrums are not used and a suitable base is built for the outer column. The connecting beam prevents unequal settlement of the exterior column by holding it in position with respect to the inner column. Cantilever footings can be built of concrete or steel.

(6) Continuous Footings

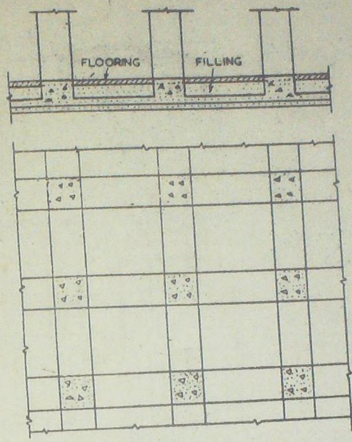
These consist of continuous reinforced concrete slabs extending over two or three columns. A deeper beam can be constructed in between the columns to increase the stability. Suitable steel reinforcement is provided. This type of construction is desired when the different (uneven) settlement is to be prevented. Further they are suitable wherever safety against earthquake is essential.



Figs. 50-51. Continuous R.C.C. Footing.



Figs. 52-53. R.C.C. Raft.



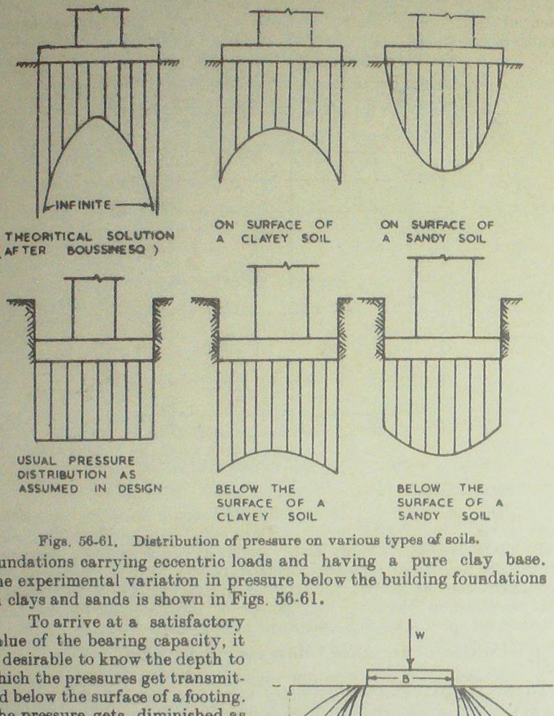
Figs. 54-55. R.C.C. Raft with beams.

(7) **Raft foundation**

This consists of thick reinforced concrete slabs covering the entire foundation area. These are reinforced with layers of closely spaced bars at right angles to each other. When the loads are excessive, thicker concrete beams running between the columns can be added for greater rigidity. These foundations are used when the bearing power of the soil is so low that individual spread footings cannot be economically used.

Distribution of pressure below spread footings

Settlement of a foundation occurs mostly due to the excessive vertical pressures being transmitted from the base of the footings into the soil below. Generally in footing design, we assume that the load is distributed uniformly over the area below the footing. However, it has been noticed that the variation of pressure changes from the centre of the footing to the edges. This depends on the rigidity of the footing base, the type of soil underneath and the depth of excavation at which the footing is laid. Mathematical formulae have been used to determine this variation in pressure. Generally we can consider the building foundation as having a rigid base. The variation of pressure along the width of the footing is more in the case of shallow foundation and gets decreased as the depth of excavation increases. For foundations built on sandy soils at the ground level, the pressure at the edge is zero while at the centre it is maximum. In case this foundation is laid below the ground level, there will be some pressure at the edges which has to be taken into account. Excessive pressures at the edges are caused in the case of foundations built on clays. This is especially true of



Figs. 56-61. Distribution of pressure on various types of soils.

foundations carrying eccentric loads and having a pure clay base. The experimental variation in pressure below the building foundations on clays and sands is shown in Figs. 56-61.

To arrive at a satisfactory value of the bearing capacity, it is desirable to know the depth to which the pressures get transmitted below the surface of a footing. The pressure gets diminished as the depth increases. The pressure spreads in the form of a bulb, the shape of which depends on a number of factors, *e.g.* the type of loaded areas, type of soil, compactness of soil, etc. The variation of the pressure at different levels can be connected by equi-pressure lines (Isobars). In Fig. 62, the variation of pressure below a circular footing is shown. It may be seen that below a depth of $1\frac{1}{2}$ times the width of the footing, only 20% of the pressure is left. Hence the borings for the determina-

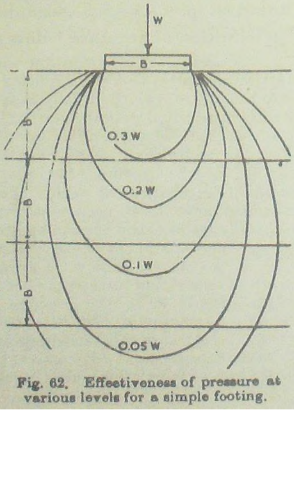


Fig. 62. Effectiveness of pressure at various levels for a simple footing.

tion of the soil type should extend from 1·5 to 2·0 times the width of the footing.

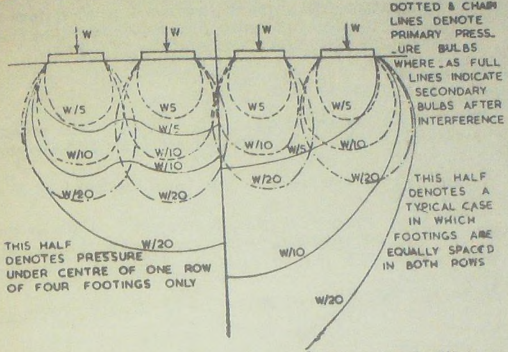


Fig. 63. Pressure contours for a row of columns in a building.

In buildings consisting of units of individual footings, the pressure bulbs will overlap each other and a combined bulb of pressure can be drawn for a group of footings arranged in a line.

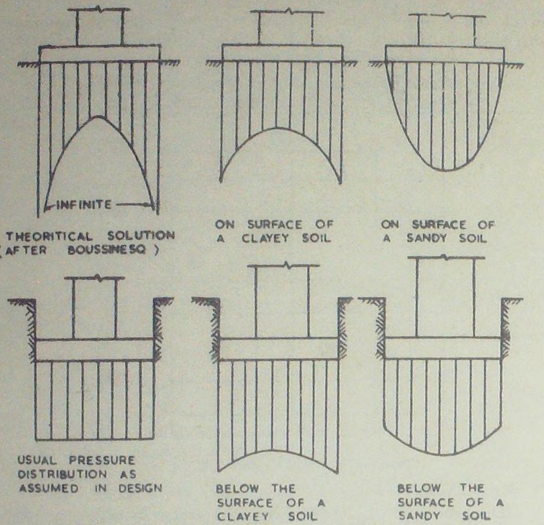
In the building design, it is essential to see that the foundations settle equally. Differential settlement, *i.e.*, the excessive settlement of one footing with respect to others should be always avoided as that leads to dangerous conditions.

For foundations supported on clays, the settlement increases with the width of the foundation for the same unit pressure. It is not true that for equal unit loads, bigger and smaller footings will settle to the same extent. This would mean that different allowable pressure is to be used for different footings on such soils to get a uniform settlement.

For the construction and design of raft foundations, etc., the following considerations should be made :

(*i*) It is absolutely essential to avoid differential settlement in the various parts of the raft to as much extent as possible. If different parts of a large raft built on sand carry different unit pressures, it is desirable to establish construction joints at the boundaries between these parts.

(*ii*) Raft foundation on clay should be designed to carry three times the normal load and still the differential settlement should not be large so as to damage the building. It is essential to take into account the difference in weight of the building and the excavated soil from the foundation. It may be worthwhile to vary the depth of foundations in accordance with the loads in such a manner that the difference between the load from the building and the soil



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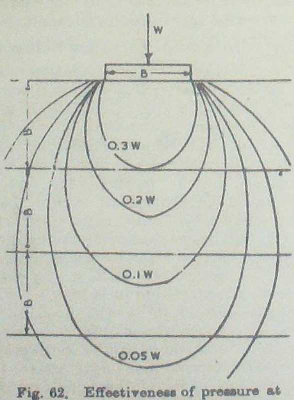

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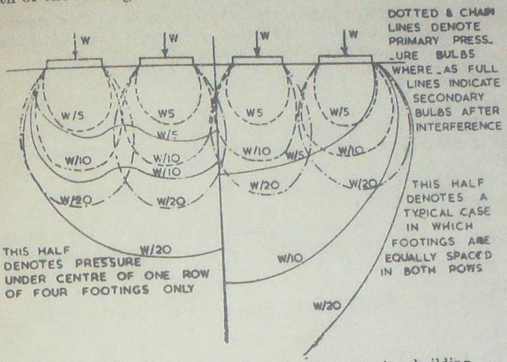

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(*iii*) For flexible buildings, the construction of a rigid foundation will eliminate differential settlement to a large extent but the cost of such construction will be excessive.

Pile Foundat ons

Definitions

Pile: This is an element of construction placed in the ground either vertically or slightly inclined to increase the load carrying capacity of the soil.

Bearing piles: These transmit the super-imposed load to a stronger strata below.

Friction piles: These are designed to transmit the loads by the frictional force existing between the sides of the pile and the ground.

Battered piles: This is a pile driven at an inclination to resist the inclined forces.

Sheet piles : These are thin units of steel or timber driven as piles.

Materials used

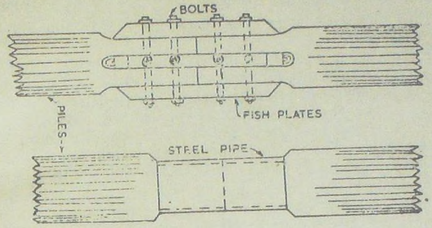
Piles can be made of wood, concrete, reinforced cement concrete, steel, prestressed concrete and composite materials.

The various types of piles for foundations are described below :

(1) **Wooden Piles** : Usually timber trees are used as piles after the bark and the branches are removed. The type of trees which are used in India are Bakul, Owli, Rayani, Jamba, Deodar, Sal, Teak, etc. The circular piles vary in diameter from 30 cm. to 40 cm. If square sizes are used, they are obtained from the interior portion of the tree by cutting off the side planks. They also vary in size from 30 to 40 cm. square. The lower portion of the piles is tapered to 15 to 18 cm square size. The length of the piles is about 20 times the top width. Longer piles are liable to fail on account of buckling.

The foot of a wooden pile should be cut perpendicular to its axis to permit a vertical driving. In soft or silty ground it may not be necessary to sharpen the pile end. If such a pile comes across a harder strata, it will have a wider bearing area over it and hence provide a stronger foundation. The blunt end will also break any obstruction like roots, etc., without tilting the pile. When coarse gravel or boulders are liable to be encountered it is desirable to reduce the area of the pile foot. In stiff clays it is advantageous to make the end pointed. While pointing, the end is formed into a pyramid shape, the edge of which is 8 to 10 cm. square. If this tip is less than the above size, the timber pile end will not be able to resist the action of any hammering. The length of this point can be $1\frac{1}{2}$ to 2 times the diameter of the foot.

The timber point may be protected or replaced by a metallic shoe. Various types of shoes have been designed for use with different types of piles. Shoes are used while driving through soils containing boulders, gravel, hard clays, etc. They may be of cast

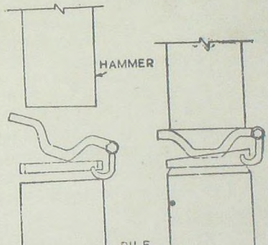


Figs. 64-65. Joining wooden piles.

iron and should have sufficient length of wrought iron straps to connect them with the pile.

Whenevor it is necessary to use a longer pile than available in usual lengths, it is customary to splice the piles together with their ends abutting each other. Additional strength can be obtained by the use of steel plates (fish plates) bolted to the sides of the piles. Wooden fish plates can also be used but they increase the section of the pile considerably. As an alternative, a heavy pipe of steel can be put over the pile end and fixed to it.

The head of the pile is subjected to a heavy impact of the driving machine and hence gets distorted and chipped off. To prevent this damaging effect, rings of wrought iron are fitted to the pile head. They vary in section from 5×1 to 10×2.5 cm. In fitting the rings, the pile is suitably cut for about 15 cm. from the top and a sloping surface is provided for a part of this length. These rings can be removed after the pile is driven.



Figs. 66-67. Collar for wooden piles and it sremoval.

To increase the hold of the piles with the ground, small pieces of timber are bolted around the sides of the pile. This increases the surface area in contact with the soil.

The timber piles deteriorate due to decay or insects. Decay is caused by the presence of a type of plant life called fungi which lives on certain products present in the wood. The rate of disintegration depends upon the moisture and temperature conditions of the piles. Some types of these fungi develop quickly under high moisture conditions. Timber fully below water throughout the year does not decay. It is desirable to ensure that the variations in the water level around the timber piles are least.

The termites or insects are of two types, *i.e.*, which grow in wet conditions and those which grow in dry conditions. They live on the cellulose present in the timber. Only few timbers are safe from this attack. Another class of insects which are liable to destroy timber piles are "marine borers" but these are usually found around the coastal areas. The life of timber piles which are not suitably guarded against the action of marine borers is considerably reduced.

Chemical preservation or mechanical protection is commonly provided as a treatment of wooden piles. Treating timber with creosote oil under pressure is usually carried out. The amount of creosote to be applied depends upon the type of timber used and the degree of protection needed. Several other chemicals like zinc chloride, copper sulphate, mercuric chloride etc. which are poisonous to the animal life have been used for the preservation of timbers but they are liable to be washed away by the water table fluctuations. The various methods of chemical preservation and their suitability under various conditions are described in details in books on "Building Materials".

Mechanical protection is afforded by various types of coverings like thin sheets of metal or a layer of felt soaked in various chemicals. These treatments are not expensive but are mainly used as a protection against marine borers.

Chemically treated piles should be handled very carefully so as to avoid the breaking of outer fibres which act as protecting coverings.

Advantages of wooden piles :

(*i*) They are less expensive as most of the timber available can be used after suitable treatment.

(*ii*) They can be made in longer lengths by joining the individual pieces easily.

(*iii*) Cutting of these piles is very easy.

(*iv*) They can be driven quickly and with lighter machinery.

Disadvantages:

(*i*) They deteriorate by the action of water or insects.

(*ii*) They have a lesser load bearing capacity.

(*iii*) Whenever long piles are to be driven, it is necessary to join a number of small individual units and this entails lot of joining work and the cost is high.

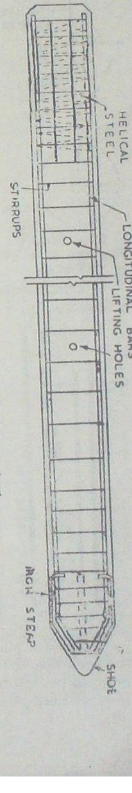
(2) **Concrete Piles** : Concrete piles can be broadly classified to two types :

(*i*) *Precast Concrete Piles.* These are cast at a suitable place, cured and afterwards driven like a timber pile.

(*ii*) *Cast-in-situ Piles.* These are cast at the place where they have to rest finally. They may have a casting which also remains intact.

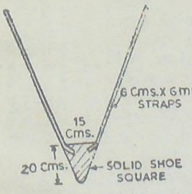
Precast Concrete Piles : Precast concrete piles are commonly of square section with chamfered corners. Other shapes, *e.g.*, octagonal types are also available. Octagonal type has a better appearance and steel reinforcement can also be placed easily in it. Whenever these piles are to be driven through hard soils, cast iron or mild steel shoes are used at the end which is driven into the soil. Generally for normal work, 1 : 2 : 4 mix is used whereas for heavy loads and for driving through harder soils, 1 : $1\frac{1}{2}$: 3 mix is employed.

The diameter of these piles varies from 25 to 60 cm. Certain specifications lay down rules for the minimum lateral dimension and least diameter depending upon the length of the pile, *e.g.*, 35 cm. for piles upto 10 metre in length and 40 cm. for piles between 10 and 15 metre. Precast concrete piles are available inlengths from 3 to 30 metre but generally less than 5 metre are not used.

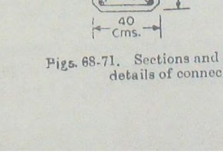


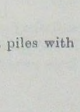
Precast piles are constructed without taper but have pointed lower ends. Whenever tapering is desired, it should not exceed 2 cm. per metre length of the pile.

The reinforcement consists of longitudinal bars with spiral at the top and bottom ends and suitable ties in between. However, in some cases the spiral may extend through the entire length of the pile. The longitudinal reinforcing bars are separated by cast iron or pressed steel forks placed diagonally across the section at 1 to $1\frac{1}{2}$ metre intervals. The ends of these longitudinal bars should bear on the shoe. Sometimes it is desired to project these longitudinal bars beyond the head of the pile and a special hood is built while driving.



These piles are cast in the forms either horizontally or vertically. Generally horizontal casting is preferred. When piles are cast in this position, it should be ensured that an unyielding base is provided

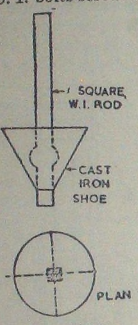




Figs. 68-71. Sections and elev. of R.C.C. piles with details of connectors and shoe.

for the pile so that concrete may not get disturbed while setting. Use of vibrators is essential. The forms are removed after about 48 hours. The pile is cured in its position for a week. After this, it is removed and placed in stacks for further curing. A period of about 3 weeks is allowed to lapse before they are driven. Whenever a rapid construction is desired, special quick hardening cement may be used so that the pile develops the desired strength earlier.

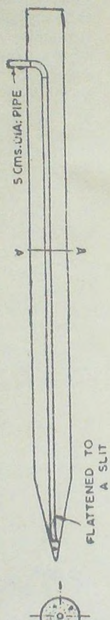
Special devices are used to permit convenient handling of piles. C. I. bolts screwed into plates are cast in the piles near the centre of cross-section at the points of lifting. The points where the pile is to be lifted are to be suitably calculated.



Figs. 72-73. Plan and Elev. of C. I. Shoe.

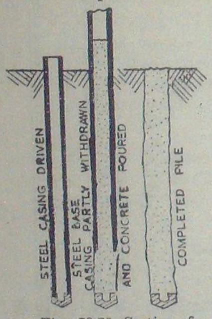
If a pile is to have a hole in the centre for insertion of a jet pipe for water injection while driving, a pipe is cast along with the concrete. Sometimes an oilcoated tapered wooden core is left but this has to be constantly rotated to prevent its sticking with the concrete.

Adding an extra length to precast piles is done by stripping the head and overlapping the longitudinal bars for a distance not less than 40 times the diameter of the bars. These longitudinal bars may also be welded.



Figs. 74-75. Plan and Section of a pile with water jet hole.

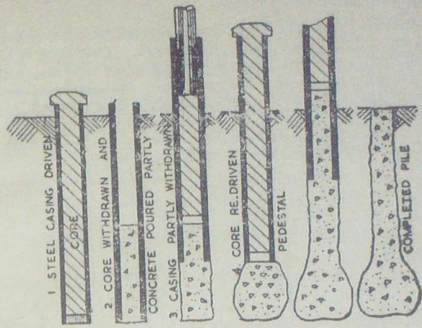
Cast-in-situ Concrete Piles : Cast-in-situ pile is a concrete pile built in its permanent location within a hole made for this purpose. This hole may be made by excavating with auger or by driving a suitable casing. The various types of cast-in-situ piles are described below :



Figs. 76-78. Casting of Simplex pile.

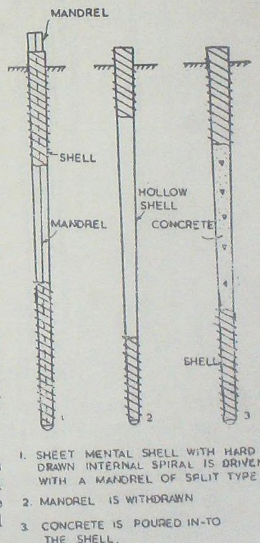
(*i*) *Simplex Pile*. A hollow cylindrical steel pipe is driven into the ground to the required depth. A cast iron or steel base is placed under the pipe to displace the soil. The reinforcement is placed into the pipe, if needed. Concrete is poured to a depth of about one metre into this pipe. After pouring the concrete, the enclosing pipe is withdrawn to some extent. Concrete is again poured into the pipe and the pipe is withdrawn. As the casing is pulled out, the hole gets filled with concrete which acts as a pile.

(*ii*) *Pedestal Pile.* The first step in the construction of this



Figs. 79-84. Pedestal Piles.

type of pile is to drive a casing and a core into the ground. The core is removed and concrete is placed to some depth inside the casing. The core is again placed and casing is pulled up by about one metre while the pressure is being exerted on the concrete with the core. The concrete is rammed so as to form a pedestal. The core is removed and concrete poured into the casing. Finally, as the concrete gets filled, the casing is withdrawn. Hence a concrete pile with a pedestal at the bottom is formed. If reinforcement is necessary, the same is placed after taking out the core and suitable arrangements for ramming the concrete are made.



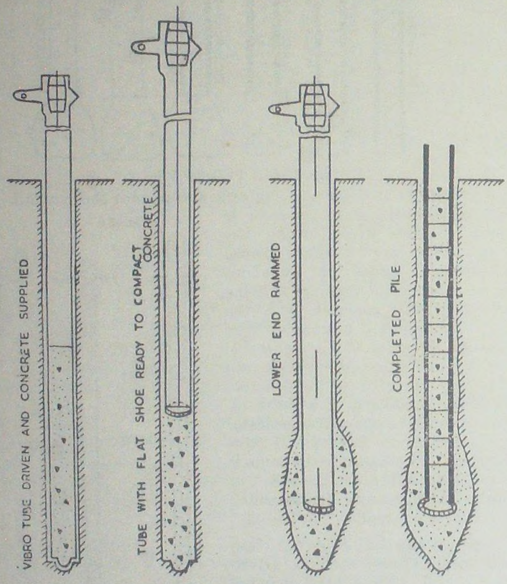
(*iii*) *Raymond Pile.* A thin sheet steel tapered shell is driven into the soil with a steel mandril inside. The mandril is removed and suitable reinforcement placed, if necessary. The shell is filled with concrete.

(*iv*) *Mac Arthur Case Pile.* This is formed by driving into the ground a heavy steel casing in which a core is inserted. The core is removed and

Figs. 85-87. Raymond pile. →

a corrugated steel shell is introduced. The shell is filled with concrete and the casing is withdrawn.

(*v*) *Vibro Piles.* Vibro piles are formed by driving a steel tube fitted with a C. I. shoe into the ground. The tube is filled with concrete and is extracted by a succession of upward pulling and downward tamping blows. The pile thus gets enlarged every time and fits in the surrounding soil securely. The upward and downward movement is repeated 80 times per minute and a pile of concrete is formed at the rate of about one metre per minute. These piles are cast rapidly and have a uniform dense concrete.



Figs. 88-91. Vibro pile.

Advantages of Precast Concrete Piles :

(*i*) Best concrete can be prepared by proper workmanship. Any defect can be immediately repaired.

(*ii*) The reinforcement remains in proper position and does not get displaced.

(*iii*) The concrete has only to withstand loads after complete curing has taken place.

They can be cast beforehand and a quick driving progress can be ensured.

(*v*) They are more convenient when driven through wet conditions.

(*vi*) They are more suitable when a part of their length is to remain exposed.

(*vii*) They are not affected by any other additional forces which act on them while adjacent piles are driven.

Disadvantages :

(*i*) They are heavy and difficult to transport.

(*ii*) Lapping of additional length means extra cost, labour and energy.

(*iii*) They have to be heavier in section to withstand the handling stresses.

(*iv*) The shocks of driving make them weaker.

Advantages of Cast-in-Situ Piles :

(*i*) There is less wastage of material as exact length of pile is cast.

(*ii*) The time spent on curing etc. is saved.

(*iii*) They can bear heavier loads by improving upon their cross sectional profile, *e.g.*, Pedestal piles.

Disadvantages :

(*i*) Good quality concrete cannot be easily obtained due to the unusual height of dumping.

(*ii*) The reinforcements are liable to get displaced.

(*iii*) They cannot be used under water.

(*iv*) The green concrete loses strength after coming in contact with the soil.

(*v*) The shells are affected by casting additional piles adjacent to them.

(3) **Composite Piles** : Wooden piles can advantageously be used below the ground water level as they are more durable under water. Hence a pile consisting of wooden section for its lower portion and a concrete section for its upper portion can be used. A wooden pile of the desired length is driven into the ground to its required depth and the shell with mandril inside is placed on top of it. The mandril is removed and concrete poured into the shell. This will make a composite pile. The joint between the wooden and the concrete section is designed to withstand any forces coming on it when the adjacent piles are being driven.

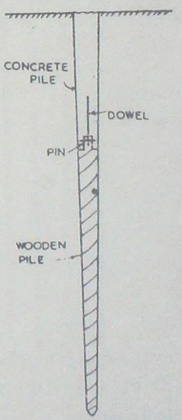


Fig. 92. Composite-pile.

(4) **Steel Piles** : Steel piles may be of I-section or hollow pipe section. Because of a small sectional area, steel piles are easy to drive. The pipes are driven with open ends. Compressed air may be used to drive out the soil within the pipe and thus facilitate the driving. These pipes are filled with concrete. Steel piles are mostly used as bearing piles because of their less available surface area to take the loads by frictional forces.

Another form of steel pile is the screw pile which is used in very soft soils. Shafts of screw piles can be of cast iron or mild steel and the helices can be of cast iron, cast steel or mild steel. The helix should consist of one complete or two half turns and should have sufficient pitch so that stones do not get jammed in between the blades. The diameter of the helix can be as much as 2 metre. They are driven by fixing a capstan with electrical motor to the head of the pile. A framework is built while the pile is being screwed. The spacing of screw piles is about twice the diameter of the helix. Water jets may be used to aid in the driving of screw piles.

A disc pile has a metallic disc attached to its foot so as to enlarge the bearing area. They are not commonly used for building foundation.

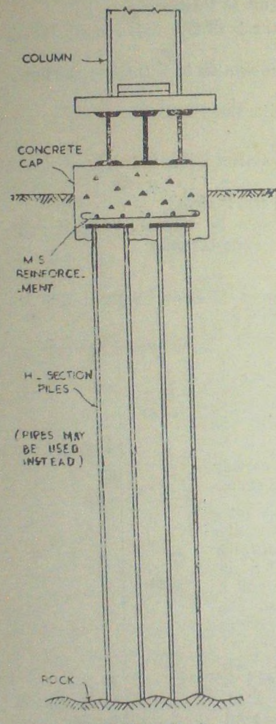


Fig. 93. Steel H-pile.

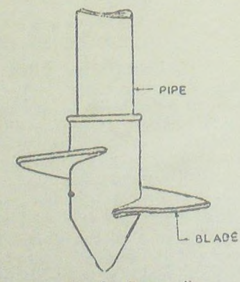
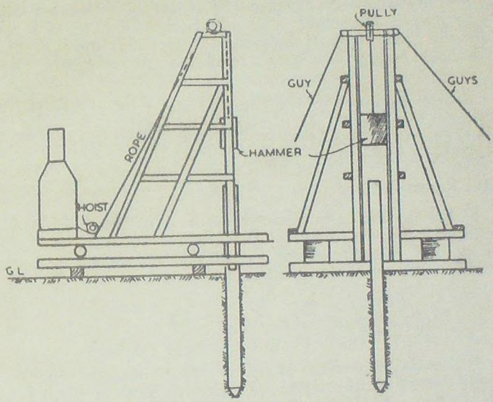


Fig. 94. Screw pile.

Pile driving

Pile driving is an operation of forcing a pile into the ground without previous excavation. Various methods are used for driving piles. The simplest is to drive with a heavy weight called a drop hammer. This is dropped on the head of the pile and is guide dduring its fall by suitable staging. The hammer is raised by pulling a rope manually or by a steam engine or electric motor. The weight of this hammer for driving concrete or wooden piles is about ½ to 1 ton and for driving heavier piles it may be as much as 2 to 3 ton. The height of drop varies form 1½ to 3 metre. These hammers are made of hard wood or cast iron or cast steel. The pile driving frame is kept in vertical position by suitable guy ropes. Arrangements for automatic falling of the hammer from desired height are made.



Figs. 95-96. Pile driving with a hammer.

Steam hammer : A heavy hammer is dropped on the pile through a small height but in quick succession. Single acting or double acting steam hammers are available. These hammers are raised with the aid of high pressure steam and are dropped by gravity (single acting) or by steam (double acting). Special devices are used to protect the head of the piles from damage due to the excessive blows which they receive. The advantages of steam hammers over the ordinary drop hammer are :

(*i*) The damage to the pile head is less.

(*ii*) The number of piles driven in a given time is more as the pile is practically kept in motion while the driving is in progress.

(*iii*) Less vibrations occur in the soil adjacent to the piles and hence the structures in the surrounding area are affected to a lesser extent.

Water jets : These can be used to drive piles easily in hard soils. However, they are not very much effective in silty or clayey soils. Water jet is applied to the foot of the pile generally by pushing one or two jetting pipes along with the pile as it is being driven. The diameter of the pipe is usually 5 to 8 cm. and the nozzle may be about 2·5 cm. in diameter. Whenever it is apparent that difficulty will arise in driving the piles before the process is started, it is desirable to have a central hole with a proper nozzle cast along the pile (*see* Figs. 74-75). The jet pressure should be sufficient to overcome the soil pressure easily and hence a minimum of 20 kgm/sq. cm. is desirable. As much as 6,000 litres of water per minute may be needed for harder soils. It is necessary to stop jetting before the final depth is reached. A minimum distance of one metre should be kept as a margin to allow a proper bearing for the pile.

Special Methods : Screw piles and disc piles are driven into the ground with the aid of driving drums and winch crabs. The drum is fixed to the top of the pile which is further rotated gradually by applying a torque from the crab with the help of wire ropes.

Under-Reamed Piles

Structures built on expansive soils often crack due to the differential movement caused by the alternate swelling and shrinkage of the soil and under-reamed pile foundation provides a satisfactory answer to the problem.

The principle of this type of foundation is to anchor the structure at a depth where ground movements due to changes in moisture content or consolidation of the poor strata are negligible.

The vertical movement of ground due to seasonal changes in moisture content in deep layers of expansive soils is limited to a depth of 3·5 m. In shallow depths of such soils, the length of piles can be reduced.

Single under-reamed piles may be provided for foundation of lighter structures (up to two storeys) and double under-reamed piles for heavier structures, in shallow as well as in deep layers of expansive soils.

Single and double under-reamed piles may also be provided for foundations of structures in poor soils overlying firm soil strata. In such soils for double under-reamed piles, however, both the under-reams rest within the firm soil strata.

Piles of uniform diameter are also provided for foundations of lighter structures in shallow depths (not exceeding 2 m.) of expansive soils and in poor soils overlying firm soil strata.

The length of piles will depend on the depth of stable zone and the piles are taken at least 50 cm. into it. Uniform diameter piles in expansive soils are however taken down sufficiently deep into the firm soil strata so as to develop the required anchorage against uplift.

Diameter of piles is usually not less than 20 cm.

Diameter of the under-reamed portions are normally two to two and half times the diameter of the shaft and do not exceed three times.

Piles are provided at all the junctions of walls and at intermediate points, where necessary. The spacing of under-reamed piles is normally kept a minimum of twice the under-reamed diameter for normal loading. In double under-reamed piles, the vertical spacing between the two under-reamings are also kept equal to one and a half times the under-reamed diameter.

Pile Caps

A group of piles is covered and connected together by a cap. Reinforced concrete piles have got R.C.C. pile caps, the reinforcement of the piles being continued into the caps. The piles are continued into the cap to a distance of at least 8 cm. and further the cap projects around the piles by at least 10 cm. The number of piies per cap should not be less than three so as to ensure stability of the group. Whenever less than three piles are used, a general practice is to connect the caps with each other.

Bearing Power of a Pile

The number of piles required to support a given structure was previously found out by dividing the total load coming on the group of piles by the load taken by one pile. This caused excessive settlements in some cases and hence it is desirable to know the settlement produced by the group of piles as a whole. Settlement may be caused by the pile groups yielding as a unit or the soil below may get compacted. The pressure transmitted by the group to the various layers of the soil below can be computed by the aid of formulae given in standard text books on "Foundation Engineering."

The bearing power of an individual pile is also computed with the help of empirical formulae or by carrying out load tests. Dynamic formulae are used to compute the bearing power of a pile by noting its behaviour during driving. The energy used in the driving and the corresponding penetration produced in the last few blows enables us to compute the bearing power of the pile. Factors like the rate at which pile is driven, its sectional area, etc., are also accounted for. A formula commonly used is :

$$P=\frac{16\,WH}{S+C}, \text{ where}$$

P = Allowable load on the pile, in kg.

W = Weight of the hammer, in kg.

H = Distance through which the hammer falls, in metre.

S = Average penetration for the last three blows, in cm.

C = A constant and a value of 2·50 is used for drop hammers and 0·25 for steam hammers.

Static formulae are derived from the type of the soil and the size of the pile. These measure the frictional resistance along the surface of the pile and the bearing resistance of the base. Empirical values based on theoretical aspects of 'Soil Mechanics' are used. However, the extent to which pile driving affects the skin friction is unpredictable in deep layers of clayey soils or in soils of varying natures.

Test piles is the most reliable method for calculating the bearing power of a pile. The load on the pile is applied with the aid of jacks placed against suitable supports. Whenever uniform soil is available in the vicinity, three test piles are sufficient. The test pile is allowed to recover for some time before additional load is applied. The load is applied in 5 to 10-ton increments and settlement readings are taken regularly. The design load is kept for at least 24 hours. Maximum load equal to twice the design load is applied. Generally the maximum allowable load is taken as half the load which causes a permanent settlement of 0·025 cm. per ton or 2·5 cm. whichever is less. In the case of piles resting in silty and clayey soils, the maximum load is taken as the load when the settlement increases considerably with very slight increments of load. A suitable factor of safety is used to get the design load.

The following points about pile foundation are worth noting :

(*i*) R.C.C. piles are not normally economical for depths less than 4 to 6 metre.

(*ii*) Driving of piles is generally commenced at the centre of the group of piles working outward.

(*iii*) When piles are driven in clay, displacement of the soil occurs which causes heaving in the soil surface. Some type of clays get considerably disturbed and bearing capacity is decreased to a large extent. "H" section piles cause least displacement.

(*iv*) In the case of sandy soils, care should be taken that excessive vibrations are not imparted to the soil otherwise considerable settlement may occur.

(*v*) The minimum spacing of friction pile is 1 to 1·5 metre; closer spacing leading to the heaving of the soil.

(*vi*) Not more than 4 cm. deviation from the designed alignment of the pile should be accepted, the tolerance on the verticality of the pile being not greater than 1 in 50.

Pier Foundations

Piers are generally cylindrical columns used to support the loads like bearing piles, *i.e.*, the load is transferred through them to a firm strata below. The difference between piers and piles lies in the method of construction. Bearing piles are driven with hammers whereas piers are driven by excavation of the soil which they occupy. Driving of bearing piles had to be discontinued when the pile refuses to be driven in and thus may not reach the desired layer of the firm strata below. In the case of piers the excavation can be carried to the desired depth easily. Piers are preferable when the structure is to be laid on decomposed rock overlying a strata of sound rock as it becomes difficult to drive bearing piles through decomposed rock due to some rock fragments coming under the foot of the pile which prevent it from sinking further. Similarly whenever the top clayey layers offer larger resistance to the driving of a bearing pile, it is desirable to use piers. Piers can also be driven conveniently under water.

Piers may be hollow or solid in section. They can be made of bricks, concrete, R.C.C., steel, cast iron, etc. The hollow space is plugged with concrete so as to form a solid section.

There are various methods of driving the piers. These are briefly enumerated below :

Open Caisson Method : A caisson is an enclosure which is driven into the ground and later on filled up. The sides of this enclosure may be made of masonry or concrete. Typical example of this case is the use of well foundation in India. (*See* Fig. 98). In this type, a special cutting edge and a curb is laid on the ground and masonry built over it. The soil within the hollow inside and underneath the edges is excavated. This well sinks under its own weight or for stiffer soils, it may be loaded. While working under water, special grab dredgers are used for excavating the soil. When the well rests on a sufficiently hard strata (or has enough load carrying capacity on account of side friction) it is plugged by pouring concrete at the top and bottom. Two or three wells may be connected together by covering them with a continuous cap.

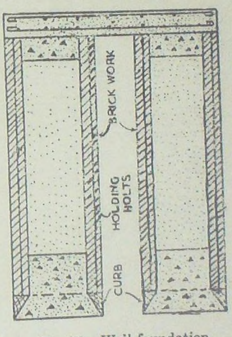


Fig. 97. Well foundation.

Compressed Air Caisson Method : This type is used commonly when the soil is exceedingly soft and rushes in as it is excavated, thereby preventing proper working within the well. The well is sealed at the top with the aid of special airlocks and compressed air pushed into the chamber. This prevents the inflow of soft soil. Men work within this chamber and excavate the soil as described above.

Ordinary Excavation Method : For stiffer soils a sort of well is excavated and the pier is built within this well. This method is used only for smaller depths.

Use of Sheeting and Sheet Piles : Whenever the sides of the excavated pit are liable to fall as the soil within is excavated it is necessary to support it with the aid of vertical or horizontal wooden planks or steel sheets suitably braced. For still softer soils, thin piles known as sheet piles are driven adjacent to each other to form an enclosure. The soil is excavated within this area and the pier built as usual.

Excavation of Foundations

The first step in excavating the necessary volume of soil

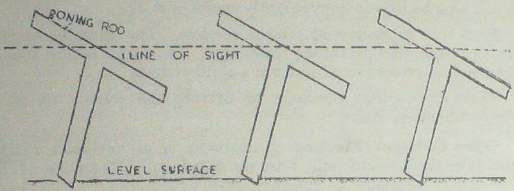
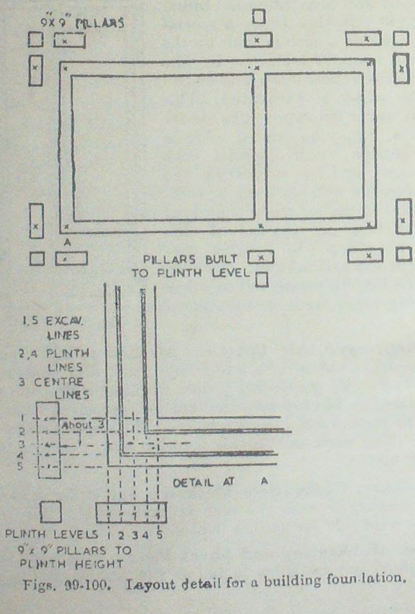


Fig. 98. Use of boning rods for levelling.



Figs. 99-100. Layout detail for a building foundation.

to be replaced by a suitable type of footings is to clear the site of all plants, debris, etc. The site is then made somewhat level so as to remove large inequalities.

After the foundation design has been finalised, a foundation plan denoting the width of excavation along with other complete dimensions is prepared. The next operation is to mark this plan on the ground surface. This is done by the aid of measuring tapes, wooden squares, pegs, strings, etc. The corners of the building are laid and the sides checked by measuring the diagonals. The entire width of foundation to be excavated is marked on the ground with the help of lime or by daugh-belling. It is essential to have permanent reference marks which should not get disturbed as the excavation proceeds. Marks denoting the width of excavation, the width of masonry at the plinth, offsets, etc., are made on small brick-pillars built in brick masonry. These pillars are erected at a distance of about one-metre from the edge of the excavation so that they may not get disturbed later on. In larger buildings, help of a theodolite is taken to mark the central lines of the walls and to check the corner angles. The plinth levels are to be accurately set and for this purpose, special brick pillars at the corners are erected and their tops finished at the desired level. (*See* Figs. 99-100).

Ordinary excavations are carried out with the aid of tools shown in Figs. 101 to 110. Most of the work is done with a spade,

Figs. 101-110. Excavator tools.
(1) Spade, (2) Pickaxe, (3) Pickaxe with flat end, (4) Kassi, (5) Crow bar. (6) Line and pins, (7) Rammer, (8) Boning rod, (9) Basket, (10) Iron pan.

a kassi (Phaorah), pick-axe and baskets or pans. Whenever rock excavation is to be carried out, chisels, jumpers, wedges, hammers, etc., are used.

Excavation with the aid of Timbering

In the case of hard soils and for small depths, excavation is carried to the desired breadth and depth without the aid of any support for the sides.

For stiff soils and for somewhat deeper excavation, light supports in the form of wooden boards about 4 cm. thick and extending to the depth of excavation are used. These supports are spaced at about 2 metre centres and are fitted with the help of struts against each other. One strut in the middle of the board or one at top and one t bottom may be used depending upon the firmness of the soil. (*See* Fig. 111).

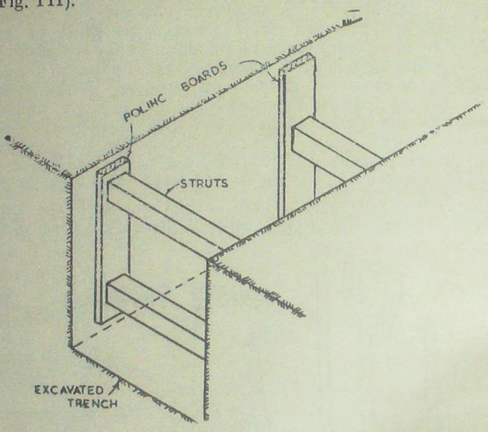


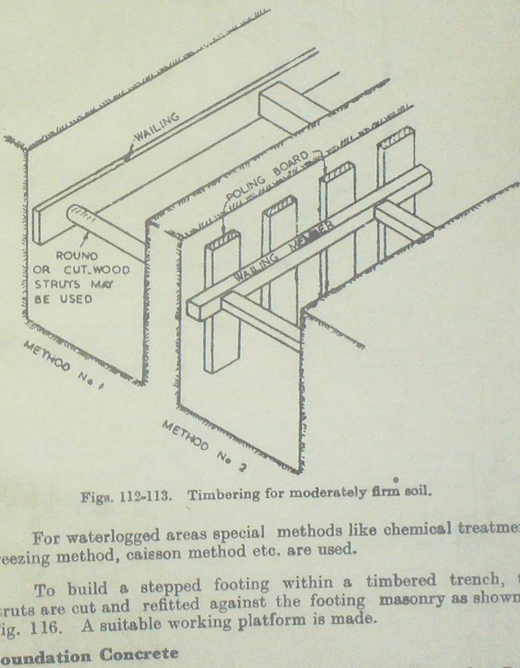
Fig. 111. Timbering for stiff soil.

For soils which are moderately firm, two methods are generally used. The first method envisages the use of horizontal boarding called wailing pieces which are strutted as described above. For cheaper work, round uncut wooden struts may be used. The second method is employed for soils which are softer. In this case poling boards, wailing members and struts are used. (*See* Figs. 112-113).

For soft soils, the poling boards have to be kept side by side otherwise the soil will come out through the intervening space. In addition, wailing members are used to give additional support and these are adequately strutted. Wedges may be inserted at the place shown (Fig. 114) to facilitate the tightening and removing of the members.

For deep excavation and in very soft soils, runners, *i.e.*, thick wooden planks pointed at the ends are driven deeper than the desired excavation depth, wailings and struts being used as usual.

For soils which immediately flow as they are excavated, arrangement as shown in Fig. 115 is used. The trench is excavated 1 to 2 metre in depth and the soil allowed to fall. Sides are then supported by vertical sheets (poling boards), wailed and strutted. A secondary system of runners is used and these are wailed and strutted to support the excavation. Wedges are inserted between runners and wailing pieces. Wedges securing one runner are slightly loosened. The earth from its foot is removed and the runner thus dropped is rewedged. In this manner the whole system of excavation is completed.



Figs. 112-113. Timbering for moderately firm soil.

For waterlogged areas special methods like chemical treatment, freezing method, caisson method etc. are used.

To build a stepped footing within a timbered trench, the struts are cut and refitted against the footing masonry as shown in Fig. 116. A suitable working platform is made.

Foundation Concrete

Generally lime concrete is used for foundation work. Brick ballast, broken stone or shingle are used as aggregate. Usually 4 cm. maximum size aggregate is permitted. The usual proportions are 13 cu.m. of lime, 26 cu.m. of surkhi and 100 cu.m. of

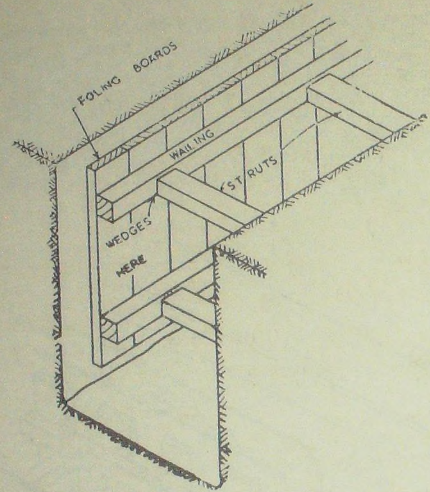


Fig. 114. Timbering for soft soil.

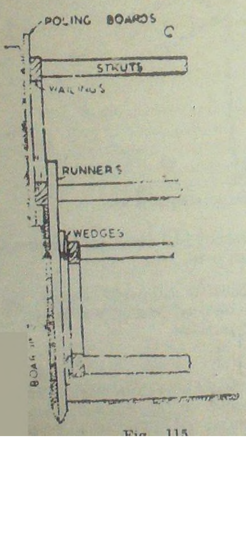


Fig. 115

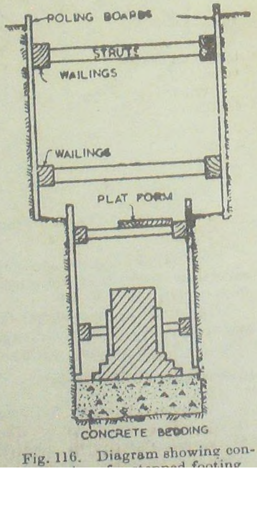


Fig. 116. Diagram showing con-

of aggregate. The materials are measured and mixed on specially constructed brick platform and protected from any admixture of dirt or other foreign materials. The ballast is stacked in rectangular layer of ½ metre thickness and on the top of it properly mixed lime and surkhi are spread. The stack is made as big as to last for one day's concreting. These materials are mixed three times dry and three times wet. Water just sufficient to wet the concrete is added. This mixture is placed in position in layers not exceeding 15 cm. in thickness and thoroughly consolidated with 5 kgm. rammers. Consolidation is taken as complete when a layer of mortar appears on the surface and exposed aggregates are not visible. Whereever joints are unavoidable, the end of each layer is sloped at an angle of 30°. The concrete is cured for a period of not less than 10 days and no brickwork built over it for a period of 7 days. Alternatively cement concrete of weak proportions, *e.g.*, 1 : 8 : 16 can be used.

QUESTIONS

1. What do you understand by the term 'Foundation'? Name the various type of foundations used for a building.

2. Describe briefly as to how the foundation is provided for a 2 brick thick masonry wall. Illustrate your answer with the aid of a sketch.

In what way a stepped foundation can fail? What are the general rules for proportioning the various offsets in this type of footing?

3. An isolated brick column of 1½ bricks square is to be constructed for a building. Illustrate with sketches a suitable footing for this column.

4. What are the various type of footings suitable for (*a*) Isolated R.C.C. Column ; (*b*) Isolated Steel Column ; and (*c*) Isolated Timber Column.

5. When are combined footings essential? Illustrate with sketch as to how an external R.C.C. column can be combined with an internal R.C.C. column.

What is the essential difference between a combined footing and a cantilevered footing?

6. (*a*) Name the various type of foundations which are suitable for a building consisting or R.C.C. columns on soft soil.

(*b*) Write short notes on :

(*i*) Raft foundation.

(*ii*) Distribution of pressure below a spread footing on various type of soils below ground level.

(*iii*) Inverted arches.

7. When are pile foundations necessary? What are the advantages and disadvantages of piles over other types of piles? What preservation treatments are necessary for timber piles?

8. What are the various type of materials used for piles?

Discuss the advantages of cast-in situ piles over precast R.C.C. piles.

9. Write short notes on :

(*i*) Precast R.C.C. piles.

(*ii*) Pedestal piles.

(*iii*) Composite piles.

(*iv*) Screw piles.

(*a*) Pile driving.

10. What are the various methods of installing different type of piles within ground? Briefly describe the water jet method.

11. What are the precautions necessary while driving wooden and concrete piles respectively ?

What are the various methods of ascertaining the load bearing capacity of an individual pile ?

12. What is meant by 'pier foundation' ? Briefly describe various methods of constructing a pier foundation.

13. What precautions are necessary to be taken while excavating trenches for foundations in very soft soil ?

Describe the method of timbering a trench in soft clayey soil.

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3

BRICK MASONRY

Bricks arranged systematically and bedded together in mortar to form a homogeneous mass capable of withstanding and transmiting forces, without failure, is called brick masonry.

Ordinary bricks are economical and when laid in good mortar form a durable construction. Bricks are comparatively small in size and, therefore, can be easily handled. Moreover, they can be suitably arranged in various shapes to form different components of a building, *e.g.*, walls, partitions, footings, columns, steps, floors, arches, lintels, etc.

Materials used in Brick Masonry

The materials used in brick masonry construction are bricks and mortar.

(1) **Bricks** : The various kind of bricks are :

(*a*) *Common bricks* : This term is applied to bricks which are made of clay and burnt in the usual manner in kilns. Generally, these bricks are graded into three classes :

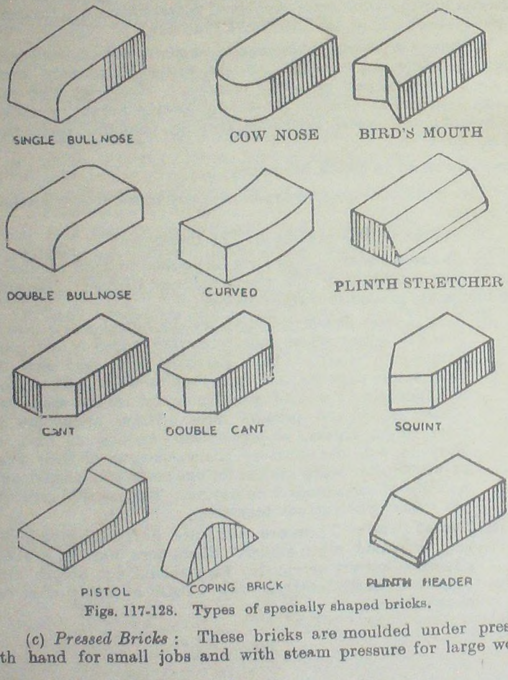
(*i*) *First Class Bricks* : These are $19 \times 9 \times 9$ cm. in size, so that ten layers when laid in mortar will form one metre height of masonry. They are made from good earth, free from saline deposits and are sand-moulded. They should be thoroughly burnt, of good colour, of regular shape with square edges and parallel faces. These bricks are free from flaws, cracks, chips, stones, nodules of lime, etc. They do not absorb more than one-sixth of their weight of water after being soaked for one hour and should show no signs of afflorescence on drying. They should give ringing sound, when struck together.

(*ii*) *Second Class* : These are also fully burnt and give a clear ringing sound when struck. Slight irregularities in shape, size or colour are accepted. They should not absorb more than one-fourth of their dry weight of water after one hour's soaking.

(*iii*) *Third Class* : These are not burnt so fully as in the previous two cases but are generally of uniform reddish yellow colour. Defects in uniformity or shape are tolerated but they should not be excessive so as to interfere in the laying of bricks.

Generally first and second class bricks are used for brickwork. They should have a minimum compressive strength of 80 kg.per sq. cm.

(*b*) *Face Bricks* : Generally selected first class bricks are used for face work. However, it is essential that face bricks should be uniform in colour, texture, size, etc. Hence special bricks having these qualities are made under controlled supervision. Further, if any markings or surface finishes are needed, special bricks are moulded for face work. These bricks can be used for garden walls, side walks, steps and other exposed work where exceptionally good appearance is desired, regardless of cost.



Figs. 117-128. Types of specially shaped bricks.

(c) *Pressed Bricks* : These bricks are moulded under pressure with hand for small jobs and with steam pressure for large works.

These bricks have regular smooth faces, sharp edges, square corners and uniform colour. They are used for face work of buildings. Such bricks are specially useful when exact dimensions are required in walls or other structural members.

(*d*) *Fire Bricks*: These are made of special fire clays. They are used for lining in fire-places, furnaces, etc., where high temperatures are prevalent and ordinary bricks get decomposed. They are slightly larger than the ordinary bricks.

(*e*) *Glazed and Coloured Bricks*: Coloured bricks are used where special colour treatment is needed or where ordinary bricks of good uniform colour are not available. Glazed bricks have one surface glazed in white or any other colour. These are used for exterior surfaces of walls or partitions, in dairies, hospitals, etc., where cleanliness is important.

(*f*) *Imitation Bricks*: These bricks are similar in size to common bricks but are made of Portland cement and sand. They are unburnt but have the same qualities as that of a good mortar.

(*g*) *Moulded Bricks*: These are special bricks made to suit different requirements, *e.g.*, giving architectural shapes to brickwork. Examples are copings, cornices, string courses, sloping walls, etc. The generally used types are shown in Figs. 117-128.

(2) **Mortar:** In order to bind the individual bricks to form the whole wall a campact mass, mortar is used. The mortar has also to form a cushion to take up the inequalities in the brick, to distribute the pressure evenly and to fill up the interstices in the bricks. The type of mortar used depends on the total load that the structure has to bear, the weathering agencies, type of finish desired, etc. The commonly used mortars are :

(*a*) Lime mortar.
(*b*) Cement mortar.
(*c*) Lime-Cement mortar.
(*d*) Lime-Surkhi mortar.
(*e*) Mud mortar.

The manufacture of these mortars and their characteristics do not fall within the scope of this book. Reference may be made to any book on "Building Materials".

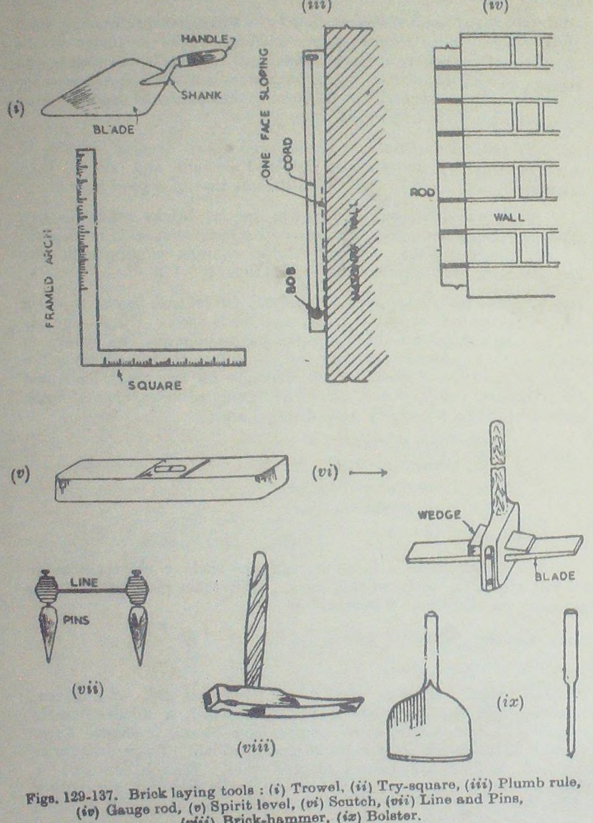
Brick Laying Tools:

The tools used are :

(1) *Trowel*: This is the most important tool of a mason. It consists of a steel blade and a shank into which a wooden handle is fixed. There are many sizes ranging from 10 cm. in length, 5 cm. in width to 30 cm. in length and 20 cm. in width. The width varies from one end of the trowel to the other. Trowels are used for lifting and spreading mortar for forming joints and also for cutting bricks.

(2) *Plumb Rule* : This is a piece of wood about 1 cm. thick, 10 cm. wide and 2 m in length. The long edges are parallel. A plumb bob is suspended from the top by a thread. This is used for checking the verticality of the brick wall.

(3) *Straight edge* : This is a wooden piece about 1 cm long having parallel edges and is used for checking the alignment of the brick faces.



Figs. 129-137. Brick laying tools : (*i*) Trowel, (*ii*) Try-square, (*iii*) Plumb rule, (*iv*) Gauge rod, (*v*) Spirit level, (*vi*) Scutch, (*vii*) Line and Pins, (*viii*) Brick-hammer, (*ix*) Bolster.

(4) *Gauge Rod* : This is a straight edge about 10×1 to 2.5 cm. in section and may be as long as a storey height. On this rod, different bricklayers along with the joints are marked as horizontal lines. This is used in setting out the brickwork and checking that the layers are being laid at correct level and are of uniform thickness.

(5) *Spirit Level* : This is used with straight edge for getting horizontal surfaces.

(6) *Brick-hammer* : This is used for cutting bricks to suit different shapes. This hammer has got one side sharpened so as to form an edge and the other is shaped square.

(7) *Square* : This consists of a steel or wood section fitted to form a right angle. This is used for checking right angles.

(8) *Line and Pins* : A cord is wound round two steel pins and is about 10 to 12 m long. When opened, it is used for maintaining strict alignment of the courses.

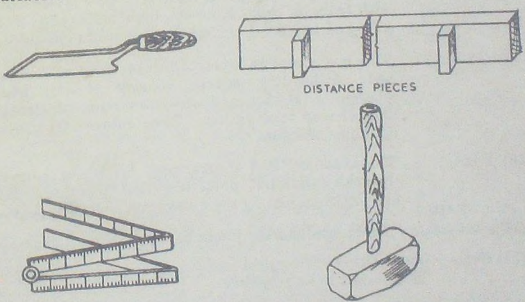
(9) *Club hammer* : This is a hammer with its head weighing about 1 to 2 kg. It is used for driving chisels, etc.

(10) *Bolster* : This is a steel chisel with a very wide blade. It is used for cutting bricks accurately.

(11) *Jointer* : This is used for pointing the joints in brickwork. They are generally of two sizes, one about 5 cm. long for vertical joints and the other about 15 cm. long for horizontal joints. The edge of the jointer makes a recess in the mortar and gives a finishing treatment. This edge may be square, V-shaped, concave, etc.

(12) *Pointing Rule* : This is a dressed piece of timber $8 \times 0{\cdot}3$ cm. in size having a bevelled edge with 1 cm. thick wooden or cork distant pieces fixed on bevelled side.

(13) *Scutch* : This is used for cutting soft bricks and dressing cut surfaces.



Figs. 138-141. Brick-laying tools : (*i*) Jointer, (*ii*) pointing Rule, (*iii*) 1 metre Rule, (*iv*) Club-Hammer.

Terms Used

(1) *Header* : This denotes the end of a brick as seen in the wall face. (9×9 cm. side).

(2) *Stretcher* : The side of a brick as seen in elevation in a wall where the brick is laid flat. (19×9 cm.).

(3) *Bed* : The lower 19×9 cm. surface of a brick when laid flat.

(4) *Bat* : A portion of a brick cut across the width. These are of different sizes and shapes, *e.g.*, ½ bat, ¾ bat and bevelled bat.

(5) *Closer* : A portion of a brick cut longitudinally with one long face uncut. The types are :

(*a*) *Queen closer* : This is placed next to the first brick in a header course. This is a half brick cut longitudinally.

(*b*) *King closer* : This is used for splayed brickwork. It is a special sized brick with its one end having a width of half a brick.

(*c*) *Bevelled closer* : This has one stretcher face bevelled.

(*d*) *Mitred closer* : This has the header face splayed.

(6) *Bull Nose* : These are bricks with one edge rounded (single bull-nose) or with two edges rounded (double bull-nose). They are used where slightly curved corner bricks are needed, *e.g.*, copings.

(7) *Frogs* : These are indentations in the bricks provided to form a key for holding the mortar. The bricks are laid with frogs on top. Nine cm. high bricks should have a frog of 10×4×1 cm. size on one of its flat sides.

(8) *Course* : This is a complete layer of bricks laid on the same bed. A heading course consists of only headers whereas a stretcher course comprises of stretchers only as seen in elevation. These courses are generally of same thickness.

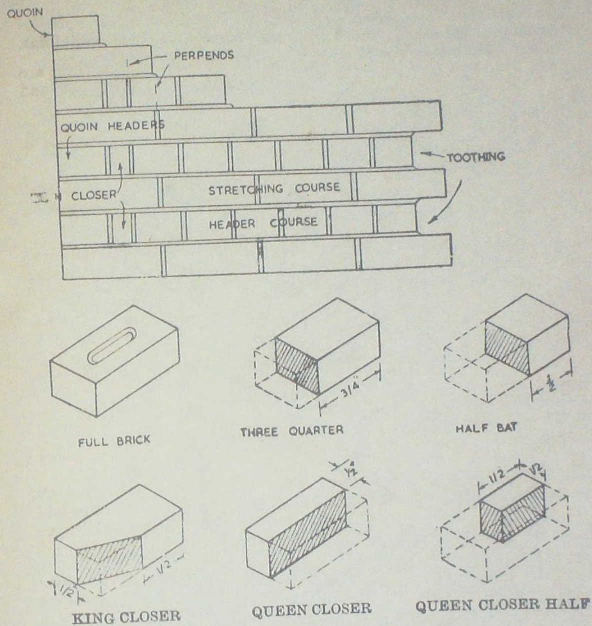
(9) *Bond* : This is the method of arranging bricks in courses so that the individual units are tied together. Bonds are distinguished by their elevation or face appearance.

(10) *Bed joints* : Horizontal mortar joints between the two courses.

(11) *Cross joints* : The short vertical joints between two bricks, also referred to as perpends.

(12) *Quoin* : A corner or the external angle on the face side of a wall.

(13) *Facing* : The exposed area of a wall or other structure. The internal surface of the wall is called backing whereas the portion in between the backing and the facing is called hearting.



Figs. 142-148. Terms used in brick work.

Causes of Failure of Brick Masonry

The correct approach to the understanding of the basic requirements in any construction is the criterion of failure. Brick masonry may fail due to the following causes :

(1) By crushing, if it overloaded.

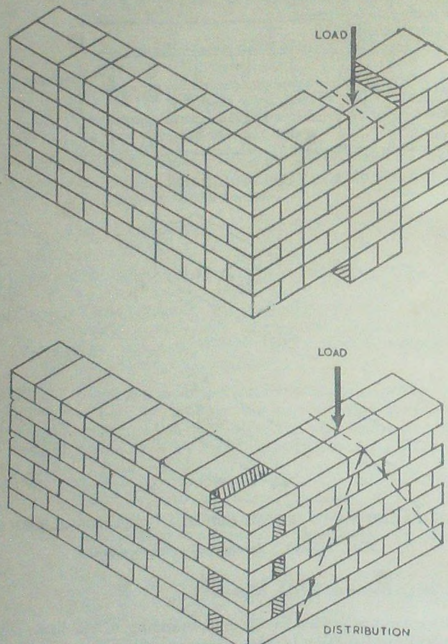
(2) By shearing along any horizontal plane.

(3) By rupture along a vertical joint under vertical loads.

Care against crushing can be taken by providing adequate dimensions. Shearing along any horizontal plane is prevented by providing a strong mortar. Rupture along a vertical plane is avoided by breaking vertical joints in brickwork.

Bonding in Brickwork

It is the process of arranging bricks in courses in order to develop longitudinal and transverse interlocking for individual bricks. The purpose is to achieve a united mass, as strong as practi-



Figs. 149-150. Effect of wrong and correct bonding bricks in a wall on its load carrying capacity.

cable, to suit the length, height and thickness of brickwork and the loads and stresses to which it is subjected. The method is to ensure that vertical joints do not come one over the other. A brick wall having a continuous vertical joint will not act as a complete unit but will consist of small portions which act as columns. Between these individual columns, there is no bonding effect except that the mortar causes adhesion between them. In such a case, if the wall is loaded, it is likely that these columns may separate out from each other by the slipping of the column faces from the mortar (Fig. 149).

However, if a wall is built so that there are no continuous vertical joints (as shown in Fig. 150) the load will get distributed. This type of construction will be more durable and strong. As bricks are small units which have equal dimensions, the process of bonding is easily performed.

Rules for bonding : To ensure good bonding, the following rules should be observed :

(*i*) The amount by which the bricks in one course overlap the bricks in the course below should be minimum ¼ brick along the length of the wall and ½ brick across the thickness of the wall.

(*ii*) The vertical joints in the alternate courses should fall in plumb (vertical) line from the top of the wall to its base, whether on the face or in the interior of the wall.

(*iii*) Bats should be used as sparingly as possible.

(*iv*) The bricks should be uniform in size and the proportion of length to breadth be such that the length equals twice the width plus one joint. Good bond is impossible otherwise the lap would not be uniform.

(*v*) The bricks in the interior thickness of the wall should be laid with their length across the wall, as it is termed headerwise.

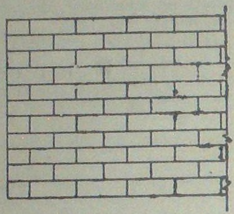
(*vi*) It is also recommended that every sixth course on both sides of the wall should be a header course or there should be at least one full header every 510 sq. cm. of wall ace. In walls 1½ brick thick or more, header shall overlap headers to provide continuous tie throughout the wall.

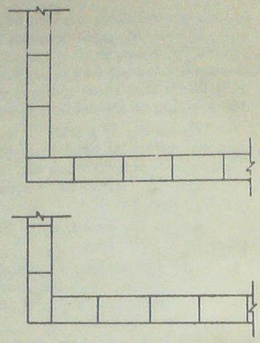
Types of Bond

(1) **Stretcher Bond** : In this type of bonding, all courses are laid as stretchers, *i.e.*, with their lengths in the direction of the length of the wall (*See* Fig. 151-153). This is used for partition walls which are only ½ brick or 9 cm. thick. In thick walls, this arrangement is impracti- cable because there is no bonding across the wall.

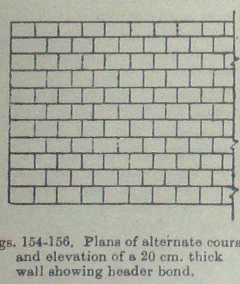
(2) **Header Bond** : This consists of all headers (*see* Figs. 154-156), *i.e.*, bricks are laid with their ends towards the face of the wall. This is used for walls which are one brick thick and is specially useful for curved brickwork where cutting of stretchers would entail lot of inconvenience. This bond does not possess the strength to transmit pressure in the direction of the length of the wall and, consequently, is not employed for walling.

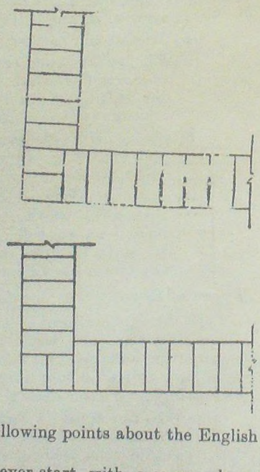
(3) **English Bond** : This bond is produced by laying alternate courses wholly composed of headers or stretchers. For breaking the joints vertically, it is essential to place queen closer after the header





Figs. 151-153. Elevation and plans of alternate courses of stretcher bond.





Figs. 154-156. Plans of alternate courses and elevation of a 20 cm. thick wall showing header bond.

quoin in the heading course. The following points about the English bond should be remembered :

(*a*) A heading course should never start with a queen closer as it would get displaced.

(*b*) Every alternate header comes centrally over the joint between the two stretchers in the course below giving a lap of 5 cm.

(*c*) There is no continuous vertical joint except at stopped ends.

(*d*) Walls of an even member of half bricks in thickness present the same appearance on both faces, *i.e.*, a course showing stretcher on the front face will also show stretchers on the back face.

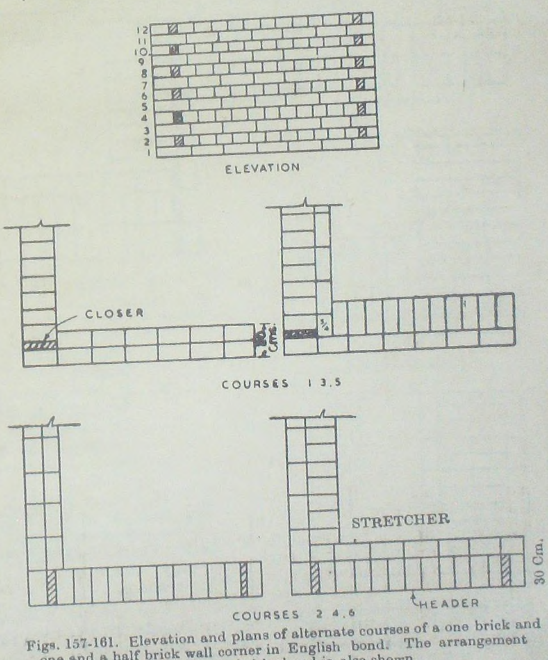
(e) Walls of an odd number of half bricks in thickness will show each course comprising of headers on one face and stretchers on another face.

(f) The middle portion of each of the thicker walls consists entirely of headers.

(g) The number of vertical joints in the header course is twice the number of joints in the stretcher course. Hence the joints in the header course should be made thinner than those in the stretcher course.

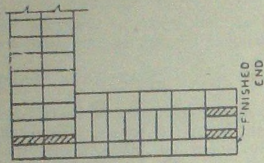
In setting out the plan of a course for any width of wall, the following steps should be followed :

(a) Draw the quoin or the corner brick.

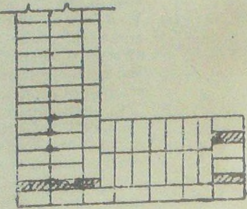


Figs. 157-161. Elevation and plans of alternate courses of a one brick and one and a half brick wall corner in English bond. The arrangement of bricks at finished end is also shown.

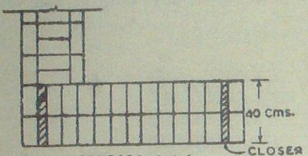
(*b*) Next to the face (which shows header in elevation) place closers to the required thickness of the wall.



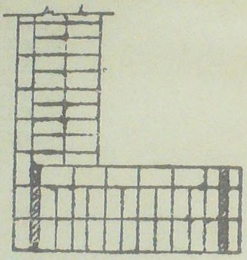
CORSES 1,3.5



COURSES 1, 3, 5

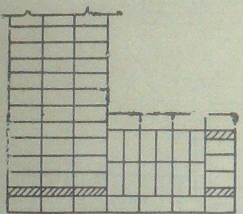


COURSES 2.4.6

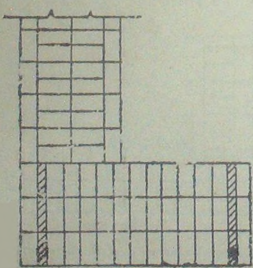


COURSES 2 2, 4, 6

Figs. 162-167. Plans of alternate courses of 2, 2½ and 3 brick walls in English bond.



COURSES 1, 3, 5



COURSES 2, 4, 6

(*c*) Set out all the front headers.

(*d*) If the thickness is a even multiple of half bricks, set out the headers in the back face.

Or

If the thickness is an odd multiple of half bricks, set out stretchers in the back face. The in-between space, if any, should be filled with the headers.

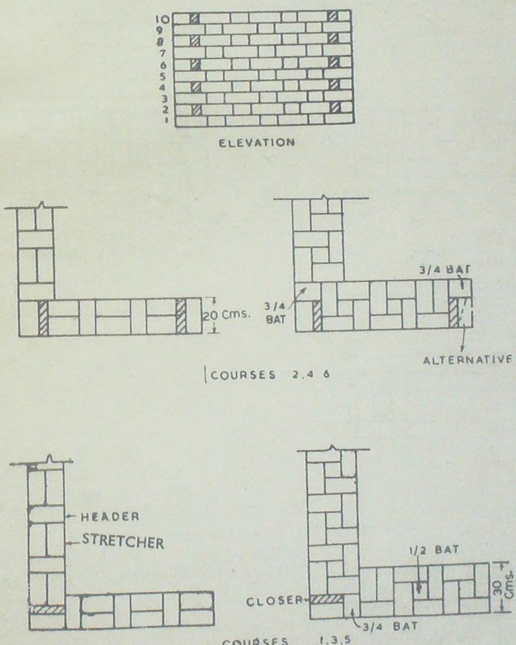
The plans of alternate courses for various thicknesses of the walls are shown in Figs. 157-167.

(4) **Double Flemish Bond :** This is made up of alternate header and stretcher in the same course. The entire course for facing, backing and hearting or filling is laid in this style. The following point about this bond are worth mentioning :

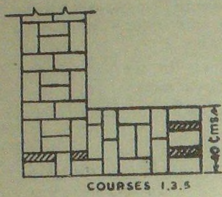
(*a*) The headers and stretchers appear in the same course alternately on the front and the back faces.

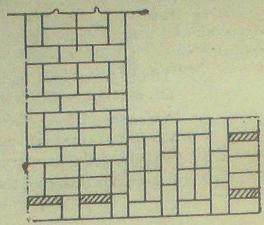
(*b*) A header in any course is in the centre of a stretcher in the course above or below it.

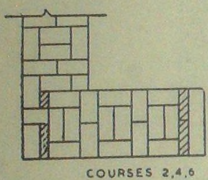
(*c*) Closers are inserted in alternate courses next to the quoin header for breaking the vertical joints in successive courses.

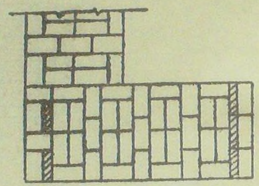


Figs. 168-172. Elevation and plans of alternate courses of one brick and 1½ brick walls in Double Flemish bond.

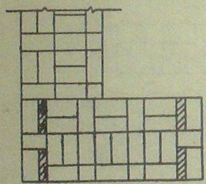


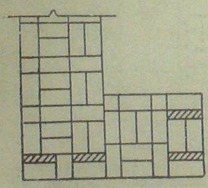






Figs. 173-178. Arrangement of bricks in alternate courses of 2, 2½ and 3 brick walls in Double Flemish bond.





(*d*) In walls having a thickness equal to odd number of half bricks, bats are to be used.

The plans of walls built in Double Flemish bond for various thicknesses are shown in Figs. 168-178.

Comparative Merits and Demerits of English Bond and Double Flemish Bond

(*a*) English bond is stronger than Double Flemish bond for walls thicker than 1½ bricks, because of the use of large number of headers.

(*b*) The Double Flemish bond has a better appearance on the face than English bond because of alternate headers and stretchers in the same course.

(*c*) Double Flemish bond is economical since a large number of bats can be used.

(*d*) In Double Flemish bond, the number of joints in the consecutive courses being the same, there is no difficulty in maintaining the correct breaking of joints.

(*e*) A fairly uniform face is obtained on both sides of a one brick wall, if Double Flemish bond is used. This is because all stretchers are not of equal length and hence the combined length of two headers plus the joint in between exceeds, at places, the length of the stretchers if English bond is used. Whereas in the case of Double Flemish bond, there are less irregularities visible.

(*f*) To construct the walls in Double Flemish bond, extra care is needed to keep the vertical joints in alternate courses one above the other. This means that extra labour cost is involved

(5) **Single Flemish Bond** : This consists of a facing of Flemish bond with a backing of English bond in each course. The *advan- tages* of this are :

(*a*) The strength of English bond as well as the appearance of Flemish bond are partly attained

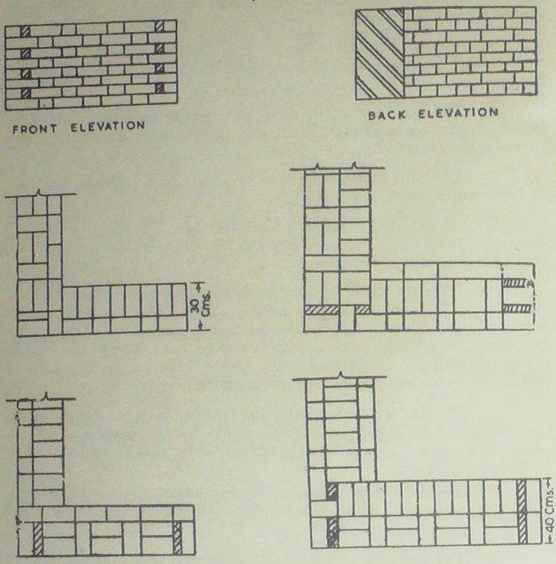
(*b*) Cheaper bricks can be used as a backing, whereas good bricks can be employed for face work which is to be done in Flemish bond.

The *disadvantages* of this bond are :

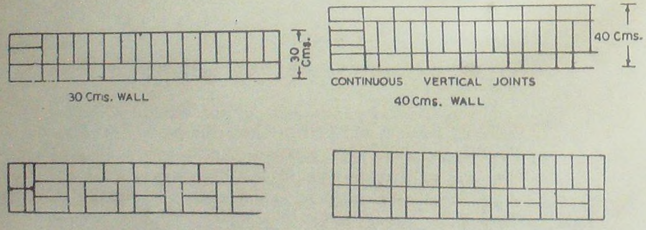
(*a*) This cannot be used for walls less than 1½ brick in thickness.

(*b*) A long continuous joint occurs in the vertical direction for some portions and thus weakens the wall. (*See* Figs. 179-188).

(6) **Garden Wall Bond** : This type of bonding is used for garden compound walls. As already pointed out, it is difficult to make uniform wall of one brick thick in English bond due to the variation in the lengths of the stretcher faces. Strether and header bonds can be constructed but they are not very strong. Two types of garden wall bonds are commonly used.



Figs. 179-184. Front and back elevations and plans of alternate courses of 1½ and 2 brick wall corners in Single Flemish bond.



Figs. 185-188. Plans of alternate courses of 1½ and 2 brick walls in Single Flemish bond (alternative arrangement) : vertical joints are continuous to some extent.

(*a*) *English Garden Wall Bond* : This consists of one course of headers after three or five courses of stretchers. A queen closer is placed next to the quoin header. The middle course of stretchers is started with a header to give the necessary lapping.

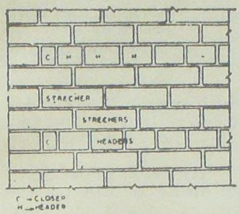


Fig. 189. English Garden Wall bond.

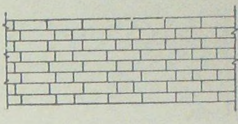


Fig. 190. Flemish Garden Wall bond.

(*b*) *Flemish Garden Wall Bond* : This comprises of one header after three or five strechers in each course. A $\frac{3}{4}$ bat is introduced next to the quoin header in every alternate course and a header is placed over the middle of each stretcher.

(7) **Facing Bond** : This is used where bricks of different thicknesses are used in the facing and backing of the walls. This bond consists of one header course after several stretcher courses. The distance between the successive heading courses is the least common multiple of the thickness of backing and facing bricks, *e.g.*, if the facing bricks are 10 cm. thick including mortar joints and the backing bricks are 9 cm. with mortar joints, the heading courses will be kept apart at a distance of 90 cm. which is the least common multiple.

(8) **Raking Bond**. Walls which are very thick have less stretchers in them and hence their longitudinal stiffness gets decreased. This defect is overcome by the use of raking courses at certain intervals along the height of the wall, say. after sixth or eighth course. The joint of bricks thus laid cannot coincide with the joint of the ordinary courses directly above or below. Raking courses should not be laid one above the other as there will be weakness at the junction of the raking with the face bricks. The alternate courses of raking bonds are laid in different directions for maximum strength. It is also used in strengthening the footings of very high walls. The two types of such bonds commonly used are :

(*a*) *Herring Bone Bond*. The bricks are laid at an angle of 45° starting at the central line and proceeding towards the face brick. This is used for walls which are thicker than 4 bricks or for pavings. When used for pavements, bricks are 'laid' on edges.

(b) *Diagonal Bond.* After the face bricks are laid, one or more bricks are bedded between the face bricks so that the opposite corners touch the latter. This determines the angle at which the bricks should be laid. The small triangular spaces at the ends are filled with bricks cut to the shapes needed. This is used for walls of 2 to 4 bricks thick.

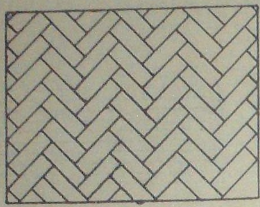


Fig. 191. Zig-zag Bond.

(9) **Zig-Zag Bond.** This is similar to herring bone bond except that the bricks are laid in a zig-zag fashion. This is commonly used for brick pavings.

(10) **Dutch Bond.** This bond is built up with $\frac{3}{4}$ and $\frac{1}{2}$ brick closers along with the regular header and stretchers. This is slightly stronger at the junction than the common type of bonds used.

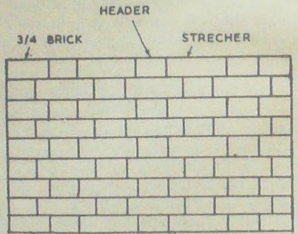


Fig. 192. Dutch bond.→

(11) **English Cross Bond.** This consists of alternate courses of headers and stretchers where every alternate stretcher course has a header introduced next to the quoin stretcher. This is used for walls where strength as well as beauty is required.

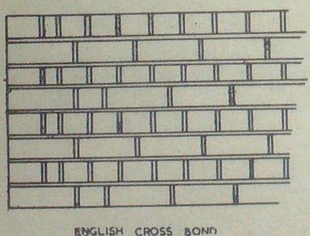


Fig. 193. English Cross bond.

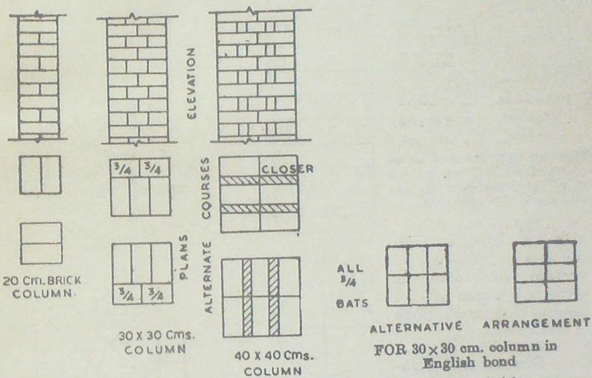
(12) **Soldier and Rowlock** : Soldier course consists of bricks standing vertically on end. This cannot be bonded properly with the wall and hence has a tendency to weaken it. Similarly bricks laid on edge are called Rowlock courses. They are used for sills, cornices, etc.

Bonds in Other Structures

(1) **Columns** :—Columns can be of square, rectangular, circular or other shapes. The various type of bonds described above can be used but the commonly used are English and Double Flemish types.

(a) *English Bond.* A 20×20 cm. column is made by laying two bricks together and the next course is laid at right angles to this.

30×30 cm. column is built in two types. In one type ¾ bats are only used. They are placed as shown in Figs. 203-204. In



Figs. 194-204. Plans of alternate courses and elevation of one brick, one and a half brick and two brick columns in English bond.

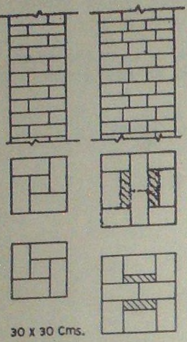
the second type two ¾ bats and three full bricks are used in each course. However, there are continuous vertical joints in the second type whereas in the first type the bricks have to be cut to size.

In 40×40 cm. column, closers of ½ bricks have to be used parallel to the stretcher face. The arrangement as shown in the figure for first course is also used for the second course except that the bricks are turned through one right angle.

In larger sized columns bricks are arranged in a similar fashion and suitable closers are added wherever necessary.

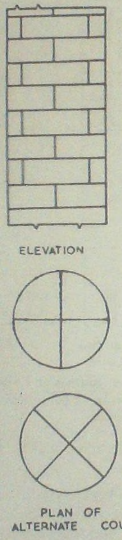
(*b*) *Double Flemish bond.* The smallest size of the column which can be built in this type of bond is 30×30 cm. A square bat is to be used in every course in the centre of the column and this creates continuous vertical joints which weakens the column. However, the headers do not come over the centre of the stretchers as in the case with the true Flemish bond (*see* Figs. 205-207).

The plans of alternate courses of 40×40 cms. brick column in Flemish bond are shown in Figs. 209-210. Continuous vertical joints occur at certain portions of the column and create zone of weakness.

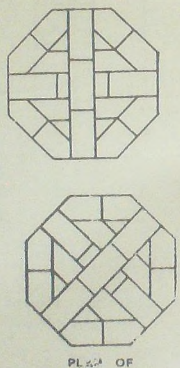


Figs. 205-210. Plans of alternate courses and elevations of $1\frac{1}{2}$ and 2 brick square column in Flemish bond.

Circular and Octagonal Columns. These may be constructed of cut or moulded bricks to suit the size. They are generally made in English bond. At places, bull-nosed bricks may be used if fully circular section is not desired.

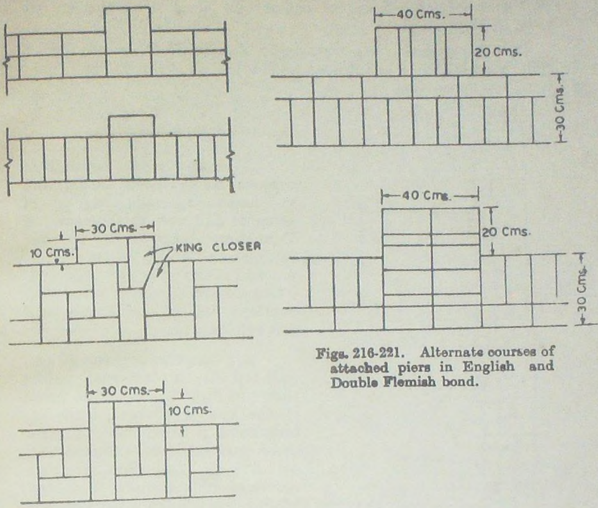


Figs. 211-213. Circular column made of special bricks.

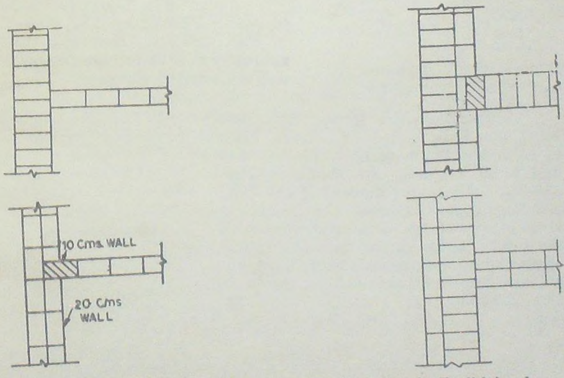


Figs. 214-215. Octagonal column.

(2) **Piers attached to walls.** These are used for increasing the stability of the walls and for enhancing the architectural beauty of straight walls. They are projections from the wall acting as columns and can be constructed in English or Dou-



Figs. 216-221. Alternate courses of attached piers in English and Double Flemish bond.



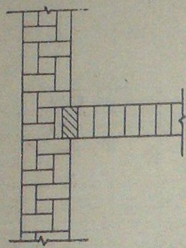
Figs. 222-225. Plans of alternate courses of junctions in English bond.

ble Flemish bond. Plans of courses for some of these piers are shown in Figs. 216-221.

(3) **Junctions.** (*a*) *Right-angled Junctions* : These are formed when two walls meet or intersect each other at right angles. They are of two types, *i.e.*,

(*i*) T-junction.

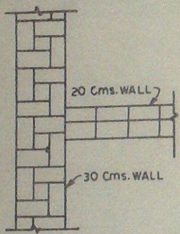
(*ii*) Intersections.



T-junctions can be built in various bonds listed earlier and the connecting walls may be of same or different thicknesses. A T-junction between a 10 cm. internal wall and a 20 cm. external wall is shown in Figs. 222-223. One course of 10 cm. internal wall overlaps the 20 cm. main wall and acts as a tie.

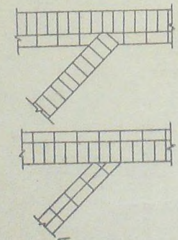
A T-junction between 20 cm. wall and 30 cm. external wall is shown in Figs. 224-225. One brick of the header course of the internal wall is fitted into the stretcher course of the external wall with a 5 cm. lap. The stretcher course of the internal wall 'butts' against the header course of the external wall.

A plan of a T-junction laid in Double Flemish bond is shown in Figs. 226-227. Here also the internal wall is tied to the external wall as described above.

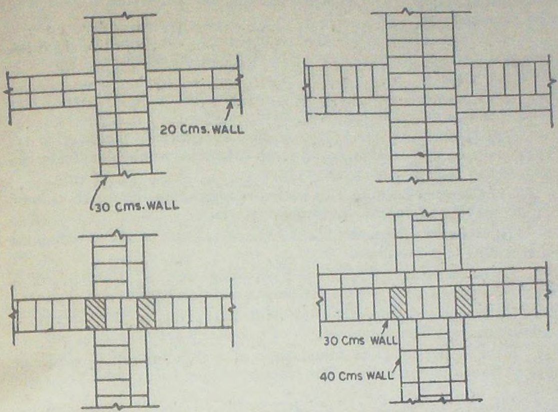


Figs. 226-227. T-junction in Double Flemish bond.

Intersections are formed when two continuous walls cross each other. Plans of an intersection between a 20 cm. wall and a 30 cm. wall are shown in Figs. 230-233. Alternate courses of one wall are continuous whereas the bricks in these courses of the other wall abut with the bricks of the continuous wall. In the courses which are discontinuous, key headers are fixed into the wall as shown in Figs. 230-233.



Figs. 228-229. Squint junctions in English bond.



Figs. 230-233. Intersections of walls in English bond.

(*b*) *Squint Junction* : Occasionally a wall intersects another at an angle other than a right angle. Such junctions are known as squint junctions. These are rarely used in brickwork. Plans of squint junctions laid in English bond are shown in Figs. 228-229. The heading course of the squint wall is bonded into the stretching course of the main wall. The alternate stretching course of the squint wall butts against the heading course of the main wall. The first brick in the stretching course is a bevelled bat.

Fire-places and Chimneys

Even today, fire-places are provided in the kitchens and living rooms of a house for fires and heating purposes respectively. They also serve as a means of ventilation. Sometimes boilers are incorporated with the fire-places and a cheap supply of hot water is obtained. For driving out the smoke and the products of combustion, fire-places need vertical shafts which are termed as Chimneys. These produce a draught which keeps the fire burning constantly.

The following terms are used in connection with the chimneys and fire-places :

(*a*) *Chimney Flue* : This is a shaft which carries gases from a fire-place through the building to the atmosphere. This flue is not less than 400 sq. cm. in sectional area and is carried in brickwork or stone masonry.

(*b*) *Chimney Back* : This term applies to the back of a fire-place opening.

(*c*) *Chimney Jambs* : These are the vertical sides of a fire-place opening.

(*d*) *Chimney Bar* : This is a metallic bar which ties the jambs of chimney together.

(*e*) *ChimneyBreast* : If the chimney or the fire-place opening projects outside the wall face the portion so projecting is called chimney breast.

(*f*) *Chimney Cowl* : This is a cap or fitting to a chimney and promotes an upward draught in the chimney.

(*g*) *Chimney Gutter* : This is suitably shaped piece of metal which collects and diverts water which otherwise would penetrate the roof at the back of the chimney stack.

(*h*) *Chimney Lining* : This is the rendering on the inner side of a flue ; may be of special fire-proof material.

(*i*) *Chimney Piece or Mantel piece* : This is an ornamental surrounding to a fire-place.

(*j*) *Chimney pot* : This is a terra-cotta unit at the top of a chimney stack. This increases the height and prevents down draught.

Chimneys and fire-places are built according to the prevalent building codes. The various parts of a chimney are described below :

(*a*) *Foundations* : The foundations of a chimney are as deep as that of the adjacent walls. The chimney is bonded properly to the wall.

(*b*) *Chimney Breast* : A fire-place generally needs greater depth than the thickness of a wall. Hence the chimney is accommodated in a projection called chimney breast. This projection can be avoided

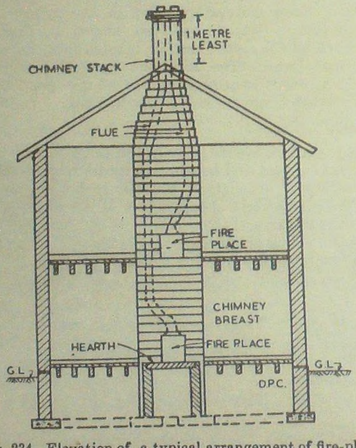


Fig. 234. Elevation of a typical arrangement of fire-places of a building on different floors.

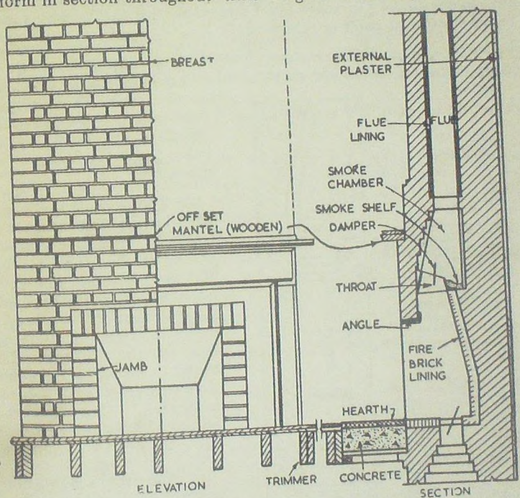
if chimney is provided in external walls where the projection can be provided on the outer side.

The jambs of a chimney must not be less than 20 cm. in width. The fire-place opening will depend on the size of the room or the type of the fire-place. The smallest room may need a fire-place opening of $\frac{1}{2}$ m. width and $\frac{1}{2}$ m. height. The chimney breast can be widened and finished suitably so that it may look in proportion to the wall from which it projects.

The head of a fire-place has a masonry arch or a concrete lintel. If the projection of the breast beyond the wall is greater than 10 cm. the arches have to be built on iron bars for support.

The back wall of a chimney should be at least 10 cm. thick, if the two fire-places are laid adjacent to each other otherwise a minimum of one brick thickness is needed.

(c) *Flues :* These are at least 20×20 cm. in size and should be uniform in section throughout their height. However, a throating



Figs. 235-236. Elevation and section of a fire-place.

(*i.e.*, reduced opening) may be given at the end. Each fire-place should have a separate flue and the partitions between the flues should be air-tight so that gases do not pass from one flue to the other. If the two flues get connected and if fire is lighted in one fire-place, smoke will be created as air will be drawn from the other fire-place. The flues are bent at places so as to negotiate the upper fire-place. Moreover these bends reduce the downdraught and prevent the admission of rain. These bends should be gradual and should not be at an angle less than 45° to the horizontal. The inside of a flue is plastered or rendered with mortar to prevent escape of flame or smoke through the cracks or the open joints. The materials used for the flues must be incombustible and durable. Special circular, rectangular or square fire clay flue linings may be provided.

(*d*) *Chimney Stacks* : The chimney breasts are reduced in width when they penetrate above the roofs. According to the building codes, the chimney stacks must be carried upto a height of at least one metre above the highest point of the adjoining roof. To prevent down draught, the chimney stack is generally taken at least one metre above the ridge. The maximum height of the stack is taken as six times the least width. The thickness of the walls is at least 10 cm. Special consideration should be given to prevent the rain water coming down the walls. This can be prevented by constructing the chimney stacks in water-proof cement mortar to a height ½ metre below the lowest point of intersection.

The top of the flue is covered with a chimney pot. This pot is supported on the brickwork and held in a manner so as to throw off the water. Tall chimney pots are not needed unless the flues are short or are liable to produce down-draught.

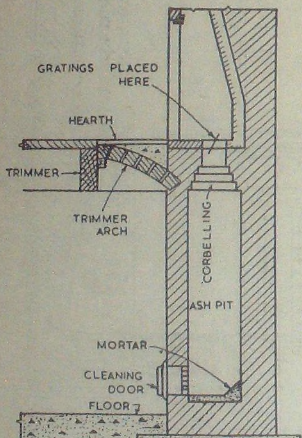


Fig. 237. Section of a fire-place ash pit placed in a basement.

The front of the hearth must have a thickness of at least 15 cm. and should extend on the sides at least 15 cm. beyond the inside clear opening of the fire-place. A projection of at least ½ metre is needed outside the face of the breast. This hearth is made of incombustible material and securely supported. All woodwork should be kept away from the fire-place hearth.

The fire-place interior is made of fire clay blocks, metal gratings, metal frame and may be surrounded by glazed tiles. The fire clay block is bedded on the mortar and backed solidly with concrete or brick in cement. The upper surface of this backing is sloped to prevent soot from accumulating.

Brick Laying

Proper laying of bricks is a great art. Brick work should be systematically done keeping in view the bonding, jointing and finishing. The laying of brick masonry is practically the same whether it is to be laid in walls or columns or footings, etc., but some special considerations have to be given to individual items. The procedure of laying bricks in different structures is described briefly in the following pages :

(1) **Walls.** Following are the steps adopted in the construction of walls :

(*a*) *Selection of bricks.* Bricks are selected for different parts of the walls, *i.e.*, for facing, hearting and backing. As described on page 54, the bricks for face work should be of uniform size and good quality.

(*b*) *Stacking of bricks.* The bricks should be stacked in regular stacks of 1,000 bricks in such a manner that their edges or corners do not get damaged.

(*c*) *Wetting of bricks.* Burnt bricks have a great tendency to absorb water. Therefore, before the bricks are laid in the walls, they should be thoroughly soaked in water. The reasons for wetting bricks are :

(*i*) The bricks will tend to spread the mortar under them more evenly.

(*ii*) They will adhere better to the mortar.

(*iii*) A dry brick will quickly absorb water from the mortar. This is dangerous when using cement mortar as enough water will not be available for proper setting of the cement mortar, thereby resulting in weak or failing of brickwork.

(*iv*) Wetting of bricks washes the kiln dust from them. A clean brick will produce a better joint and bond with mortar.

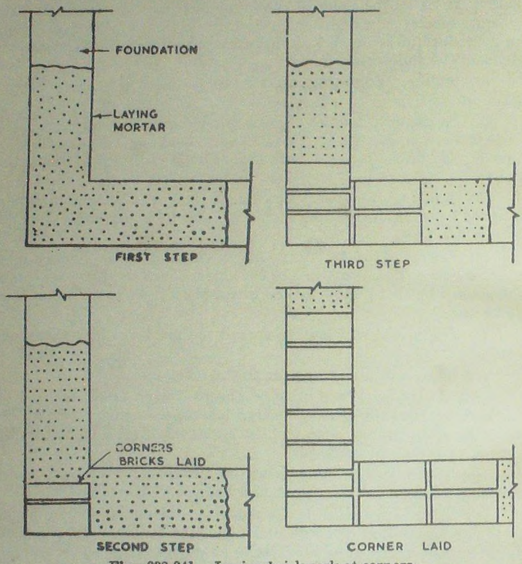
(*d*) *Spreading mortar on foundations.* Mortar is spread on the top of the foundation concrete and should be at least 1·5 cm. deep. This is spread in the area which is to be covered by the corners of the wall. The corners of the wall have to be built first and then in between portion is built up.

(*e*) *Laying first course* (*of corners*). The mason will lay one brick at the corner and will press it on the mortar so as to have only 1 cm. joint between the concrete and the brick. Then the first closer is covered with mortar on the sides and placed gently against the first brick so as to form a 1 cm. horizontal joint with the foundation and also a 1 cm. vertical joint with the first brick. The excess mortar which oozes out is cleaned off and the level of the laid bricks is checked.

If the bricks are not exactly in level, they are hammered. The edges of the bricks should be at a correct distance from the edge of the foundation concrete.

Other headers are laid in the same manner, *i.e.*, they are covered with mortar on the sides and pushed into place, the level and their edge line being checked.

(*f*) ***Laying second course.*** The mortar is spread over the first course to a depth of at least 1·5 cm. End stretcher is laid on the mortar and hammered down till the mortar joint is 1 cm. thick. Mortar is thrown on the end of the other stretchers and they are



Figs. 238-241. Laying brickwork at corners.

pushed into place. The level and plumbness are checked for this course.

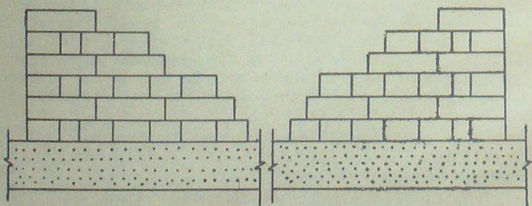


Fig. 242

The balance of the courses needed for the corner are laid in a similar manner. Since wall in-between is built with corners as a guide, the plumbness and the alignment of the bricks in the corners should be carefully checked. The bricks should not be moved after they are laid. The built up corners will present an appearance as shown in Fig. 242.

(*g*) *Building the in-between portion of walls.* This is done by stretching a cord along the headers or the stretchers as shown in

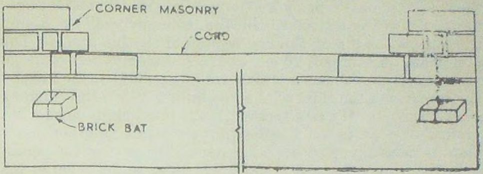


Fig. 243.

Fig. 243. This cord helps in keeping the alignment of the courses and maintaining them in one level. The various courses are built one after the other in a similar fashion.

(*h*) When the wall has been built up to the height of the corners previously laid, corners of the building are raised further and the construction is completed as described above.

(*i*) When the walls rise to a height of about 1 to 1·5 metres the masons cannot work from the ground and need platform for working which is called scaffolding. This is described in detail later on.

(*j*) All the walls should be uniformly built as far as possible. However, it must be ensured that the difference in level between two walls in the building is not greater than 1 metre to avoid unequal settlement.

(*k*) All the joints should be cleaned and finished after every day's work.

(*l*) Whenever all the walls cannot be taken to the same height in a building, the higher portions are stepped so as to have a proper bond with the masonry to be built up later on.

(2) *Columns.* The bricks are laid on mortar in the order shown in Figs. 194-214. The second course is also laid as shown. The laying of mortar, pressing of bricks, finishing of joints, etc., is exactly the same as described above. However, it is essential that absolute plumbness of a column must be ensured and also the central line of the column with respect to the other parts of the building is maintained in the correct position. Columns should not be loaded till the mortar has set and has developed sufficient strength to withstand the loads.

(3) *Chimneys.* The exact location of the chimney is marked with a chalk on the footing. Mortar is spread along the line which indicates the chimney position on the footing. Brick No. 1 is laid in the corner in the manner explained above. Brick No. 2 [*see* Fig. 245-246] is placed and pressed so as to make a 1 cm. joint with brick No. 1. Mortar is thrown against brick No. 3 and is also placed in position. The other bricks are also laid in mortar in the order shown in the diagram. Then the excess mortar is cleaned off and the second course laid. Similarly, when several courses have been laid, the first section of the flue lining is lowered till it rests on the footing. The laying of courses is continued till the chimney wall is about two courses below the top of the first section of the flue lining. To make the chimney fire proof, 20 cm. above and 20 cm. below the joint in the flue lining, the cement mortar must be applied on the inside edges of the bricks and the sides of the flue lining. When the chimney wall reaches the top of the first section of the flue lining, mortar is applied round the edges of the flue lining top and another flue lining section is carefully placed. The remaining part of the chimney is laid in the same manner. However, it must be ensured that the chimney is truly vertical.

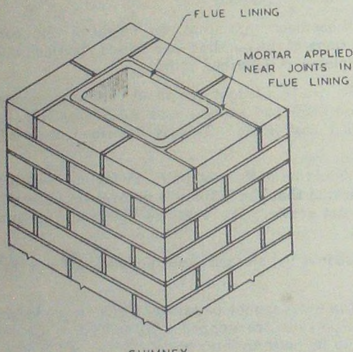


Fig. 244. Laying of brick-work in chimney.

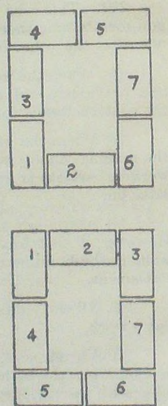


Fig. 245-246.

Joints in Brickwork: Joints are the weakest parts of a masonry structure and unless special care is paid to them, the brickwork cannot be of good strength. Appearance of brickwork also depends on the proper laying and finishing of joints. Most of the defects in brick masonry joints occur on account of improper application of mortar. Some of the important points regarding the joints in the various courses of brickwork are :

(1) *Bed joints in stretcher courses* : Mortar for bed joints should

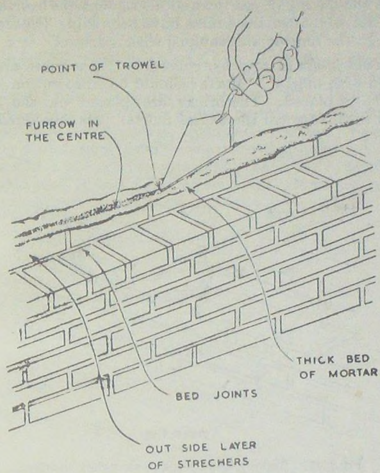


Fig. 247. A deep bed of mortar is spread and a furrow formed with a trowel

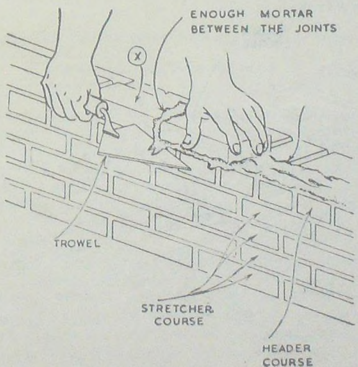


Fig. 248. Making bed joints in stretcher courses.

be spread evenly and must be quite thick. Generally mortar is not spread ahead for a distance greater than five or six brick lengths. This avoids the drying of mortar and also keeps the mortar plastic so that it can set well after the bricks have been laid. The bricks should be pressed on the mortar and tamped with a trowel.

(2) *Head joints in stretcher courses* : These must also be completely filled with mortar. Mortar should be thrown on the end of each brick to be placed. The bricks are placed on the mortar bed and pushed into place till the excess mortar gets squeezed out. An

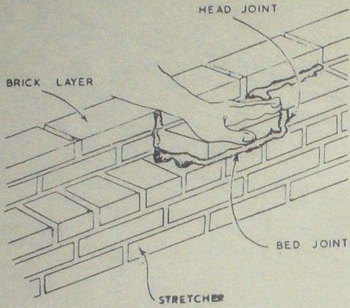


Fig. 249. Making head joint in stretcher courses.

alternate method is to apply mortar to the brick already laid and then push in the next brick. The mortar which squeezes out is removed with a trowel.

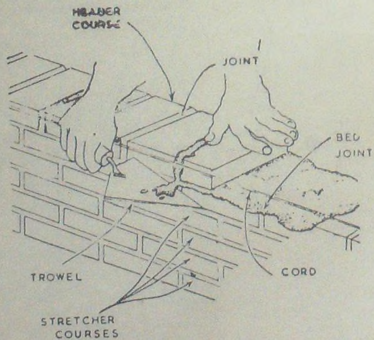


Fig. 250. Making cross joints in header courses.

(3) *Cross-joints in header courses* : Cross joint should be carefully made and should be full of mortar. Before each header is laid, the edge of the brick, as shown in Fig. 250, should be covered with the mortar that will stick to it. The header should be pushed into place so that mortar oozes out above the cross joint as well as at the bed joint. The excess mortar is scraped off with a trowel.

(4) *Closer joints in stretcher courses* : The last brick to be placed in a wall along stretchers should be laid in such a way that the head joints are completely filled with mortar. (*See* Fig. 251). With the bed joints already made, mortar is applied to the ends of the bricks x and y which have previously been laid. Mortar is also placed on both ends of the closer brick. The closer is then pushed inside without disturbing the bricks already laid. The excess mortar

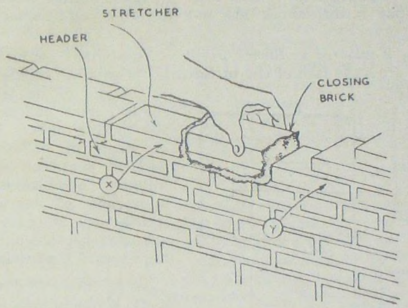


Fig. 251. Fitting closer brick in a stretcher course.

is scraped off. A similar procedure is followed in laying the closer bricks in header courses.

Finishing of Joints or Jointing and Pointing in Brickwork : The purpose of finishing the joints is to improve the appearance of brickwork and to make it more waterproof. Merely drawing one edge of trowel along the joint is detrimental for brickwork as it may disturb the adhesion between the mortar and the brickwork. The finishing of joints as the brickwork proceeds is termed as **jointing** whereas finishing of joints after the brickwork has been completed is called **pointing.**

The edges of the joints in brickwork will be deficient in hardness and density. The expansion and contraction of masonry is liable to cause the mortar in the joint crack or loosen the brick from the mortar. The mortar near the exposed face is, therefore, prone to dislodgement. Unless the wall is to be plastered, it is necessary to refill very compactly the surface joints for a depth of about 2 to 3 cm. with a neat mix of cement mortar of proportion 1 : 1. This process is known as pointing. Normally, while laying the mortar in joints at the surface, an offset is left to a depth of about 2 to 3 cm. The joint is subsequently cleaned by scraping and brushing out all loose material with a wire brush. The rich mortar is then applied, pressed and finished smooth. Pointing should not be allowed to dry rapidly. When cracking due to shrinkage is expected, either high alumina or sulphate resistant cements should be used or the mortar proportions increased from 1 : 1 to 1 : 2 or 1 : 3.

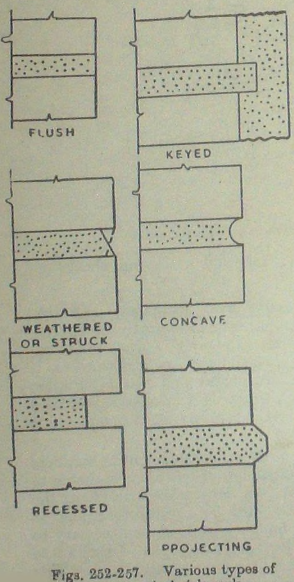
Different kinds of pointing finishes are given below :—

(1) *Flush or Flat Joint* : This is the simplest type of joint and when rubbed gives a good finish. The mortar is pressed into the joint as the work goes on and depressions are filled. A trowel is kept parallel to the face of the wall and the joint is finished. The joint may also be rubbed by a piece of stone held against the wall to improve appearance. This type of joint is needed at places where depressions in brickwork are not desirable, *e.g.*, factories, cellar, garages, etc.

(2) *Weathered or Struck Joint* : This joint permits water to drop off from the face of the brickwork. The joint is made by holding the handle of the trowel below the bed joint and smoothening the mortar in one direction to an angle of about 60°. The vertical joints are first struck followed by bed joints. The appearance of this joint is not satisfactory if ordinary bricks are used because unevenness in the edges of the bricks is visible.

(3) *Recessed Joint* : This joint is made with a jointing tool, the thickness of the rubber attached in front of the tool being equal to that of the joint. Rubber attachment is used as it adjusts itself to any irregularity of the brick edge. This tool is used after any projecting mortar has been removed. The brick should be carefully selected and should have uniform thickness. This joint is at least 1 cm. in thickness. This is satisfactory in face-work for good textured bricks and good quality of mortar.

(4) *Concave Joint* : This may be formed by a rounded jointer. The vertical joints are formed first and then the bed joints. The jointer is used by



Figs. 252-257. Various types of joints in brickwork.

two masons in conjunction with pointing rule. The rule is held with the bevelled edge on the same level and parallel to the lower edge of the joint. The jointer resting on this rule is moved to and fro while it presses the mortar to the required depth. This type of joint gives a very attractive appearance to the brickwork.

(5) *V-Joint* : This is made in a manner similar to the one described above, but a steel jointer with a bevelled edge is used. This is used to give an appearance of narrow joints. The finishing should be done before the mortar sets.

(6) *Projecting Joint* : Mortar is left projecting from the joints. This type of joint affords a rough surface which can be helpful in keying the plaster which is applied later on. Bricks of various colours, if used with mortars of suitable colours, will provide a beautiful appearance.

(7) *Stripped Joint* : This is made by placing wooden strips as the masonry is built up. These strips ensure a joint of uniform thickness and may be removed after the mortar has set slightly.

A concave joint ensures good water tightness. Recessed and stripped joints are expensive and are not fully watertight. Joints in the exterior faces of walls should be entirely filled with mortar to reduce water penetration. It is essential that the joints are made smooth and dense by exerting considerable pressure on the tool with which they are made.

Reinforced Brickwork

Plain brick masonry cannot take tensile stresses as the bricks get pulled apart at the mortar joints. Reinforced cement concrete is a structural material which can be put to all type of uses, but owing to its high cost, it is not economical to use it for members which carry a small load and yet cannot be made of plain brickwork. Examples are the construction of small lintels, slabs and beams. To increase the load carrying capacity of plain brickwork, steel reinforcement is introduced in between the mortar joints. This type of brickwork can withstand tensile and shear stresses if the loads are not unduly great. However, the following points about Reinforced Brickwork Construction should be noted :—

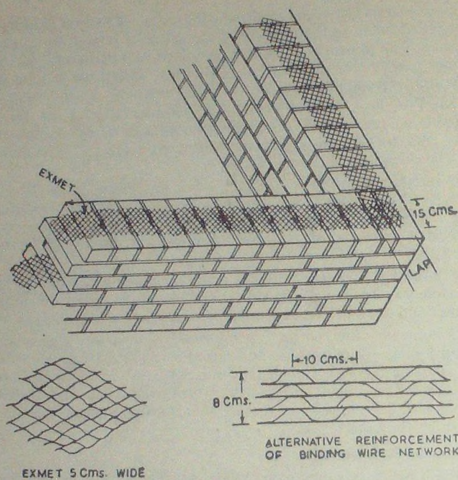
(1) All the bricks must be of uniform size and structurally sound.
(2) Cement mortar in the proportion of 1 : 3 should be used for bonding the brickwork.
(3) The joints have to be built in such a way that the reinforcement gets sufficient cover and is also prevented from corrosion.

Advantages of Reinforced Brickwork :

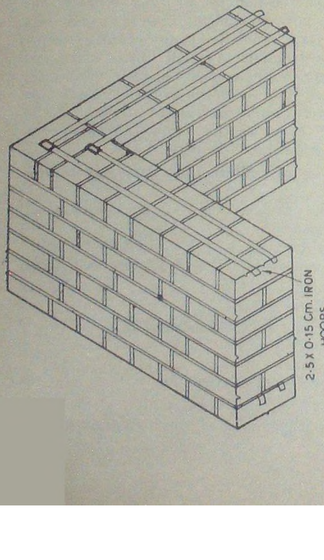
(1) The simplicity of work or ease of construction.
(2) Fire-proof construction.
(3) Better bonded structures.
(4) Cheap, sound and permanent construction.

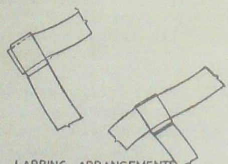
Types of Reinforced Brickwork :

(1) *Walls* : Reinforcement may consist of iron bars of expanded



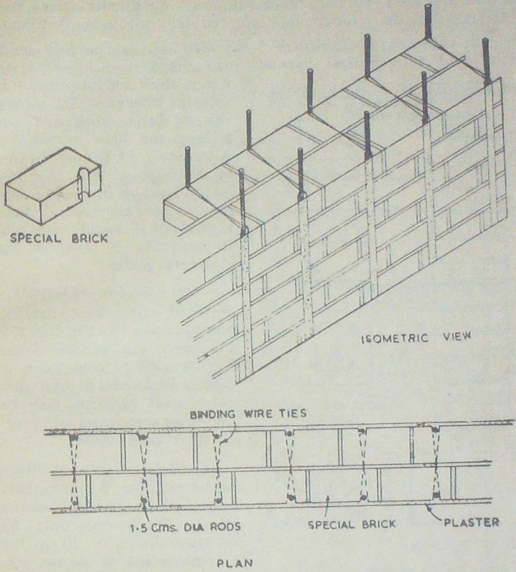
Figs. 258-260. Reinforced brick wall details using mesh reinforcement.





Figs. 261-263. Reinforced brick wall using hoop iron reinforcement.

metal mesh. Standard patented expanded metal meshes are available in different widths and different gauges. This metal is available



Figs. 264-266. Reinforced brick wall with iron rod reinforcement and special bricks.

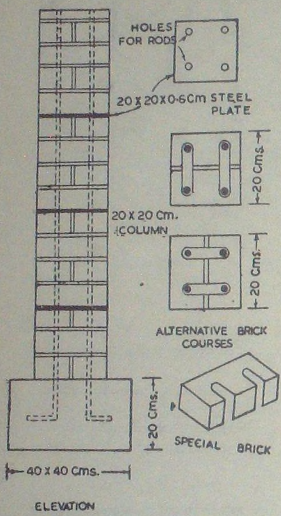
in coils which can be spread while the brickwork is being laid. Mortar is evenly spread on the brickwork and the expanding metal (XPM) is spread on it. The next course of bricks is laid over it.

Another type of reinforcement which is used for walls is hoop iron. These are steel flats about 2.5 to 3 cm. in width and are from 1.5 to 2.5 mm. in thickness. These flats are dipped in molten tar to increase their resistance against rusting and are immediately sanded so as to increase the grip with the mortar. One strip is provided for half brick thickness of wall and every sixth course is reinforced. The joints at the corners are hooked as shown in Figs. 261-263.

Another form of reinforcement employed for walls which have to withstand pressure (*e.g.*, retaining walls) is the placing of vertical reinforcement passing through openings made in special types of bricks. This vertical reinforcement is tied at suitable intervals with fine wire. In addition XPM may be spread in certain courses.

A cheap and quick type of construction is done by erecting vertical bars and building brickwork around them. Ordinary bricks are used and the joints have to be adjusted. As an alternative, bars of about 6 mm. diameter are laid longitudinally within the bed joints.

(2) *Columns* : These are built with 'special purpose made bricks' and with vertical bars running through them. Steel plates 6 mm. thick are introduced at certain intervals for strengthening brick work and also to keep the bars in position. Alternately XPM may be cut to the shape of the pier and laid at suitable intervals along the height of the column. Bent bars of small diameter (about 12 mm.) can be used in the horizontal joints.



Figs. 267-271. Details of a reinforced brick column using rods and special bricks.

(3) *Lintels* : Lintels are provided with bars running longitudinally (*see* Fig. 272-273) in between the vertical joints and extending from joint to joint. Additional 6 mm. diameter steel stirrups may be used after some intervals to resist the vertical shear.

(4) *Slabs* : Ordinary bricks can be used for the construction of these slabs. Slabs of definite depths can only be constructed, *i.e.*, 10, 20 cm. or a combination of these. A 10 cm. slab is made by laying bricks flat or on an edge and 20 cm. by laying two bricks one above the other on edge or flat. However, slabs of a thickness slightly greater than these are formed due to the thickness of the joints being greater than that of the ordinary masonry joints but while measuring the slab, it is usual to give thicknesses in terms of brick dimensions neglecting the thickness of the joint mortar. Similarly the reinforcement is placed at intervals which form multiples of brick units. *Slabs*

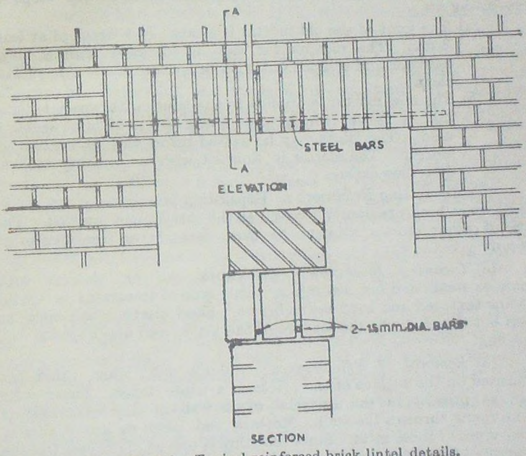
For laying Reinforced Brickwork (R.B.) slabs, a centring consisting of supported platform is needed. This is covered with earth, well beaten and finished with sand. The centring is not removed till five to twenty-eight days have passed after the slab is laid, the exact period depends on the loads coming on the slab and the weather condition. In floors and roof slabs, reinforcement not greater than 12 mm. in diameter is used. The ends of all rods are bent into semicircular hooks. Wherever lapping of reinforcement is necessary due to short lengths of steel available, a lap of at least 40 times the diameter of the bar should be given.

(5) *Beams* : The construction of R. B. beams is similar to that of R. B. Slabs. However, thick rods up to 2.5 cm. in diameter can be used as reinforcement.

Some important points regarding R. B. work are given below :

(1) *Working Stresses* :

Safe compressive stress in bricks	30 kg./sq. cm.
Safe tensile stress in steel	1500 kg /sq. cm.
Ratio of the modulus of elasticity for steel to that of brick	40 : 1
Bond stress between steel and mortar	6 to 7 kg./sq. cm.
Shear in brickwork	5kg./sq. cm.



Figs. 272-273. Typical reinforced brick lintel details.

(2) Before starting work, all rods should be bent to correct shapes and cut to proper sizes.

(3) All joints should be thoroughly filled with mortar and all reinforcement should be well surrounded by mortar. Care should be taken that the bottom rods in the slab have adequate cover of mortar and do not touch the centring.

(4) All work shall be kept moist by means of wet straw or wet sand for the first two days. It should then be profusely watered and kept wet till the centring is removed.

The crushing strength of bricks should not be less than 125 kg./sq. cm. The allowable stresses can be increased by 33% for occasional loadings such as winds, earthquake forces, etc. The safe shearing and tensile stresses should be $\frac{1}{10}$th of these values.

(3) *Storey height* : The unsupported height between the floors has a very important bearing on the stability of walls. The different building codes permit storey heights of 15 to 20 times the wall thickness. Whenever storey heights are excessive, lateral supports as described later on are given. Greater the ratio between the storey height and the wall thickness, the lesser is the permissible safe stress in masonry. This ratio is termed as slenderness ratio ; the following values of reduction in the permissible safe pressures are given.

Slenderness ratio	Reduction in max. permissible pressure
up to 6	Nil
,, 7	10%
,, 8	20%
,, 9	30%
,, 10	40%
,, 11	50%
,, 12	60%

Slenderness ratio is calculated as given below :

(*a*) For walls with no lateral support at top—
1½ actual storey height is taken in calculation.

(*b*) For walls with lateral support at top—¾ storey height.

(*c*) Piers with no lateral support at top—2 actual storey height.

(*d*) Piers with lateral support at top—actual storey height.

(*e*) The height of the lowest or only storey is measured from the base of the wall and the height of any other storey is measured from the level of the underside of the floor to the level of the underside of the floor structure of the storey above or half the height of the gable.

The allowable ratios of the storey height or length to the thickness of the wall are given below :

Walls built in 1 : 3 to 1 : 4 cement mortar	14
,, ,, ,, 1 : 2 lime mortar or 1 : 6 cement mortar	13
,, ,, ,, mud mortar	12

(4) *Spacing of Buttresses and Cross Walls.* The thickness of the walls is dependent on the lateral supports for the walls. The rules for the maximum permissible ratio of the wall length to the wall thickness have been given above. Walls are divided into distinct lengths by Return Walls, Cross Walls, Party Walls, or External Walls. Alternatively piers of a height equal to the height of the wall and breadth not less than twice the thickness of the wall projecting on each side of the wall for a distance not less than the thickness of the wall or suitable buttresses having enough stability are used. The

length of the wall is measured from the centre of one Return Wall or pier to the centre of the other. Minimum values for different wall thicknesses for different wall lengths are given at the end of this article.

(5) ***Window and Door Openings, Recesses, etc.*** : Generally codes specify that the wall thickness should be increased whenever any portion is removed from the wall. This removal may be on account of a window or door opening, fitting of pipe inside the wall or depressions for the placing of switch boxes, radiators, etc., within the walls. It is a general practice to use richer mortar for the jambs of doors and windows or other openings to get a higher strength at these places. However, some rules for recesses and openings are given below :

Recesses :

(*a*) The wall at the back of the recess shall not be less than 20 cm. thick.

(*b*) An arch or lintel shall be built in every storey over this recess.

(*c*) The recesses causing decrease in wall thicknesses shall not be greater than $\frac{1}{2}$ the superficial area of the walls.

(*d*) Face width of a pier at the site of a recess shall not be less than $\frac{1}{6}$th the width of the recess.

Openings :

The total area of openings shall not exceed :

(*i*) Half the elevational area from the soffit of the first floor to the roof.

(*ii*) Two-thirds of the area of any storey height above the ground floor.

(*iii*) The total width above ground floor not greater than $\frac{3}{4}$ of the length of the wall.

(6) *Character of Occupancy* : Greater stability is needed for commercial buildings, *e.g.*, ware-houses, factories, hotels, etc. Hence minimum thickness rules for these types of buildings are framed and typical values are given in the table at the end of this article.

(7) *Function of the Wall* : Where loads are not the controlling factors, certain walls are made thicker than the other walls, *e.g.*, in every building external walls are built of a greater thickness than the internal walls.

(8) *Fire Resistance* : Different types of walls have to endure fire for a certain minimum period of time and should not transmit heat to such an extent so as to damage the adjoining property. Walls have to be of suitable thickness so that they do not bulge or collapse when they get heated due to fire. Typical values of thicknesses are given for different types of walls for various endurance periods.

(9) *Bond between the face work and the backing* : If the face work is not of the same type as the backing, additional thickness for

the backing portion has to be used depending on the type of face work.

A formula for the calculation of wall heights for known values of wall thicknesses and allowable pressure is given below :

$$H = 6f^{0.7n}$$

where H = height of the wall in meters.
f = Safe bearing pressure of the wall in tons/sq. metre.
n = Thickness of the wall in bricks.

Suitable values of wall thicknesses for different types of construction are given below :

Height of wall	Length of wall	Thickness of wall when built in cement sand mortar 1 : 3 to 1 : 4	Thickness of wall when built in lime sand and surkhi mortar 1: 2 or cement sand mortar 1 : 6	Thickness of wall when built in mud mortar
1	2	3	4	5
Structural, external and party walls exposed to weather.	Whatever the length	At least 30 cm. or cavity wall 25 cm.	At least 30 cm.	At least 30 cm.
Structural external and party walls protected from weather.				
Not exceeding 5 m.	-do-	20 cm. for the whole of its length.	20 cm. for top 2 m. and 30 cm. for the rest of the bottom portion.	30 cm. for the whole of its height.
Exceeding 5m. but not exceeding 8 m.	Not exceeding 10 m.	20 cm. for the whole of its height.	30 cm. from the base for the height of one storey and 20 cm. for the rest of its height.	30 cm. for the whole height.
	Exceeding 10 m.	30 cm. from the base for the height of one storey and 20 cm. for the rest of its height.	-do-	-do-

Height of wall	Length of wall	Thickness of wall when built in cement sand mortar 1 : 3 to 1 : 4	Thickness of wall when built in lime sand and surkhi mortar 1 : 2 or cement and mortar 1 : 6	Thickness of wall when built in mud mortar
1	2	3	4	5
Exceeding 8 m. but not exceeding 10 m.	Not exceeding 8 m.	20 cm. for the whole of its height.	30 cm. from the base for the height of 2 storeys and 20 cm. for the rest of its height.	40 cm. from the base for 2 storeys and 30 cm. for the rest of its height.
	Exceeding 8 m. but not exceeding 12 m.	30 cm. from the base for the height of one storey and 20 cm. for the rest of its height.	-do-	-do-
	Exceeding 12 m.	30 cm. from the base for the height of 2 storeys and 20 cm. for the rest of its height.	-do-	-do-
Exceeding 10 m. but not exceeding 13 m.	Not exceeding 12 m.	30 cm. from the base for the height of 2 storeys and 20 cm. for the rest of its height.	40 cm. from the base for the height of 1 storey, 30 cm. for the height of next 2 storeys and 20 cm. for the rest of its height.	50 cm. from the base for the height of 1 storey, 40 cm. for the height of next 2 storeys and 30 cm. for the rest of the height.
	Exceeding 12 m.	40 cm. from the base for the height of 1 storey, 30 cm. for the height of next 2 storeys and 20 cm. for the rest of its height.	-do-	-do-

Joint between Old and New Masonry

While constructing new brickwork along with an old one, it is imperative that the new brick masonry is going to settle much more than the old brick masonry. Hence care must be taken to prevent the cracking and separation of the new masonry from the old one. This is accomplished by leaving bricks projecting from the old work and also in the new work. This is called toothing. Each alternate course projects into the other wall with sufficient lap and also maintains the proper bond. Sometimes these projections are formed of three or four courses with a similar distance in between. Further care can be taken by constructing the new wall in small heights so as not to allow undue settlements.

Ornamental Brickwork

The decorative effect in brickwork can be produced by the use of special types of bricks, mortar joints and different arrangement of bricks.

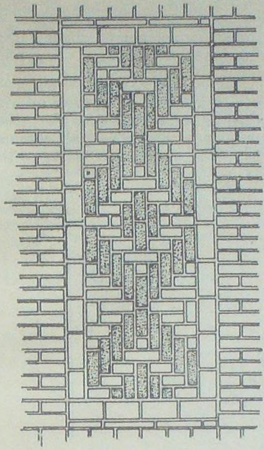
Bricks of different thicknesses can be used to give architectural treatment. Machine made bricks with sharp and angular faces lend a beautiful appearance to a wall. A thinner brick appears better in certain locations. Bricks which are coloured can be suitably arranged to produce a good pattern. The texture of the bricks is also important. Smooth faced bricks are preferred at places where dust-storms are prevalent whereas sandy textured bricks give a pleasing appearance.

The texture of joints and the colour of mortar has also to be adjusted in respect to the types of bricks and the treatment desired. Joints smoothened with a trowel should not be used for rough textured bricks for which flush or recessed joints are good. Black mortar should be avoided for face work. Generally mortar which does not present contrast with respect to the bricks should be used, *e.g.*, white mortar should not be used with red faced bricks. The horizontal and vertical joints can be made with different coloured mortars to get decorative effect. Flat joints give a plain surface whereas with recess joints deep shadows are produced which add to the ornamental effect at certain times. The thickness of the joint is also of importance. Thinner joints in certain bricks may be better than thick joints.

A combination of bricks, tiles and stones can produce a good appearance. Sandstone blocks with rough texture and creamy colour present a good appearance when fixed within brickwork at corners or ends of walls. Smooth polished stones cut into thin slabs can be used as a covering for garden walls, parapets, etc.

The arrangement of bricks will affect the appearance considerably. Bricks can be arranged into different designs and also can be left projecting wherever needed. A different texture for the bricks, which are left projecting, can be used.

Brick walls having a large area in elevation can be suitably decorated by the provision of decorative panels. Small bricks can be laid diagonally, vertically or projecting so as to give good patterns (*see* figures 274 and 275).



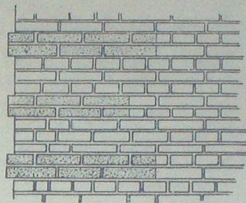
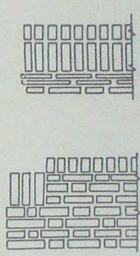
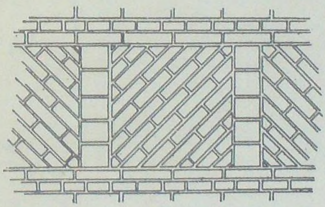


Fig. 277. Ornamental brickwork quoins.



Figs. 278-279. Ornamental brickwork parapets.



Figs. 274-275. Ornamental brickwork panels.

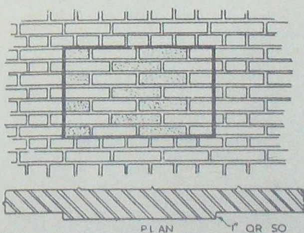


Fig. 276. Ornamental brickwork raised panels.

Quoins can be built of bricks which have a different colour or which are left projecting. The quoins are generally made darker than the remaining wall or are built of rusticated bricks. A similar treatment can be given to door and window openings.

Parapets are finished at top with bricks laid as headers on edge or two layers of bricks one of which is laid on edge and the other on end. Small tiles can be used to give a decorative appearance. As stated earlier, thin stone slabs can be used as a covering to the brick parapets.

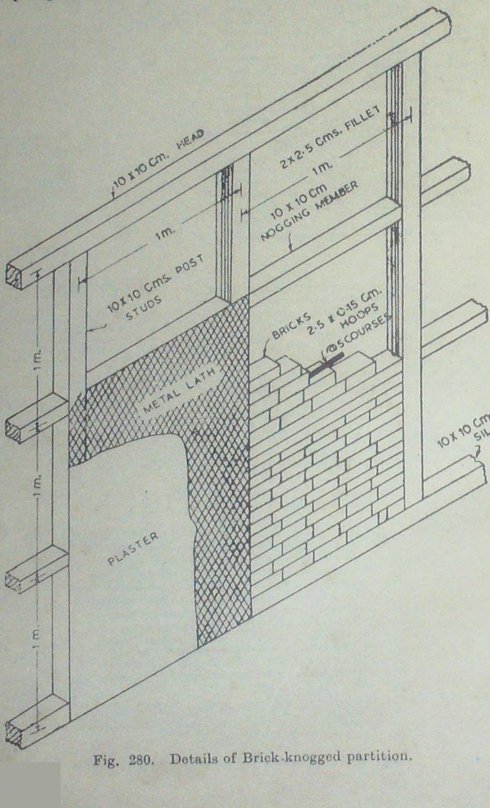


Fig. 280. Details of Brick-knogged partition.

Brick Knogging

Brick knogging consists of a framework of timber in which bricks are laid and both sides are plastered. The upright posts are 10×10 cm. size and are placed at 1·0 m. centres. The horizontal members are 10×10 cm. and 1·0 m. vertically apart. All surfaces of timber coming in contact with the masonry are given a coating of hot coal tar. The bricks are laid in the openings of the framework and are placed in such a way that equal projections of timber are left on both the sides. Reinforcement consisting of 2·5×0·15 cm. hoop iron is provided after 4-5 courses. Both the sides of bricks are plastered so as to have the surface in flush with the timber. If wooden members are of shorter width and the entire area is plastered, the plaster peels off from the wooden members and falls down. In such a case a metal lath is fixed to both the sides of the knogging and the entire area is then plastered. To provide a proper hold for bricks with the vertical members of wood, small wooden sections of 2×1 cm. size are fitted to the vertical members and the bricks are suitably notched to fit into them.

Brick Steps

Brick steps are used for rooms which have a low plinth. Standard bricks are used but they should be sufficiently hard so as not

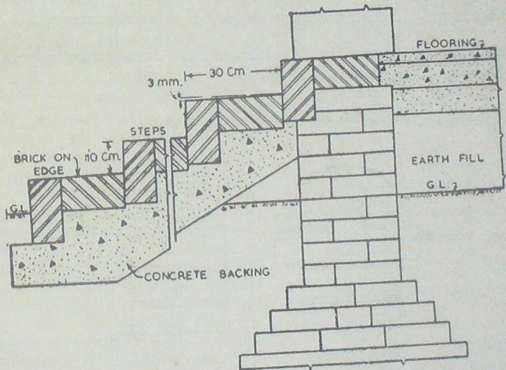


Fig. 281. Details of brick steps and entrance to a building.

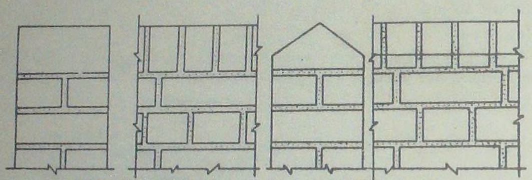
to get damaged. The steps are laid on a concrete foundation and the risers consist of bricks laid on end whereas the treads are made of bricks laid on edge. The top step is given a slight slope to throw off the water. Proper bonding of bricks is essential. All the brickwork should be done in cement mortar.

Brick Parapets

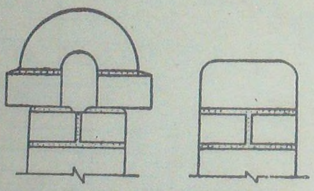
Parapets are the extensions of walls above the roof level and are used as a means of hiding the back gutters from view. These provide an architectural means of improving the appearance. The top of a parapet is covered by copings to shed off the rain water. The construction of a parapet is similar to that of an ordinary masonry wall. However, ornamental parapets can also be built.

Brick Copings

Copings are provided as a means of covering to the walls, *e.g.*, garden walls, parapets, etc. The effectiveness of a coping is gauged from its ability to throw off water. Several types of brick copings can be built. Bricks can be laid on edge on the top of a wall and suitably joined so as to stand the water erosion. These bricks may have built noses at the top for adding to their beauty. Specially made semi-circular bricks can be laid as coping on the bricks which are built slightly projecting from the wall. This type of coping can



Figs. 282-285. Typical brick copings.

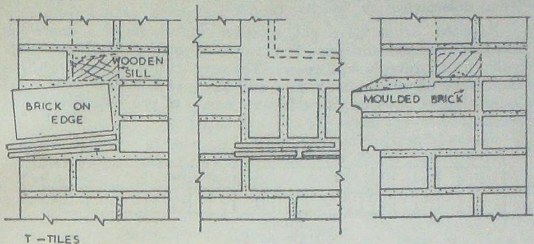


Figs. 286-287. Brick copings.

shed off the water easily. Tiles can be introduced in between the bricks on edge so as to drip the water easily. A saddle back brick can also be used as a coping.

Brick Sills

The objectives of providing a window sill are to give a better appearance to the window opening and to afford protection to the wall below. Slight slope should be given to the top of the sill so as to shed off the water from the window. Bricks can be used for making



Figs. 288-290. Typical brick sills.

window sills. They are placed on edge and slightly tilted. Tiles may be introduced below them to improve the appearance. These tiles are left slightly projecting. As an alternative special purpose moulded bricks with suitable throatings can be used for brick sills.

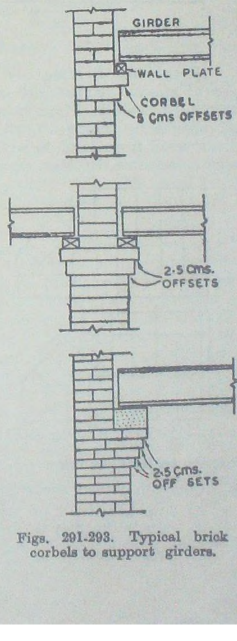
Brick Corbels

These are bricks projecting from a wall and are used to support beams, lintels, etc. The maximum projection of the corbel should not exceed the thickness of the wall. Further each corbel should not project more than 5 cm. from the corbel below. Headers provide a better means of constructing corbels as they can be bonded well. The corbels may be continuous or discontinuous. Discontinuous corbels are used to support concentrated loads at certain places.

Jambs

These are vertical sides of openings left in walls to receive doors, windows, fire-places, etc.

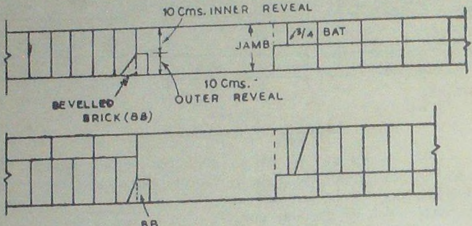
The simplest type is to have a square jamb. This means that the wall is finished there as a dead end. The bricks have to be bonded suitably as in the case of dead ends (*see*



Figs. 291-293. Typical brick corbels to support girders.

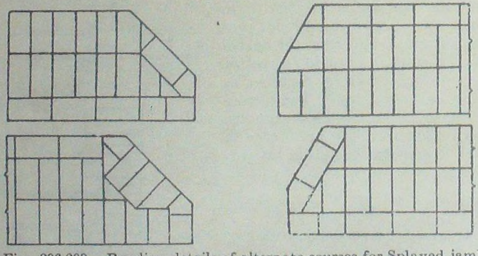
Figs. 294-295). Square jambs are not desirable as they allow rain and wind to enter freely into the room, once the pointing or plaster becomes defective.

Rebated jambs have got recesses in which the doors or window frames can fit in. The parts of such a jamb are outer reveals, inner reveals and recess. The proportions of these components depend on the wall thickness and the type of frame to be used Rebated jambs provide an effective means of preventing entry of water.



Figs. 294–295. Plans for alternate courses at jambs.

For better lighting of a room or to enhance the architectural beauty, splayed jambs with reveals are used. These are generally made in thick walls. The bonding can be of English or Flemish type and should be strong to withstand the forces of arches or lintels which span from jamb to jamb. The cut bricks should be avoided as far as possible. Recesses may be 5 cm. or 10 cm. in depth.



Figs. 296-299. Bonding details of alternate courses for Splayed jambs.

Defects in Brickwork

Common defects occurring in brickwork are :

(*i*) Sulphate attack on mortars.

(*ii*) Use of unsound materials.

(*iii*) Frost action.

(*iv*) Corrosion of iron and steel.

(*v*) Crystallisation of salts.

(*vi*) Linear changes resulting from variation in moisture content.

Defects on account of sulphate attack lead to expansion of mortar thereby causing cracking of brickwork, spalling of brick edges, deterioration of mortar, wide horizontal and vertical cracks in the plaster and the falling off the plastered surface. The cause of this attack is the chemical action between the sulphate salts present in bricks and the aluminium constituents of Portland Cement. This action is rapid in the presence of water and hence wherever moisture penetrates or excessive dampness occurs, this type of defect is prevalent. Prevention of moisture penetration will avoid this defect to a large extent. Bricks of low sulphate content and sulphate resistant cement in mortar should be used.

Unsound materials cause the formation of small pits with nodules of friable materials at the mortar joints. General expansion and cracking of brickwork is visible. Unsoundness in lime is caused by the presence of unslaked particles, which may be present in the mortar unless care is taken to effect complete slaking. Similarly unslaked lime particles may be present in the bricks also.

Defects due to frost action would cause cracking in the brick-work. Prevention of water accumulation would go a long way in preventing this defect.

Brickwork may get opened or cracked and stained due to corrosion of metals lying adjacent to it. Unprotected iron and steel are liable to get corroded when acted upon by moisture and they increase in bulk thereby causing cracks in the masonry. Protecting the metal surface with cement mortar, at least 1 to 2 cm. thick, is essential to prevent corrosion. Partially embedded steel or iron members should be surrounded with bituminous compound for portions not embedded in mortar.

Crystallization of salts or efflorescence is a prominent defect in brick masonry. In moist climate, damp places like basements or under leaky gutters, masonry often gets disfigured by the formation of a white deposit called efflorescence. This deposit originates from the mortar and frequently spreads over a part or the entire face of the wall. Absorbed water dissolves the salts of soda, potash and magnesia contained in the mortar and, while evaporating, forms a crystalline deposit on the surface. In addition to the unsighty appearance, the crystallization of salts in the pores of the bricks or mortar may cause disruptive expansion resulting in disintegration due to cracking. Avoiding the use of porous bricks in contact with lime-stone or cast-stone ; protection of brickwork against contamination with salt bearing materials during building operations and from being thoroughly soaked during construction and correct design of damp proof courses are some of the preventive measures.

Brickwork may crack due to the shrinkage movements arising from changes in moisture contents. This defect is more common with concrete and sand lime bricks. Stepped cracks appear on the surface. They seldom continue below damp proof courses and mostly appear during the first long spell of dry weather or in work situated in unexposed position, *e.g.*, partitions and inner leaves of cavity walls. Good quality bricks should be used in dry condition. All the work should be protected from rain during erection.

QUESTIONS

1. Briefly describe the various types of bricks used in brickwork. What are the different types of mortars used for brick masonry work ?

2. Illustrate with sketches the meaning conveyed by the following terms when referred to brickwork :

(*i*) Headers ; (*ii*) Stretchers ; (*iii*) Closer ; (*iv*) Bond ; (*v*) Perpends ; (*vi*) Toothing.

3. What is the significance of bonding in brickwork ? Explain by sketches the difference between English bond, Double Flemish bond and Single Flemish bond.

4. What are the advantages and disadvantages of English bond over Flemish bond ?

Draw sketches to illustrate the layout of bricks in alternate courses of a right angled corner of 40 cm. walls in English Bond.

5. Write short notes on :—

(*i*) Stretcher bond ; (*ii*) Header bond ; (*iii*) Single Flemish bond ; (*iv*) English Garden wall bond ; (*v*) Zigzag bond ; (*vi*) Dutch bond.

6. Draw to a suitable scale the arrangement of various bricks in alternate courses of :—

(*a*) A right angled corner of 40 cm. wall with 30 cm. wall in English bond.

(*b*) A right angled corner of a 2½ brick wall with another 2½ brick wall in Double Flemish bond.

7. Briefly describe with sketches the construction of a 30×30 cm. and 40×40 cm. brick column in English and Flemish bonds.

8. Write short notes on :—

(*i*) T-junctions ; (*ii*) Intersections ; (*iii*) Jambs ; (*iv*) A 60° Squint junction.

Draw typical layout for bonding arrangements using one and a half brick wall thicknesses in all the above cases in English bond.

9. What are the characteristics of an efficient fire-place ? Draw a typical elevation, section and plan of a fire-place in a living room of a building. Indicate also as to how the flues of two-three fire-places at different floors can be accommodated in one chimney breast.

10. Briefly describe step by step the construction of 40 cm. exterior walls of a building in first class brick masonry. What are the essential points to be kept in view to get proper bed and side joints?

11. Write a short note on the various types of joints used in brick work. Illustrate with sketches.

12. What are the advantages of reinforced brick work construction ?

Write short notes on :—

(*i*) Reinforced brick walls ; (*ii*) Reinforced brick lintels.

13. Briefly describe the factors which determine the thickness of brick walls.

What are the safe allowable pressures on :—

(*a*) Burnt brickwork in cement mortar 1 : 4.

(*b*) Burnt brickwork in mud mortar.

14. Write short notes on :
    (*i*) Brick knogged partitions ; (*ii*) Brick copings ; (*iii*) Jambs ; (*iv*) Brick steps.

15. What are the commonly observed defects in brickwork ? What preventive measures can be taken in each case ?

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4

STONE MASONRY

Stone has been recognised as a building material since primitive days.

Stone masonry is used for the construction of walls, columns, lintels, arches, footings, beams, etc., of a building. Stones are abundantly available in nature and when cut and dressed to proper shapes, they provide an economical material for the construction of various parts of a building. However, stones are not available in all parts of India and are costly to work into different shapes. It is also difficult to handle stones because of their heavy weight. Generally, wherever stones are available, bricks cannot be manufactured economically and *vice versa*. Hence stone masonry is an integral feature of buildings located in hilly areas. Stone masonry also provides a good architectural look. Stones are also used for the construction of monumental structures.

Materials used for Stone Masonry

The materials used for stone masonry are stones and mortar.

The common types of stones available in India for stone masonry are :

(1) *Granites* : These are the hardest types of stones and are difficult to work with. They are available in various colours ranging from white to green. These are used for the construction of steps, walls, sills and as facing over other masonry. They are found in Dharwar, Madras and Kashmir.

(2) *Sandstones* : They are made up of quartz cemented by a matrix of silica. They also contain mica, felspar and oxides of iron. The colour of sandstones is due to the presence of other minerals in them. They can be worked easily to take any ornamental shape. Their texture being coarse, they give a good appearance when used along with brick masonry. Coloured sandstones are used in the facework of buildings to give architectural treatment. They are used for walls, columns, facings, steps, flooring, etc. They are mostly found in Bombay State, Rajasthan and Andhra Pradesh.

(3) *Limestones* : These are calcarious rocks and consist of carbonate of lime. They are available in various colours and are easy to work with. They are used for walls, floors, steps, etc. However, they are liable to get disfigured in acidic atmosphere.

(4) *Marbles* : They are very useful material for flooring and monumental structures. Marbles are available in various colours and can take very good polish. They are available in Rajasthan and Bombay State.

(5) *Slates* : These are available in hilly areas and are metamorphic rocks. Generally they have a black colour. Slates can be split in thin sheets along their bedding planes. They are mostly used for roofing work.

The properties of stones which are important for stone masonry are strength and durability. Economy and appearance are additional requirements. The main considerations for durability are the lasting qualities of the stone itself and the locality where it is to be used. Porous stones are unsuitable for areas prone to heavy rainfall and frost. Stones, *e.g.*, marbles having low porosity and low coefficients of expansion and contraction should be used in areas subjected to large variations in rainfall and temperatures.

Generally lime and cement mortars are used for stone-masonry. Their function is to initially provide a workable matrix and ultimately a hard binding material, which renders masonry into a monolithic unit. Hydraulic lime and Portland cement are used as cementing materials and natural or river sand as fine aggregate. Sand serves a twofold purpose, firstly, it is a filler material so economy is obtained and secondly, it adds to density thereby adding strength and also reducing shrinkage.

Defects in Stones

Before using a stone in a building, the following defects should be checked :

(*a*) *Vents* : These are small figures or hollows in the stone which render it liable to decomposition.

(*b*) *Shakes* : These are minute cracks containing calcite which form hard veins. As the stone weathers, these veins being stronger, project beyond the surface of the stone and render it a bad appearance.

(*c*) *Sand holes and clay holes* : These are cracks or holes filled with sandy or clayey matter. They are liable to decomposition when subjected to weathering action.

(*d*) *Mottle* : Stones have spottled appearance due to the presence of chalky substances. Such stones are not fit for use as building material.

(*e*) *Shelly bars* : These are small fossils or shells and when found in excess, render the stone liable to decay.

Terms Used in Stone Masonry

(1) *Bed Surface* : The surface of a stone perpendicular to the line of pressure.

(2) *Bedding Planes* : The planes which separate the different layers of stone and are at right angles to the pressure which acts on the stone mass during its formation in nature.

(3) *Ashlar Masonry* : Masonry composed of rectangular units usually larger in size than a brick. The stones are properly bonded, sawn, dressed and have proper thin mortar joints.

(4) *Rubble Masonry* : Any stone work which is not highly finished.

(5) *String Course* : This is a continuous horizontal course of masonry projecting from the face of the wall and is intended to throw-off water.

(6) *Corbel* : This is a piece of stone projecting from a wall to support a structural member.

(7) *Cornice* : This is a moulded course of masonry having large projections. It is used for throwing off water.

(8) *Block in-course* : This is a course of stones erected on the cornice. The object is to hold down the cornice and also to give emphasis to this part of the structure.

(9) *Cramp* : This is a slate or metal connection used in stone work.

(10) *Diaper-work* : Surfaces and panels in stone work formed by the use of square stones in an ornamental manner is called diaper work.

(11) *Drip-Stone* : A projected stone moulding having a throated under surface to throw water off the walls.

(12) *Grouting* : Spreading and working of mortar over the stones to fill up any interstices between them.

(13) *Mouldings* : These are ornamental features given to constructional members to enhance their aesthetic effect.

(14) *Templates* : Pieces of stones placed under the end of a beam to distribute the load over a greater area.

(15) *Throating* : These are grooves cut on the under-surfaces of sills, copings, string courses, etc., to prevent the water from trickling down the walls.

(16) *Through-stone* : These are stones extending throughout the thickness of the wall. They act as bond stones and increase the stability of the wall.

Tools for Stone Masonry

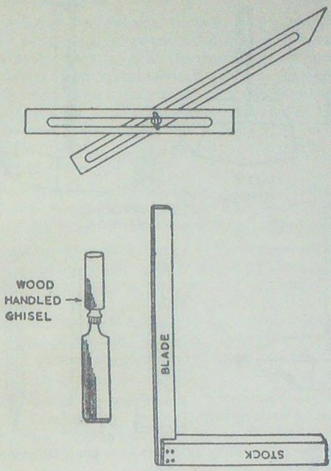
Stones are worked with hand tools as well as with machines. The following are the tools used by a mason.

(1) *Trowel* : This is used for spreading mortar and is similar to the bricklayer's trowel.

(2) *Square* : This is made of flat iron and each arm is about 50 cm. long. It is used in setting out right angles.

(3) *Bevel* : This is made of two blades of iron slotted and fastened with thumb-screw.

(4) *Spirit level* : This is used for checking the horizontality of masonry courses.



Figs. 300-302. Tools for stone masonry : (*i*) Bevel, (*ii*) Chisel, (*iii*) Try-square.

(5) *Plumb rule and bob* : This is similar to a bricklayer's plumb rule and is used to check the verticality of walls.

(6) *Mallet* : This is a wooden headed hammer and is used for driving wooden headed chisels.

(7) *Iron hammer* : This is used for carving stones.

(8) *Pick* : This has a long head pointed at both ends. This is used for rough dressing of granites.

(9) *Spalling hammer* : This is a heavy hammer used for rough dressing of stones in the quarry.

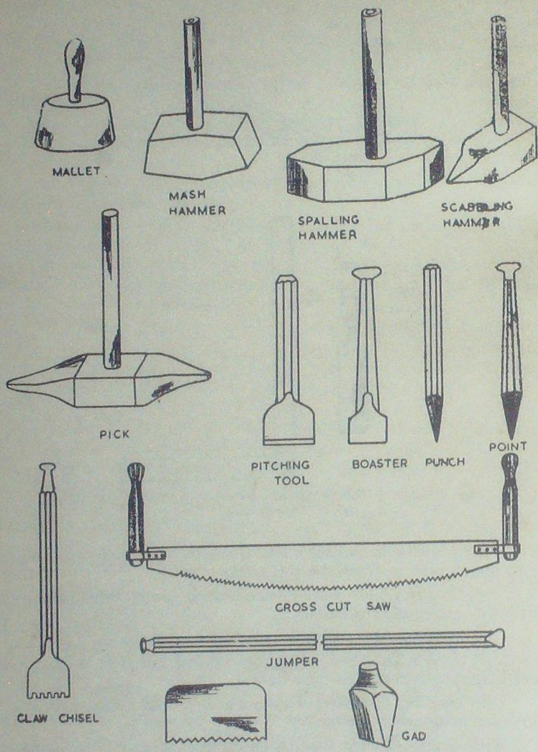
(10) *Chisels* : They are used with mallets and with hammers. They have got different shapes and have pointed heads.

(11) *Claw tool* : This has an edge with a number of teeth from 3 mm. to 9 mm. in width and is used for dressing the surfaces of stones.

(12) *Pitching tool* : This has a long edge with a thick head and is used for reducing the size of stones.

(13) *Jumpers* : These are used for boring holes.

(14) *Wood handled chisels* : These are used for dressing soft stones.



Figs. 303-316. Tools for stone masonry.

(15) *Wedge and feathers* : These are small conical wedges and curved plates. They are used for cutting the stones after they have been bored with a jumper.

(16) *Gads* : These are small iron wedges for splitting of stones.

(17) *Saws* : These may be double saw, a framed saw or a hand saw. They are used for cutting stones with hands.

Cutting and Dressing of Stones

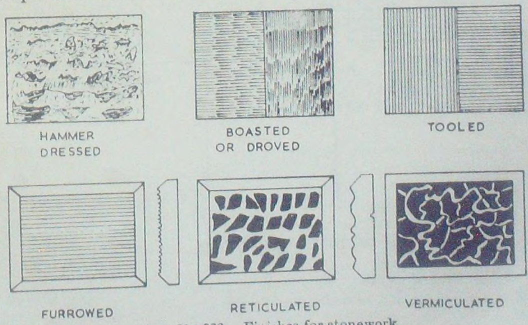
Stones, found in nature, have to be quarried from their thick beds. After quarrying large pieces of stones, it is essential to break them into smaller sizes so that they can be used in a building. They are also dressed into suitable shapes and polished to give a smooth surface, if desired. The stones are used in different types of masonry described subsequently and have, therefore, to be cut and shaped to fit in the type of work needed. Various type of finishes and the methods of dressing and cutting the stones to get the desired surfaces are described below :

(1) *Scabbling* : Irregular edges of the stones are broken off and the stone is shaped somewhat. This work is generally done in a quarry and the edges are broken with a scabbling hammer.

(2) *Hammer dressed* : Large raised portions of the stones are cut and the stone is made somewhat flat but rough due to hammer marks. These stone blocks are squared somewhat and the bed and vertical sides are dressed to a distance of 8 to 10 cm from the face. This is done to enable the stone to have proper joints. This work is done by the use of Waller's hammer. The types of stones so obtained are termed hammer faced, quarry faced or rustic faced (*see* Figs. 317-322).

(3) *Boasted or Droved finish* : The stone is cut to a little level face and is finished by means of a boaster (chisel with an edge of 6 cm. width). These marks may be horizontal or at an angle. The chisel marks are not continuous across the whole width of the stone.

(4) *Tooled finish* : In this case the chisel marks are continuous and parallel throughout the width of the stone. These are also deeper than the ones described above.



Figs. 317-322. Finishes for stonework.

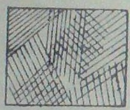
(5) *Furrowed finish* : In this case, about 1 cm. vertical or horizontal grooves are sunk with a chisel having its end shaped as a hollow semi-circle (gouge). The sides of the rock are kept either chamfered or sunk.

(6) *Reticulated finish* : In this type of work, irregular shaped sinkings are made within the central portion of the stone having a 2 cm. wide margin on its sides. These sinkings are about 6 mm. deep. The margin around the sinkings is of constant width. The sunk surfaces may have punched marks to give a better appearance.

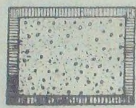
(7) *Vermiculated finish* : The sinkings are of the reticulated type except that they are more curved and give a worm eaten type of appearance. These types are not very common as they need lot of labour in construction.

(8) *Combed or Dragged finish* : This type of finish is done on soft stones. A comb is driven over the surface of this stone to remove all elevating portions.

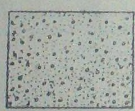
(9) *Punched finish* : Depressions are formed on the rough surface with a punch. A series of ridges and hollows are produced.



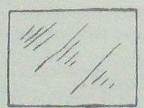
COMBED OR DRAGGED



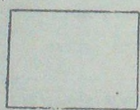
PUNCHED



PICKED



POLISHED



RUBBED

Figs. 323-327. Finishes for Stonework.

(10) *Picked finish* : This type of finish is obtained by dressing stones with a point and the depressions are smaller than the above type.

(11) *Chisel Drafted Margins* : They give a better appearance and help in getting uniform joints. The margins can be chamfered, squared or pitched. They are given a boasted or a tooled finish. Each quoin stone must have drafts at the corners so as to help in putting the stones in plumb.

(12) *Moulded finish* : Mouldings of various types can be worked on the stones to improve their appearance. These are either hand made or machine made. Various types of mouldings used are described later on.

(13) *Rubbed finish* : The surfaces of the stones are rubbed to get a smoother finish. One piece of stone is rubbed against the other. Water and sand are added to aid the operation. Machine rubbed stones are also available.

(14) *Polished Surfaces* : Stones which can take polish, *e.g.*, granites, marbles, lime-stones are first rubbed to a smooth surface and then polished by using rubber and pad, sand and water, pumice, and putty powder. However, machines can also be used for polishing.

(15) *Sand Blasting* : This is done to imprint letterings and designs on the surface of granites. The polished surface is coated with a molten rubber like compound which solidifies on cooling. The desired design is cut on this coating with a sharp tool thereby exposing the stone surface which is to be cut. A blast of sand is then blown with compressed air, the part which is exposed is cut to the depth needed.

Selection of Surface Finish

The type of finish to be adopted at a particular place depends upon the type of masonry, type of stone, the architectural effect needed, atmospheric conditions and the funds available.

The hammered finishes are suitable only on harder stones as the ridges will not stand, if made of a soft stone. Similarly tooled finishes are not suitable for soft stones. Polishing cannot be done on stones such as sandstone or limestone.

Rubble masonry will be hammer dressed and ashlar masonry will have smooth or rubbed faces. Marble if used for exterior use will have rubbed face and if used in the interior will have a polished surface.

Polished surfaces are useful where absolute cleanliness is desired, *e.g.*, hospitals, bath rooms, etc. Similarly finer finishes are used on interior surfaces whereas coarser finishes are used on external faces. However, economy is always to be considered. It is very costly to get smooth finishes in the case of hard stones whereas it is comparatively cheaper in the case of soft stones.

Types of Stone Masonry

Masonry can be classified according to the thickness of joints, continuity of courses and finish of face.

Broadly speaking there are two types of stone masonry, namely :

(1) *Rubble Masonry* : This consists of blocks of stones either undressed or roughly dressed and having wider joints.

(2) *Ashlar Masonry* : This is built of stones carefully dressed and has narrow joints.

The various sub-divisions of these two types are :

- Rubble Masonry
  - (*a*) Random Rubble :
    - (*i*) Uncoursed
    - (*ii*) Coursed
  - (*b*) Squared Rubble :
    - (*i*) Uncoursed
    - (*ii*) Coursed
    - (*iii*) Built to regular courses
  - (*c*) Miscellaneous :
    - (*i*) Polygonal
    - (*ii*) Flint
- Ashlar Masonry
  - (*a*) Ashlar fine
  - (*b*) Ashlar rough tooled
  - (*c*) Ashlar rock or quarry faced
  - (*d*) Ashlar chamfered
  - (*e*) Ashlar facing
  - (*f*) Ashlar block-in-course

Rubble Masonry

The stones in this type of masonry are pyramidal to some extent. They are not of uniform size and shape and are not finely finished. Proper bonding vertically as well as transversely is to be attained. Through stones have to be laid from back to face of wall or for at least more than half the width of the wall. Following points may be noted for all types of rubble masonry.

(1) All stones should be wetted before being laid in the masonry.

(2) The stones on the face should have full joints for a specified distance from the face.

(3) Stones from opposite faces should bond with each other, as far as possible.

(4) The backing should have sufficient bond with the facing. Building of backing and facing separately and the filling of intermediate space with small stones is objectionable.

(5) There should be sufficient headers in each course and they should be embedded into the walls for sufficient depth.

(6) The filling may not necessarily be brought to the level of each course but slightly thicker stones than the height of the courses may be allowed.

(7) The height of the stone should never exceed its least horizontal dimension.

(8) Stones should be placed on their widest side so that they may not act as wedges and force out the adjacent stone.

(9) Feather edged stones with insufficient tails should not be used.

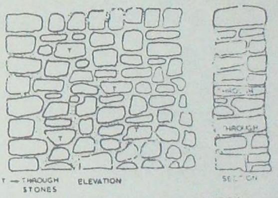
(10) The use of chips should not be allowed in bed joints for setting the stones.

(11) The width of the face stone should not be less than the height of the course.

(12) Corner or quoin stone in coursed rubble work should be of the same height as the course. In order that the vertical joint may break, one side of the corner stone is made longer than the other by about 15 cm. and the corner stones in alternate courses are placed with their longer sides on the same exposed face. The beds of corner stones must be dressed to a depth of 10 cm. and each corner stone should be of such dimensions so as to have the maximum bearing into the wall.

Random Rubble Masonry

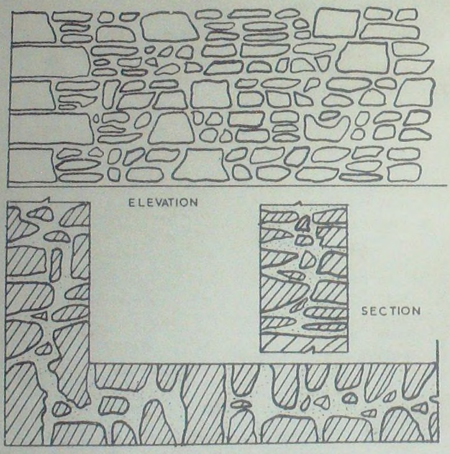
Un-coursed : Uncoursed rubble masonry is built practically without any dressing. The stones used vary very much in shape and size. The mason selects the stones at random from a heap and lays them to form a strong bond. Prior to laying, all projecting corners are slightly knocked off with a hammer, if necessary. Larger stones are laid on flat beds and in exceptional cases may be supported on small stones but not on chips. Vertical joints are not formed to plumbness. The joints are filled and finished flush. They vary in width from stone to stone. Large stones are used at corners and jambs to increase strength. Through stones are also provided at intervals to further increase the strength. One through stone is used for every square metre of face work. They are at least 400 sq. cm. in area and run to a depth of at least half metre or to the full depth if it is less than half metre. This type of masonry affords a very rough appearance.



Figs. 328-329. Random Rubble uncoursed.

If the wall is greater than half metre in thickness, a line of headers overlapping each other by at least 15 cm. should be laid through the wall. The backing stones should be of large size and 33% of them should exceed $\frac{1}{40}$th cubic metre in content. The quoins are of selected stones, hammer dressed to the required angle and laid header and stretcher alternately. No quoin should be less than $\frac{1}{10}$th of a cu. m. in content.

Coursed : In this type, the stones are laid to somewhat level courses. In each course, headers of full course height and consisting of hammer dressed stones are placed at certain intervals. Each header has a width not less than its height and projects into the wall at least three times its height. Between the headers, each course is built with smaller stones which are not less than 5 cm. in thickness. They may be placed two or three in number, one above the other, in each course. These stones need not be dressed but should have flat beds. The side joints need not be vertical but should also not form an angle greater than 60° with the bed joints. It should be aimed to break the joints in different courses. Joints may be about 1.5 cm. in thickness. In walls of thicknesses up to half metre, headers should run from face to face and act as through stones. In thicker walls, headers from the face and the back should overlap each other by at least 15 cm. The headers of successive courses should not be placed one above the other. The quoins are to be of the same height as of the course and are about half metre long. They are laid as stretchers and headers alternately. All the stones are to be set in mortar. This type of work is used for small buildings where the walls are not very high.



PLAN OF A COURSE

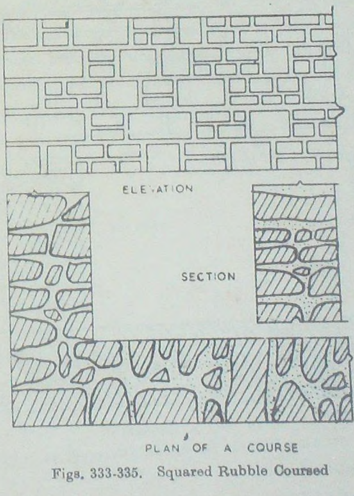
Figs. 330-332. Random Rubble Coursed. (Elevation, plan of a course and a Section)

Squared Rubble

These stones are usually squared and given a hammer dressed finish. They can also have tooled or dragged surface finish.

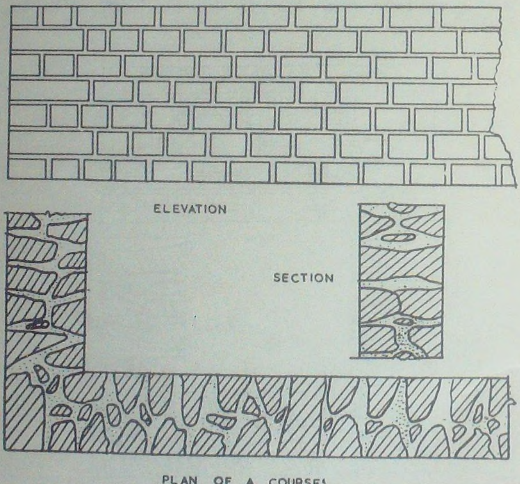
Uncoursed : The stones are laid in irregular patterns. They are squared on all joints and beds. The beds should be hammer or chisel dressed, true and square for at least 10 cm. from the face whereas the joints are finished similarly for at least 5 cm. The faces of the stones should not project more than 50 cm. from edges. A good appearance is produced by arranging the stones in series, *i.e.*, a large stone (riser), two thin stones (levellers) and one small stone (check). Most of the joints should break vertically. Bigger sized stones should be used as quoins. Chips should not be used for bedding the stones.

Coursed : This type of masonry is made up of a facing comprising of hammer squared stones with a backing of rubble masonry and bonded to the former. The stones in each course need not be of the same height. Not more than two stones, one above the other are used in each course. All the courses should be of the same height. However, the lower courses should not be thinner than the upper courses. The stones should break joints with those above them. The hearting and backing should be brought up simultaneously. The hearting is made up of flat bedded stones laid carefully on their beds. Small chips may be used whenever the joint is very thick. However no dry hollow spaces should be left. The quoins should be of stones equal in depth to the height of the course and should at least be half metre long. They are laid alternately as headers and stretchers.



Figs. 333-335. Squared Rubble Coursed

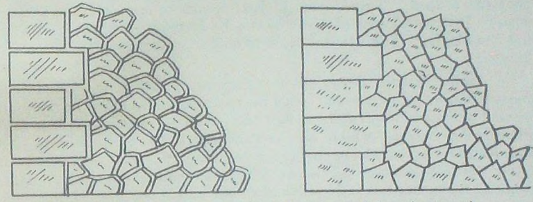
Built to regular Courses. The stones are laid in horizontal layers not less than 15 cm. in height. Stones are of equal height in a course. No course is thicker than the course below it. The faces of the stones are squared on all joints and beds. The beds are hammered or chisel dressed to a depth of at least 10 cm. from the face and the joints to at least 5 cm. from the face. The projections do not exceed 5 cm. Stones are not lesser in breadth than height. They fit in the wall to a depth not less than the height and at least ⅓rd of the stones tail into the wall to at least twice their height. Through stones are used at 2 metres apart in every course and extend from one face to the other face of the walls if they are not greater than half metre in thickness. For thicker walls headers should run from back to face with an overlap of at least 15 cm. A header should have a length of at least 3 times the height. The quoins are of the same height as the courses and are at least half metre in length. They are laid as headers and stretchers. Stones are laid in such a manner so as to break the joints vertically. At least half the height of the course is kept as the overlap between the two stones. The hearting is made of flat bedded stones which are laid carefully in mortar. Smaller sized chips are used to avoid thick mortar joints.



Figs. 336-338. Squared rubble (built to regular courses).

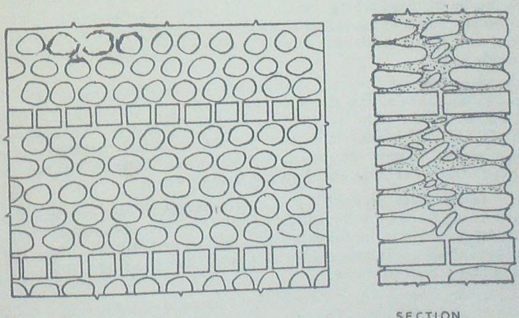
Miscellaneous Types

Polygonal Walling : The stones are roughly dressed to an irregular polygonal shape. Each stone is dressed carefully to form neat and uniform joints. The stones are laid carefully in mortar and tail backed to bond well with the backing. They are not of greater length than the breadth of the face or the length at right angles to the face. One header or through stone is inserted to run through the wall if the wall is less than half metre in thickness or else headers are laid from the face and the back overlapping each other by at least 15 cm. The stones are arranged to break joints as much as possible and long vertical joints should be avoided in face work. Small chips should not be used to support the stones on the face. If the stones are not finished at their edges properly, joints of greater thicknesses are seen. This type of work is slightly inferior.



Figs. 339-340. Polygonal walling (Inferior and Superior types).

Flint Walling : The stones used in this type of work are small in size, varying in thickness from 8 to 15 cm. and in length from 15 to 30 cm. Buildings near coasts are constructed of walls with rounded flints procured from the beaches. The walls are about half metre in thickness and may be built with a facing of cut flints and a backing of undressed flints. A second method is to shape the flints into square sizes and use them as facings. A cheap type of work is



Figs. 341-342. Flint masonry.

formed by using undressed flints. Uncoursed or coursed type of work can be made. When the flints are undressed throughout, the external and the internal flints are laid as headers and the hearting of headers and stretchers tightly packed. The mortar joints are slightly raked back with a pointed stick to improve the appearance.

Ashlar Masonry

This class of masonry consists of stone blocks accurately dressed, with very fine joints of the order of 3 mm. thick. The backing of such walls may also be built of ashlar masonry or rubble masonry. It should be ensured that the sizes of individual stones are in conformity with the general proportions of the wall in which they are placed. This is the highest grade of masonry and is very costly. Different types of patterns can be formed by suitably arranging the blocks. The various types of ashlar masonry are described below :

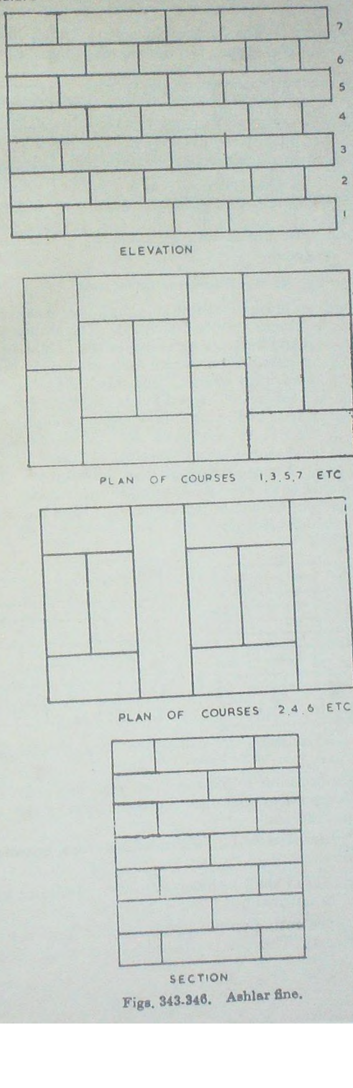
Ashlar Fine : Every stone is dressed on all beds, joints and faces perfecty true to the pattern desired. All curves or twists if needed are made accurately to suit the pattern. The stones are laid in regular courses which are not less than 30 cm. in height. All courses are made of the same thickness except when it is desired to have the top courses of lesser thickness than the bottom courses. Stones are neither less in breadth than the height of the course nor they are less in length than twice the height. The face stones are laid headers and stretchers alternately or to a different bond pattern, if so needed. The headers come under the middle portion of the stretchers. The stones in adjacent layers shall have a lap of at least half the height of the course so as to break the continuous vertical joints (*See* figs. 343-346).

Through stones are put in walls which are less than 80 cm. in thickness. These are in the form of headers which run from one face to the other. All the joints are either horizontal or vertical. They are made of fine mortar with a thickness not exceeding 3 mm. No broken edges of the stones should be visible at the joints. Stones are struck with a mallet so as to have solid bearing on the beds and the side joints.

Ashlar Rough Tooled : In this type of masonry, the exposed faces should have a fine dressed chisel drafting. This may be about 2.5 cm. in width. The portion in between the drafts is roughly tooled. All bed joints and vertical joints are similarly drafted. The size of stones, bonds, etc., are as for the Ashlar fine type. However joints as thick as 6 mm. can be allowed in this case.

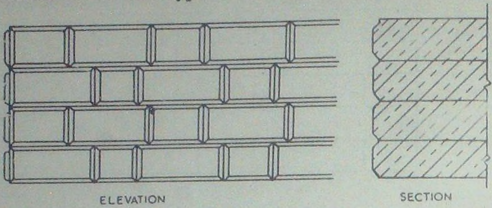
Ashlar Rock Quarry Faced : The exposed face between the drafts is not tooled, as described above, but is left unfinished. However the projections (bushings) should not exceed 10 cm. from the planes of drafts. The size of the stones and the bond, etc., is similar to the one described above.

Ashlar Chamfered : Stones have the exposed edges bevelled for a depth of about 2.5 cm. The type of joints, bonds and size of stones is the same as described above.



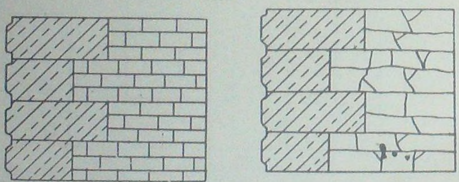
Figs. 343-346. Ashlar fine.

Ashlar Facing : The faces of stones are rough tooled, rustic or chamfered. In this type, the face work is made of these stones



Figs. 347-48. Chamfered Ashlar wall.

and the backing is of brick or rubble masonry or concrete. Hence the back face of the stones may be left rough. The stones are not less than 20 cm. in height and are about 1½ times the height in width. At regular intervals, headers are put which are in length greater than the breadth of the stone plus 40 cm. One third of the length of each course should be of headers. The bed joints of all face stones should be dressed perfectly true and square. Bond stones should run through the backing when the wall is less than 80 cm. in thickness. For thicker walls, the bond stones should overlap at least 15 cm. They are inserted at every 2 metre interval along the course. The height of the courses should equal an exact number of rubble courses or brick courses plus intermediate mortar joints. The backing is built simultaneously with the facing.



Figs. 349-350. Ashlar facing (*i*) with brick backing (*ii*) with random rubble backing.

Ashlar Block in-course : This type of work is similar to ashlar rough tooled with the only difference that the height of the course is lesser but not below 20 cm.

General Principles to be followed in the construction of Stone Masonry

(1) The stones used shall be hard, durable and tough. All stones should be laid on its natural bed.

(2) The pressure acting on the stones should not act parallel to the bedding planes. This will try to split the stones. Sometimes

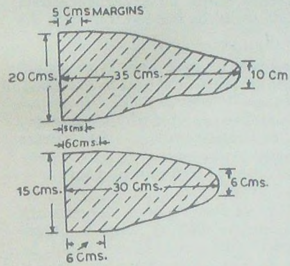
stones used in corbels are laid with pressure acting parallel to bedding planes.

(3) The bond stones and headers should not be of a dumb-bell shape.

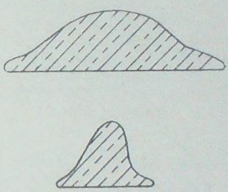
(4) Large flat stones should be laid under the ends of girders, roof trusses, etc.

(5) In all sloping retaining walls, the beds of the stones and the plan of the courses should be at right angles to the slope.

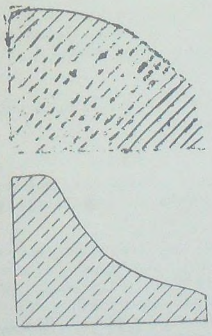
(6) All laid fine dressed stone work should be protected against damage during further construction by means of wooden boxes.



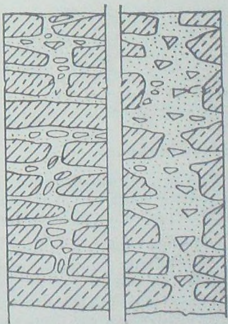
Figs. 351-352. Plans of good headers.



Figs. 353-354. Bad stretchers with thin edges.



Figs. 555-56. Good and bad quoins.



Figs. 357-358. Section through a good and bad masonry wall.

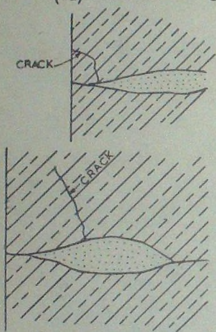
(7) Jambs for door and window openings should be made of quoins which are equal in height to the course. They should be in breadth equal to at least $1\frac{1}{2}$ times the height of the course and their length should be at least twice the height. For door openings at least three quoins should extend to the full thickness of the wall whereas for window openings two of them are sufficient. Door and window frames should be fitted into corresponding grooves cut in the quoins.

(8) All the surfaces should be kept wet while the work is in progress and also till the mortar has set.

(9) Double scaffolding will be used wherever it is difficult to fit in the stones later on.

(10) All the portions of the masonry should be raised uniformly. Wherever this is not possible, the stone work built earlier should be raked (stepped) so that the new work can be bonded well with the old.

(11) Sufficient through stones should be used and they should form $\frac{1}{4}$th to $\frac{1}{5}$th of the area in elevation.



Figs. 359-360. Defective bedding of stones

(12) The hearting of the masonry should be properly packed with mortar and chips, if necessary, to avoid any hollows or very thick mortar joints.

(13) Vertical faces of the masonry walls should be checked with a plumb rule and the battered faces should be tested with wooden template corresponding to the batter and a plumb rule to ensure a constant batter.

(14) The stones used in the masonry should be wetted before use to avoid moisture being sucked from the mortar.

(15) Masonry should not be allowed to take tension.

Dry Stone Masonry

This is the ordinary rubble masonry without any mortar. It is used for the construction of retaining walls, pitching channel slopes and rip-rap protection in earth dams.

Dry stone retaining walls : These walls are stable on account of the interlocking bond between the individual stones. Hence the stones used for this type of work should be selected carefully. These stones are roughly hammer dressed so as to have maximum bedding area. All hollows around them should be tightly packed. The stones are laid at right angles to the face batter and each course is built with a proper bond and vertical joints being broken with respect to the other courses. Through stones or headers are provided in each course at about 2 metre interval and are continued throughout the whole width of the wall. The headers should overlap each other by at least 15 cm. so as to tie the front and the back portions of the wall together. The filling behind the wall should be made up of stone chips. Earth should not be used for this purpose. Holes running through the width of the walls should be left to allow for the drainage of the back filling. These are called weep holes. The dry stone walls should have at least ½ metre top width and a batter of 1 in 4 for heights upto 5 metres. For greater heights the batter may be decreased or the portions below 5 metres from top should be made up in mortar. Long lengths of dry stone walls should be divided into panels by short lengths of walls (1 metre or so) built in mortar at intervals of 10 metres so as to restrict the damage if any within these lengths.

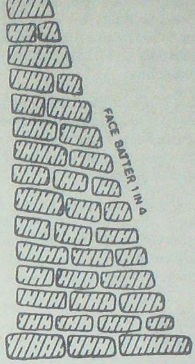


Fig. 361. Dry stone masonry wall.

Dry stone pitching : When the slope of an earthen cutting cannot stand the scouring action of water, it is protected with a layer of stones laid dry which is called pitching or revetment. The stones used for such type of work should be sound, regular in shape and in length equal to the thickness of the desired pitching. The pitching is generally given a backing of smaller stones packed well or of moorum. This is carried simultaneously along with the pitching and is well watered and rammed, if needed. The stones should be laid tightly with each other in such a manner that their lengths are at right angles to the face of the slope. Small stones may be inserted in between the larger ones to make the bond perfect. For stability at the toe of the embankment, a masonry wall is made to secure the pitching in position or else a dry stone wall of desired thickness is built.

Joints in Stone Masonry

The joints in stone masonry may be classified under the following three heads :

(*a*) Strengthening joints

(*b*) Lengthening joints, and

(*c*) Mortar joints.

A brief description of these follows.

(*a*) *Strengthening joints*

There are certain structural locations in a building where the weight of the superstructure and the adhesion of mortar are insufficient to keep the stones in position. This may lead to a possibility of failure along joint by either sliding or separations. Such failure can be checked, if the joint is strengthened by some special means such as dowels, cramps and joggles. Examples where such methods are applicable are coping stones, inclined walls, cornices and corbels ; which cannot be kept in position by the surrounding masonry.

Strengthening joints, in stone masonry, are of two types, namely (*a*) joggle joints and dowels and (*b*) ramp joints. The former type is suitable for taking care of sliding of the abutting surfaces, whereas the latter type is suitable for prevention of separation or opening out of the joints.

Joggle joints can be in the form of tongue and groove, table and slate or metal or cement joggles. These joints are suitable to prevent sliding between vertical butt joints (*e.g.* landing of stone-stair), horizontal sliding of stones, lateral movement of stones in copings respectively. Dowels are also used for resisting lateral movements.

Cramps may be metallic or of stone such as slate. Coverings of copings, cornices and projecting string courses are the situations where cramps can be used to resist the parting of stones. Lead plugs can also be used for this purpose.

Details of strengtheing joints are given below :

(1) *Table or bed joggle joint* : The projection of one stone fits into the depression of the adjacent stone. This prevents the movement of the stones along the jointing plane.

(2) *Tongued and grooved* : In this also the projection of one stone fits in the corresponding groove in the adjacent stone. This is also called joggled joint.

(3) *Slate or metal joggled joint* : In this, a piece of metal or slate is placed in between the corresponding groove of the adjacent stone.

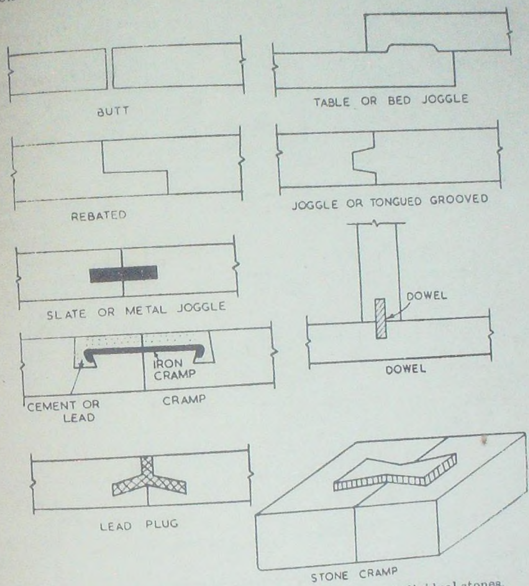
(4) *Dowel joint* : Wherever stones are liable to be displaced, then a dowel is introduced to connect them. These dowels may be of slate, gun metal, brass, bronze, etc. They are set in cement mortar.

(5) *Cramped joint* : The cramp is a piece of metal about 2 to 5 cm. wide, 6 to 12 mm. thick and 20 to 40 cm. long with ends turned down. They may be set in depressions in the top of the stone or set beneath the stones with their ends upward. They should be protected by pouring molten lead around them. These cramps can also be made of slate or other stone. They have a dovetailed shape on both ends and are set in cement. However they are not as effective as the metal cramps.

(6) *Plug joint* : This is an altenative to the use of cramps and consists of a depression below the top surface dovetailed in plan. The stones are jointed in the usual way and this depression is filled with cement or lead.

(b) *Lengthening Joints*

The different kinds of joints used for placing the individual stones together lengthwise are



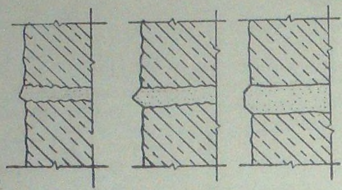
Figs. 362-370. Various types of joints between individual stones.

(1) *Butt joints* : The two stones are placed side by side with their square faces abutting each other.

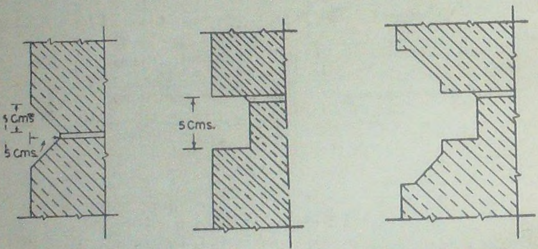
(2) *Rebated or Lapped Joints* : In this type of joint, the rebate in one stone laps over the projection of the other stone.

(c) *Mortar joints* : Joints used for rubble work are not consistently uniform in thickness. In case of the random rubble or polygonal walling, small pieces of stones or chips should be fitted into the joints to prevent excessive thickness or mortar being held in between the two joints.

In the squared rubble masonry, the joints are more or less horizontal and vertical and are uniform in thickness. Often the joints in this type of work are made flush with the surface and a bead of mortar (may be of a different colour) is provided to give the effect of a narrow joint. However, projecting joints may be used for thick joints. The common types of these joints are shown in figures 371-376.



PROJECTING



VEE CHANNELLED VEE & CHANNELLED

Figs. 371-376. Various types of joints for stone masonry.

Ashlar masonry, as described earlier, is accurately dressed so as to have very fine joints. They are mostly flush joints. However, when joints thicker than about 6 mm. are used, keyed or V-joints may be used. Other types of joints which are suitable for this type of masonry are the channelled joints or Vee and channelled joints.

Mortars used

Stone masonry mortars have to be selected depending upon the colour of the stone so as to have a good combination of colours on the face work. Generally stone masonry is built in cement mortar of 1 : 3 ratio. To increase the workability of mortar, about 15% of the cement may be replaced by lime. For limestones which get stained by the ordinary cement sand mortar, a non-staining white Portland cement mortar may be used. Generally one part of non-staining cement, one part of hydrated lime and six parts of clean sand are used for stones which are liable to be stained by cement mortar alone. Special non-staining water proof cements may be used instead. For pointing work very rich mortar should not be used.

Lifting Appliances

Lifting appliances are necessary for proper handling of heavy stone blocks which cannot otherwise be raised or lowered to the desired level and set properly. Various appliances are used for lifting and placing stones in position. Heavier stones are lifted with a derrick and carried to a place where it is to be positioned in masonry. Gantries or cranes can also be used to move the stones from one place to another. However, certain attachments are necessary for holding the stones while the derrick lifts them. The different types of such attachments are :

(1) *Grab Hooks* : The pointed ends of these hooks get fitted tightly into the corresponding notches cut in a stone. Small wooden blocks may be used on the sides of the stone to prevent damage to polished surfaces, if any. This type of attachment is used for lifting small stones.

(2) *Pin Lewice* : Pins of iron are put into the corresponding inclined holes in the stone and attached to a chain or rope bent into a triangular shape as shown in Fig 377. The tightening or pulling of the vertical rope prevents the pins from coming out of the stone and permits the stone to be raised.

(3) *Chain Dog* : In this type of attachment, the chain used is arranged as described above ; but instead of pins at the ends of the triangular rope work, hooks called dogs are fitted. These hooks get fitted into the corresponding depressions about 2 cm. deep in the ends of the stones. When the chain is lifted, the dogs get tightened and permit the lifting of the stone. Enough depth (at least 8 to 10

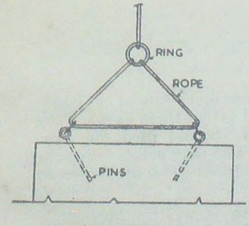


Fig. 377

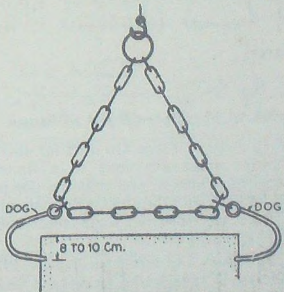


Fig. 378. Chain Dog.

cm.) of stone should be available above the end depressions so that while lifting the stones, their corners might not give way and they may fall down. This method of lifting is employed for heavy stones with long narrow beds.

(4) *Chain Lewis* : This is made up of three rings and two curved steel legs which are attached to each other as shown. A hole is formed slightly dovetailed in the top of the stone which is to be lifted. The lewis is placed into the hole with one leg at a time. A wedge piece may be inserted, if necessary. When the crane lifts the top ring, the smaller side rings get pulled apart and cause the lower tips of the legs to grip the stone. The hole should not be excessively dovetailed as otherwise there is likelihood of the edges being broken and the stone falling down.

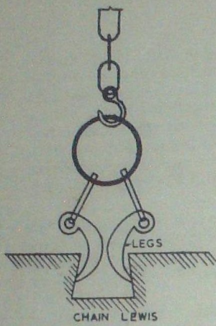
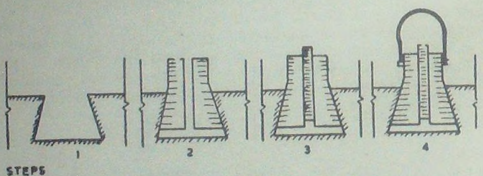


Fig. 379

(5) *Three legged common Lewis* : These consist of two dovetailed steel pieces, a parallel piece of steel in between, a shackle at the top and a round steel pin which connects all of these together. A dovetailed hole is made in the top of the stone corresponding to the shape of the legs. First the two end dovetailed pieces are inserted and the central piece is driven next. The pin and the shackle are fitted tightly. The crane hook is passed around the shackle to lift the stone.



COMMON LEWIS

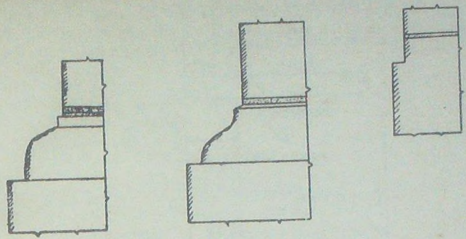
Figs. 380-383. Assembling details of a common lewis (3-legged).

Structural Members Built of Stone

(1) *Steps* : Steps are used for entrance and stairs of a building. Stone steps are used to a limited extent these days. They can be given various architectural shapes. Stones used for steps should be hard and durable. They should also take polish. Various types of stone steps and their methods of construction are described in the chapter on Stairs.

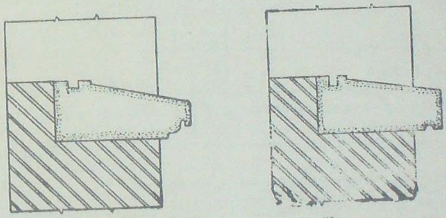
(2) *Plinth and plinth courses* : Plinth is a term applied to the horizontal projecting course at the base of superstructure, *i.e.*, between the ground level and the floor level. The height of the plinth is dependent upon the architectural treatment needed for a building, the flooding to which the area is subjected, etc. The topmost course of the plinth masonry is called plinth course. Plinth course can be made of stone and may be given special mouldings to

enhance its architectural beauty. Slight slope is necessary for the top position so as to shed off the water.



Figs. 384-386. Stone plinths.

(3) *Window Sills* : Window sills are needed for shedding off water falling on the window. They can also act as support for the vertical members of the window. They are made of bricks or stones. Special mouldings have to be given to prevent the water falling on the wall.



Figs. 387-388. Stone window sills.

(4) *String Courses* : This is a horizontal projection of the masonry throughout the length of the wall and is meant as an architectural feature. Special mouldings can be given to these courses.

(5) *Frieze* : This is a course below the cornice. This may be in flush with the wall below or may be projecting if thare is no projecting member below it.

(6) *Cornice* : This is a large projecting horizontal course provided on the top of the wall. This adds to the architectural beauty of the building and also protects the wall below it from the water trickling down its surface. Special mouldings may be given to the cornices for creating an architectural treatment.

(7) *Parapets and Copings* : These may also be made of stones. Rubble masonry or ashlar work can be used in their construction depending upon the general type of masonry used in the walls to which the parapets surmount.

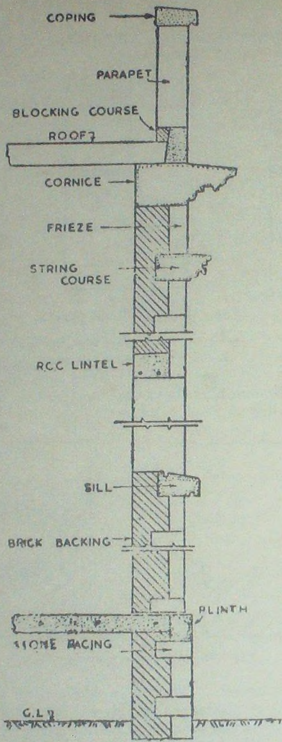
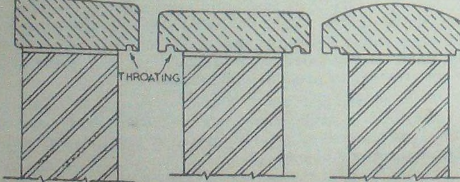
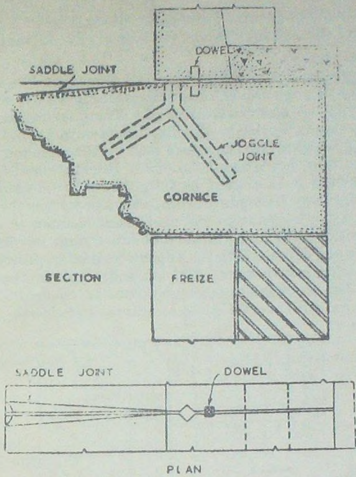


Fig. 389. Section through an exterior wall of a building showing different elements of construction in stone masonry.



Figs. 390-392. Stone masonry copings.

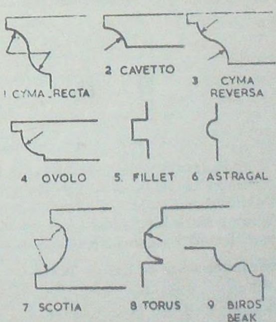


Figs. 393-394. Elevation and plan of a typical cornice.

Copings can be made of stones cut to different shapes. Mouldings can be given to the face ends of the copings to enhance their beauty. Throatings have to be incorporated to prevent the water from trickling down the face of the wall.

Mouldings

To give aesthetic effect to the various members of a building, special curved surfaces are carved on them. The moulding to be used depends upon the position of the member in the building. Crowning mouldings are not expected to carry any structure above them. Hence they are used on the top members of a building. Various types of mouldings are used and a few of them are shown in Figs. 395-403.



Figs. 395-403. 1-3. Supporting mouldings. 4-6. Connecting mouldings. 7-9. Base mouldings.

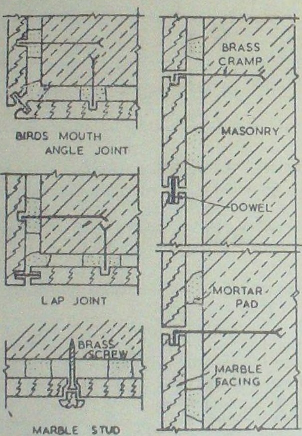
The supporting mouldings are used in members which have to support loads. They do not have hollow depressions near their upper edges.

Connecting mouldings are narrow projections used to divide a group of mouldings or various parts of a structural member.

Base mouldings are constructed to broaden the base of a loaded member and thereby distribute the loads over a large area.

Stone Lining

Costly stones, *e.g.*, marble are not economical for the construction of walls of large thicknesses. Hence only a face work built of thin slabs of these stones can be used. These facings are not acting as load bearing components of walls but have to be only fixed with the backing which takes the entire load on the member. The stones are cut into thin sheets about 2.5 cm. in thickness and fixed so as to appear as ashlar work or may be suitably cut so as to form panels. Marble facing may be kept about 2.5 cm. away from the face of the backing and can be made to rest on pads of Plaster of Paris. It is kept in position with brass dowels about 6 mm. in diameter fixed along the lower edges. The top edges are kept in position by brass cramps which are turned into the slab and fixed in the backing of the wall. The angle joints at corners can be made by the use of screws covered with marble studs or cramps and dowels.



Figs. 404-407. Details of marble linings to masonry walls.

External walls may be faced by thin slabs of stones polished suitably. These stone facings should not be greater than 8 times their thickness in height. Suitable bond stones may be used for strengthening thick facings whereas for thin facings, cramps have to be used for anchorage with the back of the wall.

Maintenance of Stone Work

(1) *Efflorescence :* This is common with certain types of mortars and can be prevented by proper drainage of the building.

Its removal is described on page 92. The stones should be kept saturated with water so that it may not get discoloured on account of acid action.

(2) *Stains* : Stains can be removed easily if they are not old and their origin is known. Iron stains have a rusty appearance and can be removed by rinsing the area with a solution of ½ kg. oxalic acid in 5 litres of water. The surface should then be scrubbed with brushes and clean water after 2 to 3 hours. Darker stains may be removed with a mixture of 6 parts of water, one part of sodium citrate, one part of glycerine made into a paste with sufficient whiting. This paste is applied to the surface and left for a few days. For very deep and dark stains, one part of sodium citrate is dissolved in 6 parts of water and the surface of stains is moistened with this solution. The surface is then covered with a thin layer of sodium hydro-sulphite crystals. This is removed after an hour. This treatment may be repeated, if necessary. The final surface is washed.

Copper and bronze stains are removed by applying a mixture of one part of ammonium chloride and 4 parts of powdered talc with ammonia water to form a paste. This paste is covered on the surface and removed after some time.

Smoke and fire stains can be removed by rubbing with powdered pumice or grit. This treatment is applied several times till a clean surface appears.

Oil stains can be removed by scrubbing with benzene or petrol. However a mixture of acetone and amyl acetate can remove deeper stains.

Tobacco stains can be removed with a weak solution of tri-sodium phosphate. Chlorinated lime paste is added to make the solution perfect bleaching agent.

Ink stains can be removed by applying a paste of whiting in a strong solution of sodium perborate and water. Chlorinated lime or ammonia water can also be used as an alternative.

(3) *Repair of cracks* : Cracks should be repaired only after the settlement causing the crack has ceased. This period may be taken as about one year. Small cracks should be cleaned with a wire brush or with a thin blade. A thick paste of cement mix is forced into the opening. Large cracks should be raked out to get a firm key for the mortar. An inverted V groove of at least 1 cm. depth is necessary. A cement mortar of 1 : 2 ratio with less water is suitable. This mortar should not be applied for about an hour after mixing and should be remixed without additional water, immediately before using. This mixture (grout) should be forced into the crack to get a good bond. Expansive agents, *e.g.*, aluminium powder can be added so as to make a tight fit for this grout.

(4) *Water proofing* : Colourless water proofing materials can keep the stone masonry free from damp, efflorescence, frost action etc. Water proofing materials obtained from heavy petroleum distil-

lates, fatty oils or insoluble soaps are best. Stones having a very close texture are difficult to be water proofed. Water proofiing substances containing resins are not suitable. They are applied as a washing coat. The water proofiing causes some discoloration of the stones but that goes off in course of time.

Artificial Stone

Wherever stone is not available and it is desired to give a face treatment of stone work, artificial stone or cast stone is used. These types of stones are nothing but cement concrete blocks with special surface treatment. Aggregates of crushed stone are used to produce a rough surface. Coloured sands may be used with coloured aggregates. Best types of aggregates are essential so as to withstand the weathering effect. Coloured cements or pigments may be used wherever coloured treatment is necessary. Cement aggregate ratio of 1 : 3 is maintained. An excessive quantity of aggregate will produce a weak product whereas a concrete containing less quantity of aggregates is going to have chipped off surfaces. Facing and backing portions of the blocks may be made of different sized aggregates, the smaller sized being used on the face. Special architectural details and mouldings can be cast economically and with ease. A polished surface can also be developed from the cast stone. The cast stone has got some advantages over the natural stone, *e.g.*, no bedding planes are present and hence the precautions regarding the placing of the stones with regard to their bedding planes are not necessary.

QUESTIONS

1. Briefly describe the different types of stones used in the construction of stone masonry. What are the common defects which are to be checked in a stone before it is used in a building ?

2. What are the factors on which a particular type of finish is selected in stone masonry work ? What are the usual types of finishes used ?

3. Name the various classes of rubble masonry. What are the important points to be kept in view while carrying out rubble work.

4. Describe briefly the following types of masonry work :—
   (*a*) Random Rubble coursed.
   (*b*) Squared Rubble uncoursed.
   (*c*) Polygonal walling.

5. Name the various types of Ashlar masonry. Briefly describe the construction of walls with Ashlar fine masonry.

6. Write short notes on :—
   (*i*) Dry stone retaining walls.
   (*ii*) Ashlar facing.
   (*iii*) Ashlar rough tooled.

7. What are the various types of joints used in stone masonry for placing stones together? Illustrate with neat sketches.

8. Write short notes on :—
   (*i*) Chain dog.
   (*ii*) Common Lewis.
   (*iii*) Plinth courses.

(iv) Cornice.
(v) Frieze.
(vi) String courses.
(vii) Artificial stones.

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5

HOLLOW BLOCK MASONRY

Concrete Masonry

The use of cement concrete blocks for masonry construction has developed rapidly due to the various advantages which they possess over traditional building materials like bricks and stones. The main advantages of concrete blocks are their large size, uniformity in design, easy handling and placing, attractive appearance and strength. Cheapness and the ease with which blocks of any size or form can be manufactured and laid are the two distinct qualities of concrete blocks as a valuable building material. New materials and methods of manufacture for these blocks are being developed and adopted regularly. The use of machine with large manufacturing capacity enables quick production. The method of steam curing enables these blocks to be laid within hours after casting.

There are several kinds of concrete masonry units depending on the shapes and sizes (Figs. 408-420) in which they are manufactured. However two distinct types of concrete masonry units are :

(1) *Regular concrete blocks* : These are precast cement concrete blocks made from dense aggregates and intended for load bearing walls.

(2) *Light weight concrete units* : Light weight aggregates are used in the construction of these units and although they are not as strong as the heavy concrete blocks, yet they are extensively used for both load bearing and non-load bearing walls. The situations where they are used for load bearing walls are external walls rendered or otherwise protected, the inner leaf of cavity walls, backing for brick work and stone masonry internal load bearing walls and partitions and infilling panels for framed buildings. As non-load bearing units, they are used in partitions and internal panels for framed buildings.

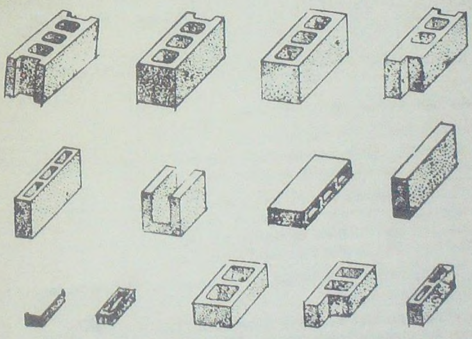
Concrete block masonry can be built in various sizes depending upon the job requirement. There is also no standard size of concrete blocks. However, as recommended by the Concrete Association of

India, the face thickness should not be less than 5 cm. and the net area should be at least 55 to 60 per cent of the gross area. Strengthening of the block in the middle, where cracking is liable to take place, is necessary. It is recommended that the cores should be at least two in number and they should preferably be oval shaped. The common sizes for building blocks are given in the table below :

Type	Actual dimensions in Cm.		
	Length	Breadth	Height
Size A	39	30	19
Size B	39	20	19
Size C	39	10	19
Tolerance	± 3 mm.	± 1·5 mm.	± 1·5 mm.

Various types of surface finishes are used. Some of them are described below :

(1) *Common finished surface.* Fine to coarse texture can be obtained by varying the mix proportions and by using suitable aggregates. Coloured aggregates can also be used. The aggregates can be exposed by treating the surface of blocks with a dilute solution of acids or by scrubbing it while the concrete has not set completely.



Figs. 408-420. ***Typical Concrete Masonry Units*** :
(*i*) Stretcher block, (*ii*) Corner block, (*iii*) Double corner or pillar block, (*iv*) Jamb block, (*v*) Partition block, (*vi*) Beam or lintel block, (*vii*) Floor block, (*viii*) Solid block used as facer in framing floor joints, (*ix*) Solid brick block, (*x*) Frogged brick block, (*xi*) Another, Stretcher block, (*xii*) Another Jamb block (*xiii*) Another partition block.

(2) *Glazed finish* : Concrete blocks can be finished with a glazed surface in any number of desired shades. This is done in a manner similar to glazing of tiles. These types of blocks are suitable for decorative work and have sufficient water resistant properties.

(3) *Slumped finish* : A concrete of desired slump is prepared so that when the forms are removed, the blocks settle somewhat. This produces a rough surface on the exterior and blocks of various dimensions are used in the face work.

(4) *Specially faced block* : Finishing materials other than concrete, *e.g.*, marble, can be incorporated on the facing side of the blocks. The smooth finish thus obtained enables the blocks to be used in various places, *e.g.*, hospital, cinema, etc.

(5) *Split blocks* : They are used for some decorative finishes in buildings and are produced by dividing the blocks into two parts lengthwise. The surface thus formed is rough and the aggregates are exposed. Hence proper selection of aggregates and their blending has to be done.

(6) *Coloured finishes* : Various types of pigments can be incorporated in the concrete mix so as to produce a variety of colours from block to block. Similarly special paints can be applied to the surface of the blocks to enhance their beauty.

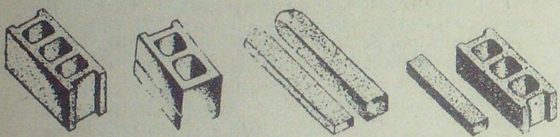


Fig. 421-424. (*i*) Standard block, (*ii*) Scored block, (*iii*) Slump block, (*iv*) Split block.

Manufacture of Concrete Blocks

The manufacture of concrete blocks is similar to that of ordinary concrete masonry. However, the following points regarding the manufacture of these blocks should be noted :—

(1) The aggregates should be correctly graded. The mixture of fine aggregates (60%) and coarse aggregates 6 to 12 mm. size (40%) is used. The fineness modulus of the mixture should vary between 2·9 to 3·6. Use of fine sand should be avoided.

(2) The concrete mix should be at least of 1 : 6 cement to combined aggregate ratio.

(3) When hand moulding is resorted to, the hollows should be vertical to get better compaction. The concrete should not have a very lean consistency. The concrete block should be taken out from the mould just at the time when it has sufficiently set.

(4) The block should not be disturbed on the moulding platform for at least 24 hours.

(5) It is preferable to use machines for casting the blocks so that a better finish and strength can be obtained.

(6) The blocks should be cured after keeping them under shade for at least 24 hours so that they are protected from the action

of wind and sun during this period. These units should then be immersed in a tank of water for at least one week. Blocks should not be stacked for at least two days after casting to eliminate any damage to the corners and edges. After curing, the blocks should be dried for about four weeks before use. Stacking during this period should be done with cells horizontal.

(7) Improper compaction should be avoided.

(8) The compressive strength of the blocks should be at least 28 kg./sq. cm. at the age of 28 days. However, greater strengths on leaner mixes are possible if good care is taken to see that the blocks are manufactured properly.

Laying of Concrete Masonry

Walls :

It is essential to check whether any cutting of blocks is necessary or not because concrete blocks are available in definite sizes. This is done by laying a course of blocks without any mortar and fitting the same within the desired length of the wall. The blocks should be laid with proper clearance to allow for mortar joints.

Next a mortar bed is spread on the foundation concrete and is evelled to have sufficient but uniform thickness of mortar everywhere. The corner block is laid first and placed in position accurately. Mortar is applied to the ends of the other blocks and are placed and pushed against the corner block in turn. After a few blocks are laid, the level of the course is checked. It may be necessary to tap some of the blocks or to put extra mortar underneath them but it should be ensured that every block has at least about 2 cm. mortar below it. The first course is also to be carefully put in plumb. The level and verticality of the first course is checked carefully so that the upper courses are brought up regularly in line and level with it.1

The succeeding courses are laid in such a manner so as to break the joints vertically. Mortar is applied to the bottom of the concrete block at the horizontal face members only. For vertical joints, the mortar is applied to the projections at the sides of the block. These courses are built first at the corner only and every time they are checked vertically and horizontally. A storey rod is used to guide the courses. For building the portion in between the corners, a chord is spread between the two horizontal end blocks of a course and the blocks are laid in between as described above. Mortar should not be spread for longer distances ahead of the block which is being laid so that it may not get dried when the block at that particular position is fitted. Excess mortar is trowelled off from the face of the joint. The final closing block is fitted carefully. If it is to be cut, the same should be done accurately and the cut edges should be true and square. All the four vertical edges of the block and the edges of the opening are covered with mortar. This block is then pushed into the opening and fitted into place.

The face of the masonry may be pointed by running a tool along the joints after the mortar is stiff but before it has set. The

(3) *Slumped finish* : A concrete of desired slump is prepared so that when the forms are removed, the blocks settle somewhat. This produces a rough surface on the exterior and blocks of various dimensions are used in the face work.

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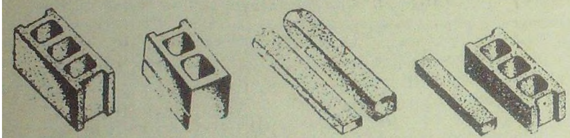

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The face of the masonry may be pointed by running a tool along the joints after the mortar is stiff but before it has set. The surface of the joint may be concave or V-shaped. Raked, flush and strucked joints are not recommended. The types of joints which can be used are weathered, V-shaped or concave as they shed off water easily. Pointing may also be done.

The following points should be noted for the construction of walls and corners in addition to what has been described above.

(*i*) Only well dried blocks should be used in the construction. The blocks should not be drenched in water before laying in the walls. Only sides of the joints should be slightly wetted.

(*ii*) Blocks for this work should have less than 10 per cent absorption for external walls and less than 15 per cent for internal walls. When blocks with higher water absorption are to be used, they should be painted with water proof materials.

(*iii*) The mortar used shall not be stronger than the concrete mix used for the manufacture of blocks. Cement, lime and sand mortar of 1 : 1 : 10 mix is preferable.

(*iv*) The joints should be about 5 mm. to 1 cm. in thickness.

(*v*) When the difference in the height of two adjacent walls is more, *e.g.*, when a main wall meets a compound wall, the two walls should be separated by a joint.

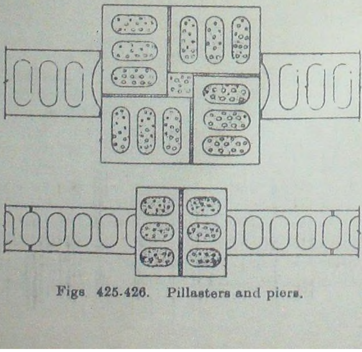
(*vi*) The corners of hollow concrete block walls crack due to thermal expansion. In the case of long walls there will be cracks in the centre of the wall. Solid concrete blocks or hollow blocks filled with concrete are used at the junction of walls to avoid cracking.

Controlled joints with metal stirrups may also be used as an alternative.

(*vii*) At the junction of load bearing and non-load bearing walls, corrugated metal ties are used. The joints between two walls are not inter-bonded.

Columns :

Whenever large bearing surfaces are needed, columns are used.



Figs. 425-426. Pillasters and piers.

They can form an internal unit with the wall or can be built separately. They are made of standard stretcher and corner blocks or other special shapes are used. The hollows within the blocks may be filled with concrete.

Window and Door Openings :

The blocks used in jambs should have one hollow near the opening which should be filled with concrete. The door and window frames are screwed to wooden plugs left in the masonry and fixed in the lintel with small dowels of mild steel. Under the windows and doors, a course of solid concrete block masonry is laid which extends into the adjacent walls to a distance of at least 30 cm. on either side. Alternatively a precast concrete sill of solid section may be used. Lintels are made of hollow channel shaped blocks filled with concrete and having steel reinforcement at their bottom.

Expansion Joints :

The masonry is liable to crack due to unequal stresses created on account of the expansion and contraction of the block. Hence controlled joints are introduced at definite intervals (5 to 10 metre) These arrest the movement of the concrete masonry units. They can be placed at the junction of load bearing and non-load bearing walls or at the junction of walls and columns or at other suitable places. There are many types of controlled joints used. At each joint, an elastic compound consisting of a mixture of chalk, sand and linseed oil is used. This is covered with cement to match the colour. The thickness of the joint is 5 to 10 mm. Two G.I. strips 15×5 cm. in size should be provided in every alternate joint for bond with the main walls.

Reinforced Walls :

Reinforcement is provided at the horizontal joints for developing higher strength in walls. Further expansion cracks which occur on account of moisture and tempera ure changes are reduced. Two horizontal bars of 6 mm. diameter are placed one each on the face of the wall. This reinforcement may be restricted to top and bottom courses of window openings, door openings, etc. Welded steel mesh can also be used.

Water Proofing of Exterior Walls :

Walls built of sound concrete blocks are able to resist free leakage of water but leakage may occur through the joints. Two coats of neat cement slurry or 1 cm. thick plaster of 1 : 4 cement mortar is helpful in water proofing the masonry. For blocks cast on a vibrating machine, painting only will be sufficient. Painting on plastered walls should be done on completely dry walls. When blocks of greater absorption are used, two coats of cement slurry should invariably be used. Dampness can also be reduced by providing suitable drip courses, proper window sills and by making the joints properly.

The recommended thicknesses in cm. of hollow concrete block walls for the various floors is given in the table below :

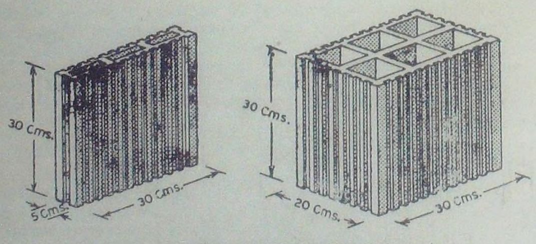
No. of floors	Foundation and Basement	Ground floor	1st	2nd	3rd
—	30 or 20	20	—	—	—
1	30	20	20	—	—
2	30	30	30	20	—
3	40	40	30	30	20

Hollow concrete block masonry is used in domestic buildings, schools, churches and other public buildings. It is specially suitable for low cost houses.

Structural Clay Tile Masonry

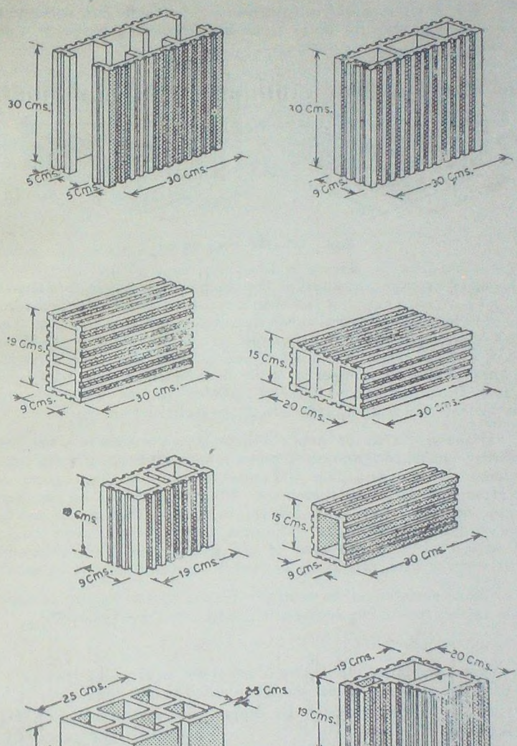
Structural tile is light in weight, fire proof, resistant to rats and termites and is free from decay caused by the contact with water or chemicals. The use of these tiles reduces the maintenance and constructional costs. Structural clay tile is a term referred to the various sizes and kinds of hollow and practically solid structural units. They are moulded from clay or diatomaceous earth. The latter gives very light tiles which can be easily cut but possess less crushing strength. These tile units are used to build foundations, walls, partitions, floors and other structural members.

The various types of structural clay units are shown in figures 427-438.



Figs. 427-428. Different types of structural clay units.

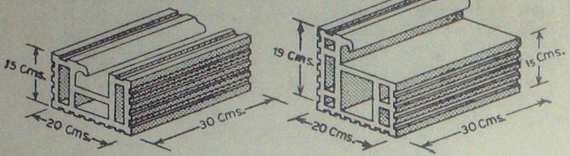
It should be noted that these units can be used while being laid on end or on side and are designed accordingly. Load bearing tiles are made in various grades, *e g.*, load bearing (L.B.) and extra load bearing (L.B.X,). Specifications have been framed in various countries



Figs. 429-436. Typical shapes and sizes of structural clay units.

to account for the various physical properties of the tiles. Generally absorption is not greater than 15 per cent for good quality tiles. The compressive strength based on gross area in kg./sq. cm. is about 100 for tiles laid vertically on end and about 50 for tiles laid on sides. For non-load bearing walls, these limits are relaxed.

The shell of a tile constitutes the four sides surrounding the hollow interior and the webs serve as partitions between the cells.



Figs. 437-438. Clay units.

The overall average thickness of the shells should not be less than 2 cm. and of the web not less than 1 cm. for end construction tiles. The shell for side construction tile should not be less then 1 cm. The width of any cell in the side construction tile, measured in the direction of wall thickness, should not exceed $4\frac{1}{2}$ times the average overall thickness of either the upper or lower bearing shells. All tiles must be free from laminations, cracks, blisters, surface roughness or other defects which would interfere in the construction.

If plaster is to be applied directly to the sides of a tile, the surfaces should be grooved to provide keys for holding the plaster in place. Common and face tile units may have grooves on one or two faces and both ends grooved. Groove should not be less than 3 m.m. and not more than 2.5 cm. in depth. They should not be more than 2.5 cm. in width. The area covered by grooves should not exceed 50% of the area of the scored faces. For walls and partitions where no plastering is needed, smooth tiles may be used.

Glazed surfaces can be obtained for the tiles in various colours, Other finishes resembling rocks, bricks, etc. can also be obtained.

Laying of clay tile units :

This is similar to the laying of concrete hollow block masonry. However, the following points should be noted in this connection :

(*i*) All the units should be dipped in water before being laid in mortar.

(*ii*) The corner tile is laid on end.

(*iii*) Mortar is applied to the inner and the outer faces in the horizontal joints and to ends.

(*iv*) Special closer units can be used for the corners.

(*v*) Columns or pillasters are built of hollow tile units arranged suitably and special blocks are cast. The courses are bonded by providing units which connect the wall with the column in alternate layers.

(*vi*) The jambs of doors and windows are made of special blocks. Lintels are used for bigger openings. They are made up of units which are commonly used for the corners. The concrete is filled into the cores and reinforcement is passed through the lower cells.

Walls of structural clay are built of units which are of load bearing or non-load bearing type having one or many cells. These units may be glazed or natural, rectangular, square or curved. Tile walls are used for residences, silos, poultry houses, etc. These walls are easy to construct and can bear heat and moisture effectively. Partitions are made of smaller units and are frequently used in construction. Similarly hollow tiles can be used for floors, roofs and foundations.

QUESTIONS

1. What are the various types of concrete block masonry and the finishes which can be adopted ?

2. How are the concrete blocks manufactured and laid in the walls ?

3. What are the precautions to be kept in view while constructing concrete block masonry ?

4. What are the advantages of hollow tile block construction ?

What are the special precautions to be taken for this type of masonry work ?

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6

PARTITION AND CAVITY WALLS

Partition walls are thin internal walls whose main function is to divide the space within a building into rooms or areas. These can be load-bearing or non-load bearing but with the sole purpose of division with strength and stability, sound insulation and fire resistance. When a partition wall is required to partially support girders over it, it is called a load bearing partition wall. A portion of the floor load, which the girders carry, is transferred to the partition wall.

Conventional partition walls are of the non load-bearing type and they are used to economise in space, weight and reduce cost. They do not have to support any other load than its own dead weight.

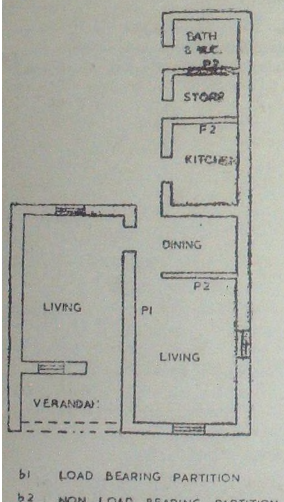


Fig. 439

Types of Non-bearing Partitions

The various types of such partition walls are :

(1) Brick-partitions.

(2) Hollow block partitions.

(3) Glass block partitions.

(4) Concrete partitions.

(5) Metal Lath partitions.

(6) Solid plaster partitions.

(7) Corrugated sheet partitions.

(8) Wooden partitions.

They are described in the following articles :

(1) *Brick partitions* :

They are of the following types.

(*a*) *Plain Brick Type* : These partitions are 10 cm. thick and are constructed by laying bricks as stretcher courses. Sufficient care should be taken in laying the bricks properly so as to develop full strength. These partitions cannot take a heavy load and hence their height is restricted. In U.S.A., partition walls of 5 cm. thickness are also used to enclose rooms of small dimensions and where the partitions are not subjected to lateral forces, *e.g.*, load due to coal or grain. Openings in brick partitions for doors, etc., must have lintels over them.

(*b*) *Reinforced Brick Partitions* : These are stronger than the ordinary plain brick partitions. The bricks are reinforced with iron strap about 2.5 cm. wide and 1.5 mm. thick which is laid horizontally every fourth or fifth course. If lime mortar is used in the construction of the partitions, the course containing reinforcement must be laid in cement mortar. Instead of hoop iron, two mild steel rods about 6 m.m. dia. can also be used. Sometimes a wire mesh is used as reinforcement for these partitions.

(*c*) *Brick Knogging* : This type of partition wall consists of brickwork built up within a framework of wooden members. This is described on pages 102-103.

(2) *Hollow Block Partition Walls* :

Structural clay tile units or hollow concrete blocks described in chapter V can be used for the construction of partition walls. Tile partition walls are similar to the tile walls except that their thickness is less and varies from 5 cm. to 10 cm. depending upon the type of partition, attachment of any fixtures and sound insulation desired. Because of large amount of air within the cells of the clay tiles, they are good insulators against heat. Tile partitions are used when they are supported by steel or concrete beams or concrete floors. They should never be used when they are supported on

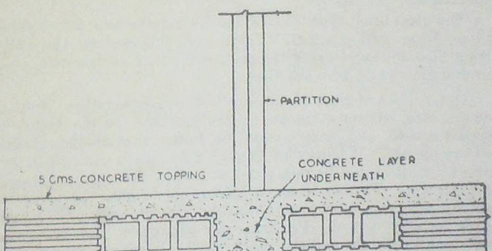


Fig. 440. Support for a partition on hollow tiles.

wooden floors or wooden frames. When a partition is supported by a tile floor, there should be a solid concrete foundation below it. This is needed because the tile, if used as a foundation, will not bear the weight coming over it. (*See* Fig. 440).

The laying of these partition walls is similar to that of the structural clay walls. If tile partition is laid from one wall to the other and has no corners, the two ends are built up for three or four courses and the in between portion is laid as stretcher units. The disadvantage of structural clay tile partition with respect to solid brick partition is that the fixing of any attachment with the partition is difficult. Whenever door and window openings occur, lintels should be provided. These lintels should be made up of structural clay units filled with concrete.

Hollow concrete blocks are also used for partitions. Light weight concrete blocks can be very suitable for insulation.

(3) *Glass Block Partition Walls* :

Glass blocks can be used in the construction of partition walls because they provide good architectural effect and also admit light. Further the glass block partitions act as insulated walls and prevent a passage of sound or heat to a great extent. Glass partitions are easy to clean and maintain.

Glass blocks can be made of different thicknesses and sizes. They are usually made square, of side 14 cm. and 19 cm. Sometimes the size 20 × 12 cm. is also made. The thickness is normally 10 cm. Different surface patterns can be developed by fluting the inner and outer surface. The jointing edges are painted internally and sanded externally to form a key for mortar.

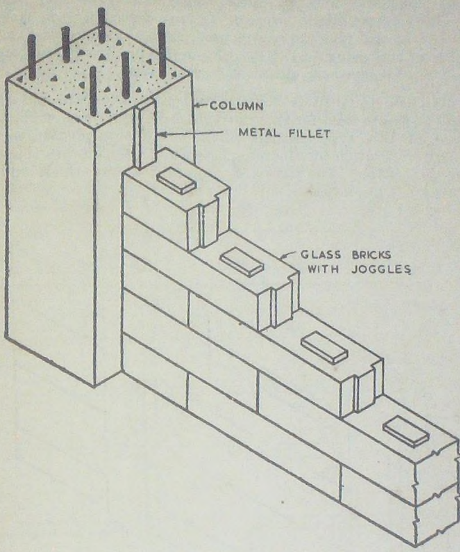
They can be of glass brick type which act as individual units and are interconnected with joggled joints. Another type is to have a glass block with hollows inside. A third type is to have glass blocks with hollow spaces, some of which can be filled with concrete. Horizontal and vertical steel rods are placed in between to act as reinforcement.

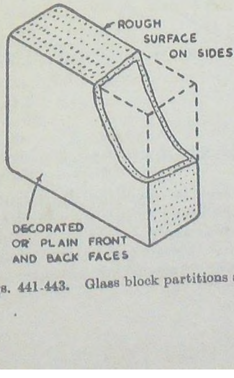
The glass brick type blocks having joggles are fitted to each other as shown in figure 441. They are connected to the wall by fixing a fillet to it and fixing the glass blocks in such a manner that their end grooves fit with the fillet.

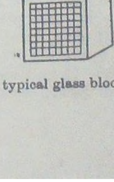
Other types of glass blocks are connected together with concrete and steel bars or with cement lime mortar. In the latter case fine sand is used and care should be taken that all the joints are filled completely. If blocks are greater than 25 cm. in height, every horizontal joint should be reinforced with iron stirrups or expanded metal stirrups. For blocks about 15 cm. in height, this reinforcement can be placed after every third or fourth course. The joints can be suitably tooled. Provision for expansion can be suitably made along the jambs and the head of each panel. Expansion joint strips about 1 cm. thick made of cork, fibre glass or other suitable material should be placed in the expansion joint. Panels which are greater than 16 square metre in area should be provided with structural stiffening members.

Loads other than the self weight of the partitions hould not be transmitted to the partitions. The joints may not be broken vertically or horizontally.

Foam glass can be used in the partition walls for insulating rooms from sound and heat transmissions. Thus they are specially suited to air conditioned buildings. Foam glass can easily be cut and worked with common masonry tools. The pieces can be joined







Figs. 441-443. Glass block partitions and typical glass blocks.

together with hot asphalt or asphaltic cements and can be plastered with a suitable medium. For insulation purposes, foam glass can be used as a core between the internal and external covering or the wall is built first and covered with a layer of foam glass which is suitably finished. Pre-fabricated construction can also be done with foam glass. Many types of facing materials, *e.g.*, asbestos cement board and plywood can be used for facing purposes. Concrete foam glass panel using 5 to 10 cm. of concrete on inside and outside and a core of 5 cm. foam glass is commonly used.

(4) *Concrete Partition Walls* : Precast concrete slabs and special concrete posts are used for the construction of partition walls. The partition of this type consists of one or two thin precast concrete slabs kept in position by concrete posts which are suitably shaped to receive these slabs. The slabs are generally 4 cm. thick and the posts are suitably designed.

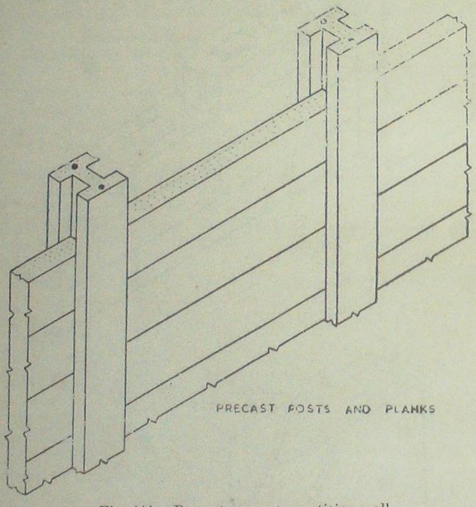
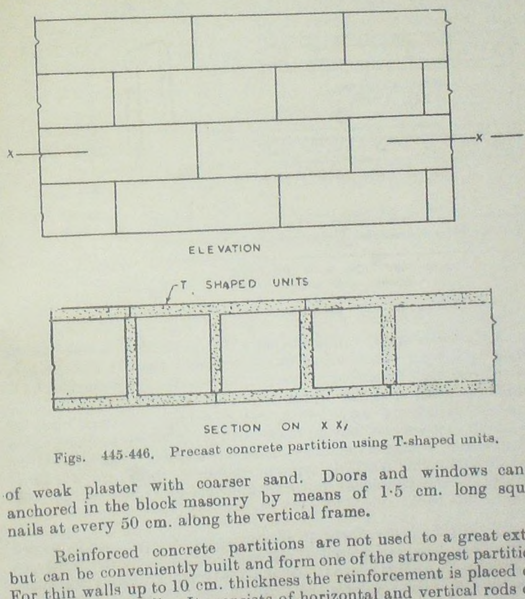


Fig. 444. Precast concrete partition wall.

T or L-shaped sections can be used for the construction of partitions. At every point the joint between the web and the opposite vertical face (skin) is overlapped by the solid shoulder of the L or T which is placed from the opposite face in the wall in alternate courses. A break in bond and interconnection of outer and inner facing of the walling is necessary.

Foamed concrete blocks can be used for the construction of partitions. The thickness used varies from 8 to 10 cm. The blocks are made in density of 6 kg./cu. metre. These blocks can be easily sawn with ordinary saw to suit the various positions. The mortar used in the construction is lime cement mortar or weak cement mortar. Rich cement mortar, if used, will give cracks along the joints. The mortar may be of 1 : 6 cement sand mix or 1 : 1 : 6 lime, cement, sand mix. Joints in the walls with foamed concrete blocks should be as thin as possible and never greater than 1 cm. The partition walls made of these blocks can be bonded with external walls by driving 15 cm. long square nails at every 30 cm. spacing in the external walls. For partitions exceeding 8 metres longitudinally, it is desirable to lay two 6 m.m. dia. bars longitudinally at half the height of the wall. No plastering is necessary for internal walls. The surface can be given a coat of coloured cement. If plastering is desired, the same can be done in two layers, the first coat being



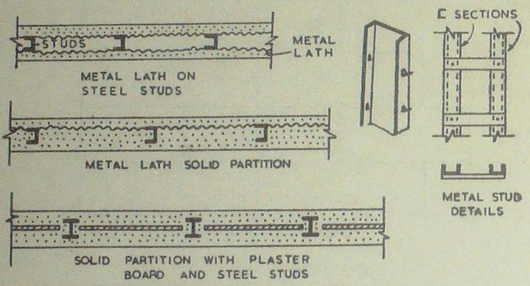
Figs. 445-446. Precast concrete partition using T-shaped units.

of weak plaster with coarser sand. Doors and windows can be anchored in the block masonry by means of 1·5 cm. long square nails at every 50 cm. along the vertical frame.

Reinforced concrete partitions are not used to a great extent but can be conveniently built and form one of the strongest partitions. For thin walls up to 10 cm. thickness the reinforcement is placed centrally in the wall. It consists of horizontal and vertical rods or a woven mesh. They are used where greater resistance of the partition is necessary.

(5) ***Metal Lath Partition Walls*** : Solid partitions are constructed by placing 2 cm. or 2.5 cm. channels vertically and fixing metal lath to it. The metal lath may be fixed on one side and the plaster applied on both the sides (*see* fig. 448). The lath is placed with its greatest dimension horizontally. The sheets are lapped at least 2.5 cm. on the ends and are fixed with the wire to the channel at 15 cm. interval. The channels are placed by driving holes into the floors and the roofs. For wooden floors and roofs, these channels can be bent and fixed by nailing.

Hollow partitions can also be made by fixing the metal lath to these steel channels on both sides. These channels are spaced at 30 to 40 cm. apart. Special cold formed channels, made up of sheet steel and bent to the required shape are used. They are from 5 to 10 cm. deep and may have projections to which the lath is fixed. Built up channels can also be used. They consist of two small channels braced by flat iron.

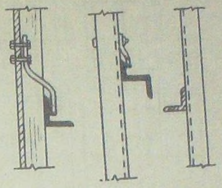


Figs. 447-452. Metal Lath Partition Wall Details.

Metal laths are of various types. The expanded metal lath is formed by cutting sheet metal in such a way that it will cover a greater area when expanded. Diamond or rectangular meshing are suitable for small spacings whereas ribbed lath is used for greater spans. Wire lathing may be woven or welded. It has a mesh of 1 to 1.5 cm. square and may be made with or without stiffners. The stiffners are V-shaped metal sections or circular rods spaced at about 20 to 30 cm. Various types of patented laths are available for different constructional purposes and are described at suitable places in this book.

(6) *Solid Plaster Partition Walls* : One type of solid plaster partition wall has been described above. Solid plaster partitions can also be built of plaster boards fixed on metal channels. They are about 5 cm. thick and the channels are 2 to 2.5 cm. in width. Channels act as supports and hence are spaced at about half metre interval. The surfaces can be rendered with plaster for a smooth finish.

(7) *Corrugated Sheet Partition Walls* : Corrugated steel sheets or corrugated asbestos cement sheets are used to a large extent for the construction of partitions. They are specially suitable for cheap type of construction and in factories. These sheets are fixed to a framework of wood or iron. The sheets can be fixed with different types of attachments to the horizontal and the vertical members of the framework. The various types of fixings to the horizontal members of iron are shown in figures 453-455.



Figs. 453-455. Supporting methods for corrugated partitions.

For fixing to wooden members, special screws and washers are used. Openings for doors, etc., can be easily left in these partitions. If it is necessary to have a smooth surface on one side, plywood boards can be fixed to the framework.

Patented asbestos cement slabs consisting of two sheets 1 cm. thick attached to an inner corrugated sheet about 5 m.m. thick are used wherever flat surface is desired. These sheets are jointed in cement mortar and can be painted or distempered. They afford durable, fire resistant, insulated and light weight partitions. Asbestos cement sheets having various textures and finishes are also available.

(8) *Wooden Partition Walls* : These may be divided into two types :

(*a*) Common partition walls.

(*b*) Trussed partition walls.

Common partition walls consist of a framework of head, sill and upright members. The uprights are tenoned into the head and sill. Solid and uniform support for the sill members must be ensured, hence they should be placed just above the girders of a floor or at right angles to the joint of the flooring underneath. The struts are usually 10 to 8 cm. ×8 to 5 cm. in size. They are placed at suitable intervals depending upon the type of facing to be used. The struts are stiffened by horizontal pieces of timbers called noggings. These are of the same width as the struts and are about 5 cm. thick. The width of head and sill is also equal to that of the strut. The head is fixed to the ceiling joint and the sill is fixed to the flooring. Sometimes these members are fitted into the walls which is not necessary if they are securely fixed as described above. If any opening is to be left, it should be ensured that the vertical and horizontal posts for the doors are sufficiently strong and are joined securely. The partition framing thus built can be covered by a layer of plaster on lath on one or both sides or by fixing boarding, plywood sheet, etc. These partitions are very light and need

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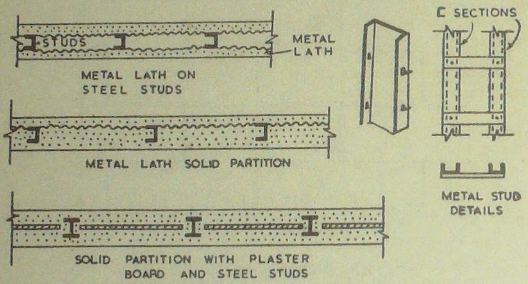

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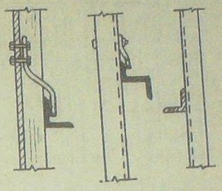

Figs. 453-455. Supporting methods for corrugated partitions.

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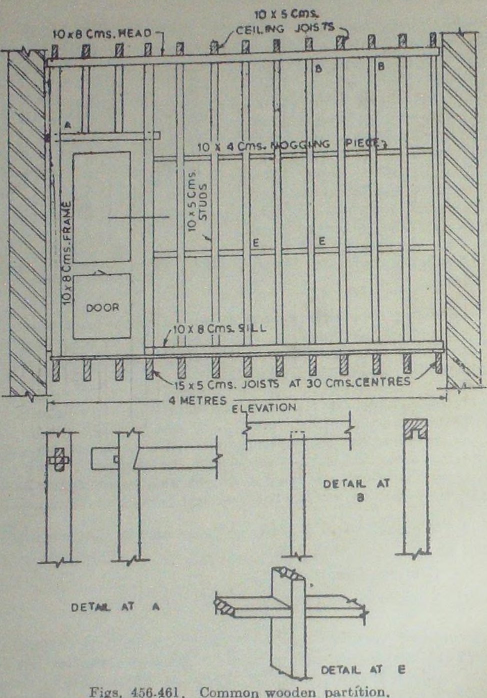
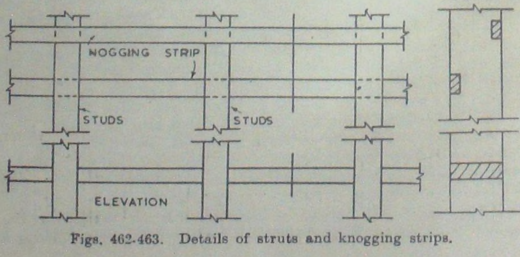


Figs. 456-461. Common wooden partition.



Figs. 462-463. Details of struts and knogging strips.

not have any supporting wall below. However, they cannot support any loads or cannot bear any big fixture.

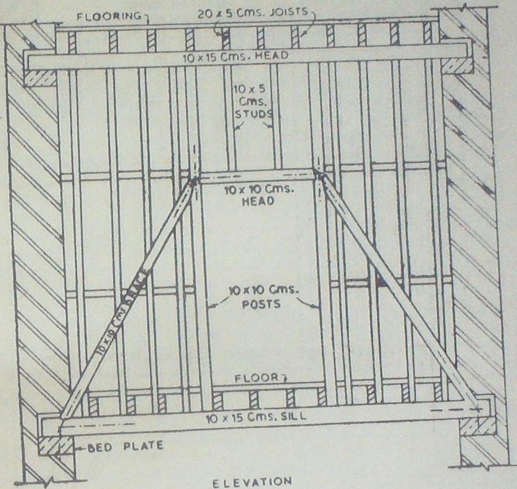


Fig. 464. Trussed partition.

Trussed partition walls are required to be constructed where there is no other means of supporting the partitions except at their ends. They are designed to support their own weight and in addition any floor loads coming on them. The main object of trussing is to arrange the members of the frame in such a manner that the loads are transmitted through the members directly on to the supports and a rigid framework is ensured. Hence triangular frameworks are desirable. A simple type of such partition is shown in figure 464. It consists of a sill, a head, inclined braces, vertical studs, knogging pieces and posts for the door opening. The joints may be held together with iron straps or iron bolts ; instead of knogging pieces, knogging strips may be used for strengthening the partition. The ends of the sill and the head rest on suitable bedding stones on the walls. The joint at the head of the brace and the door post and also the joint between the brace and the horizontal member is shown in the figure.

For partitions which have to carry floor loads also, the trusses have to be designed suitably and the number of braces is increased (*see* fig. 465). Further a horizontal member is added in between the sill and the head. This is called 'intertie'.

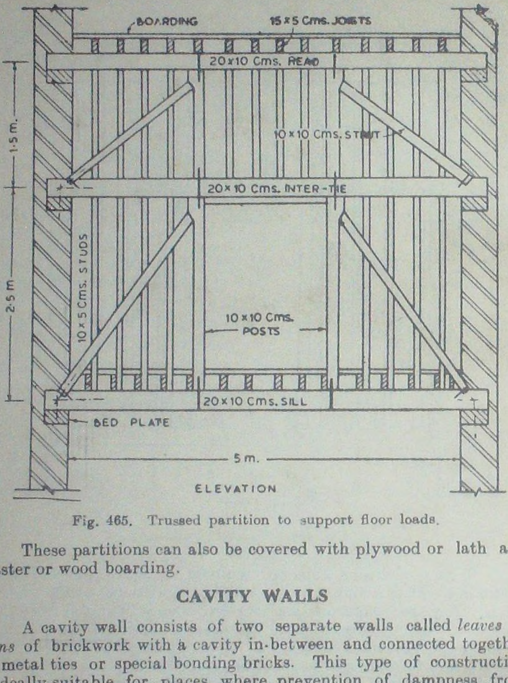


Fig. 465. Trussed partition to support floor loads.

These partitions can also be covered with plywood or lath and plaster or wood boarding.

CAVITY WALLS

A cavity wall consists of two separate walls called *leaves* or *skins* of brickwork with a cavity in-between and connected together by metal ties or special bonding bricks. This type of construction is ideally suitable for places where prevention of dampness from exterior, high insulating value against heat and sound and economy are desired. In a country like India, where the climate is either hot and/or hot-humid, cavity wall construction is very desirable for conditions of comfort, health and preservation of the building against dampness. However, it is being used to a limited extent till today.

The two leaves of a cavity wall may be of equal thickness or the thickness of the inner leaf may be increased to meet the desired structural requirement. The inner and outer leaves of the wall should not be less than 10 cm. in thickness throughout the height of the wall.

For a cavity wall to be effective, it is absolutely essential that the inner leaf is entirely disconnected from the outer leaf, except for ties. This is done by providing a cavity of uniform width, normally 5 cm. but not exceeding 7·5 cm. It is, however, at the openings for doors and windows, where special precautions are necessary.

The inner and outer leaves of the wall are securely tied together with suitable bonding ties of adequate strength. These ties should be of such a shape that water from the outer wall does not pass into the inner wall. Strong non-corrodable ties of wrought iron or mild steel thoroughly galvanised, dipped in hot tar and sanded are used. Copper or bronze metal ties are used whenever excessive corrosion is anticipated. These ties can be of wire type, the ends of which are twisted together and turned downward to prevent the transmission of water from the outer face to the inner face. Flat sections can be used of twisted or loop shape (*see* figs. 468-71). These ties should be placed at intervals not exceeding 1 metre horizontally and 40 cm. vertically. Special bonding bricks of terracotta are also sometimes used as ties.

A cavity wall is built with an outer facing of specially selected face brick and the inner leaf is made of common bricks. The ties are placed wherever the joints coincide. The 10 cm. walls are constructed in stretching bond. However at certain intervals half headers may be introduced to improve the appearance.

The cavity wall may extend down to the concrete foundation which means that water in the soil can pass into the inner face of the wall wherever the brickwork in exterior wall is not constructed properly. This would cause dampness in the floor. To prevent this, the cavity is taken only about 10 cm. below the damp proof course of the external wall and below that level the wall is built of a solid section. If water is liable to collect, the course of bricks in the external face just below the damp proof course should be laid with hollow joints to enable this water to get out. These hollow joints may be left at about 1 metre interval along the length of the course. As an alternative small weep holes may be left.

The damp proof course for these walls should be about 15 cm. below the ground level.

Whenever wooden floors are used along with the cavity walls, it is essential to use only sound and seasoned timber otherwise dampness from the cavity may cause dry rot. The ends of joints bearing into the cavity walls should be creosoted and a similar treatment should be given to wall plates resting on these walls.

The following points about the cavity walls should be noted :

(1) The horizontal damp proof course should be built in two separate widths under each leaf of the wall and divided by cavity.

(2) During construction, no mortar or any other thing should get accumulated in the cavity.

(3) The cavity should be free from any projections. Any mortar sticking excessively to the walls or ties should be promptly

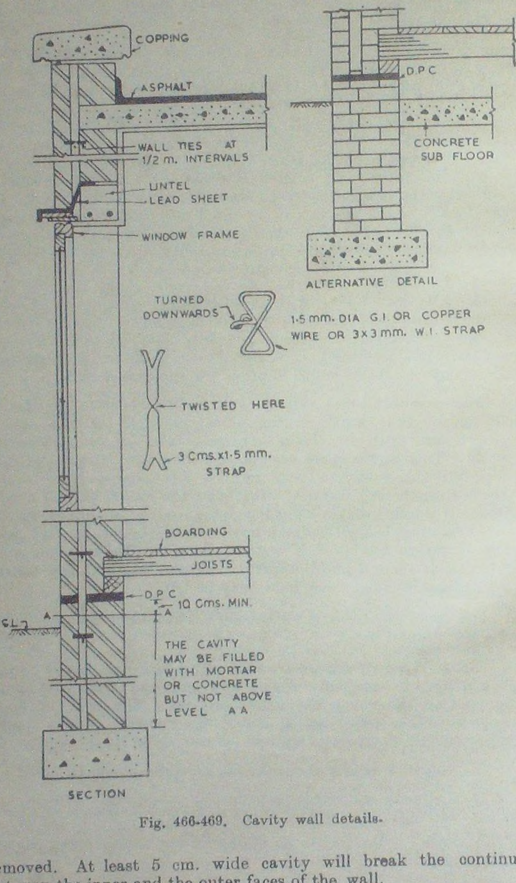


Fig. 466-469. Cavity wall details.

removed. At least 5 cm. wide cavity will break the continuity between the inner and the outer faces of the wall.

(4) The contact between the inner and outer wall should be least.

(5) Whenever openings are provided in the wall, *e.g.*, for windows and doors, heads of openings should be carefully attended to for damp prevention. Ways and means of preventing damp are described below.

(6) Ties must be of rust proof material and should be able to prevent transmission of water from inner face to the outer face.

Advantages of Cavity Walls :

The advantages of cavity wall construction are :

(1) *Damp prevention* : A cavity wall prevents dampness in a better manner than an equivalent brick wall. Only thick external walls can effectively prevent the movement of dampness. A 20 cm. solid brick-wall will not prevent the movement of dampness from the outer to the inner face but a cavity wall made up of 10 cm. inner and outer leaves and a 7·5 cm. cavity in between will be able to prevent dampness effectively. The thickness of the solid masonry constructed in both the cases is the same.

(2) *Insulation* : Air being a bad conductor of heat, a cavity wall reduces the heat transmission from external to internal faces or *vice versa*. Thus the rooms will be warmer in winter and cooler in summer. The sound insulating value of cavity walls is also greater than that of a solid wall.

The cavity may be taken as a part of thickness for walls whenever this thickness does not exceed 20 cm. otherwise the cavity is to be excluded from the wall thickness. In certain cases only thicker face of the wall is considered as the load bearing wall and is only taken into account for the calculation of wall thickness.

QUESTIONS

1. What is the difference between a bearing and a non-bearing partition ? Briefly describe with sketches the various types of brick partitions.

2. What are the advantages of concrete partitions ? Describe with sketches the various types of precast concrete partitions.

3. Write short notes on :
   (*i*) R. C. C. Partitions.
   (*ii*) Metal Lath Partitions.
   (*iii*) Solid Plaster Partitions.
   (*iv*) Corrugated Steel Partitions.

4. What are the types of wooden partitions commonly used ? Describe with sketches the construction of a trussed partition.

5. What are the advantages and disadvantages of cavity wall construction ? Draw a section through an external cavity wall of a building showing clearly all details including the prevention of damp entry at the windows.

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7

ARCHES AND LINTELS

An arch is a structure comprising of a mechanical arrangement of wedge shaped blocks, upholding each other by the mutual pressure of their own weight and maintained in equilibrium by the resistance of the supports or abutments and designed to support the superincumbent load of the wall. The materials used for the construction of arches are bricks, stones and concrete blocks. Steel and reinforced concrete arches are, however, built of a single unit and are of a rigid type. They are used to span bridges and are not covered in this chapter.

Terms Used

(1) *Arch Ring* : This is the curved ring of masonry forming the arch.

(2) *Span* : This is the width of the opening which is covered by the arch.

(3) *Voussoirs* : These are wedge shaped blocks of masonry of which the arch ring is made of.

(4) *Key Stone* : The central voussoir at the highest point of the arch.

(5) *Extrados* : The outer curve of the arch.

(6) *Intrados* : The inner curve of the arch.

(7) *Soffit* : The inner or under surface of the arch.

(8) *Crown* : The highest part of the extrados.

(9) *Abutment* : The portion of the wall which supports the arch.

(10) *Skewbacks* : These are the inclined or splayed surfaces of the abutments prepared to receive the arch and from which the arch springs.

(11) *Springing Points* : The points at the intersection between the skewbacks and the intrados.

(12) *Springing Line* : The horizontal line joining the two springing points.

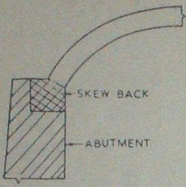


Fig. 470.

(13) *Springer* : The lowest voussoir immediately adjacent to the skewback.

(14) *Haunch* : The lower half of the arch between the crown and a skewback.

(15) *Rise* : The vertical distance between the springing line and the highest point of intrados.

(16) *Spandril* : The triangular space between the back of the arch ring and a horizontal plane tangent to it at the crown.

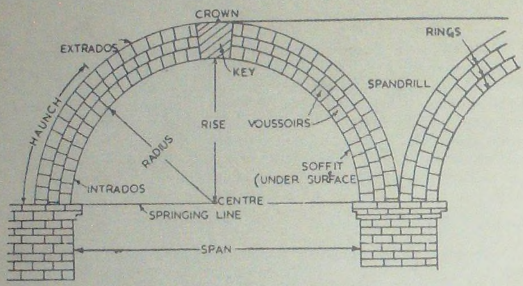


Fig. 471. Terms used in Archwork.

Stability of Arches

The arch remains stable due to the friction between the surface of voussoirs and the cohesion of the mortar. The various ways in which an arch can fail are :

(1) The crushing of the material.

(2) The sliding of one voussoir on another.

(3) Rotation of some joint about an edge.

(4) Uneven settlement of abutments.

An arch will fail in crushing, if the thrust in some part of the arch exceeds the safe crushing strength of the material comprising the arch. For this the dimensions of the voussoirs should be adequate to withstand the pressure coming on them. Usually they are of uniform height, generally $\frac{1}{12}$th of the span but not less than 20 cm. For large spans, the height of the voussoirs may bev aried, less at the crown and increasing towards the skewback.

To safeguard against sliding of one voussoir on another, the angle between the line of resistance and the normal to any joint should be less than the angle of internal friction. Also the depth of the voussoirs should be adequate to resist the tendency of the joints to open and slide upon one another.

To prevent rotation or overturning, the line of thrust or resistance should lie within the intrados and the extrados. Further the line of thrust may be made to cross each joint away from the edge to avoid crushing at an edge.

The abutments of the arch should be sufficiently strong to resist the thrust of the arch due to the superincumbent load and the self weight of the arch. The arch should be symmetrical to avoid unequal settlement of the abutments.

Types of Arches

The intrados is a combination of arcs of various radii and centres or may have one arc with one centre.

One-centred arches are :

(*i*) Semicircular,

(*ii*) Segmental which is less than a semicircle,

(*iii*) Horse-shoe which includes more than a semicircle, and

(*iv*) Stilted which consists of a semicircular arch with two vertical portions at the springings.

The two-centred arch can be of many types, some of them being described below :

(*i*) *Blunt Arch* : In this type of arch, the centres are within the arch itself.

(*ii*) *Gothic or Equilateral Arch* : The radius of the intrados equals the span and the centres are on the springing lines.

(*iii*) *Acute Arch* : In this type of arch, the centres are outside the arch.

Two types of three-centred arches, one in which the central portion of the arch is drawn with one centre and the other two centres are used for making up the ends of the arch, whereas in the second type this procedure is reversed are shown in Figs. 479-480.

In the four-centred arch, the centres for the lower section do not coincide as in the case of three-centred arch.

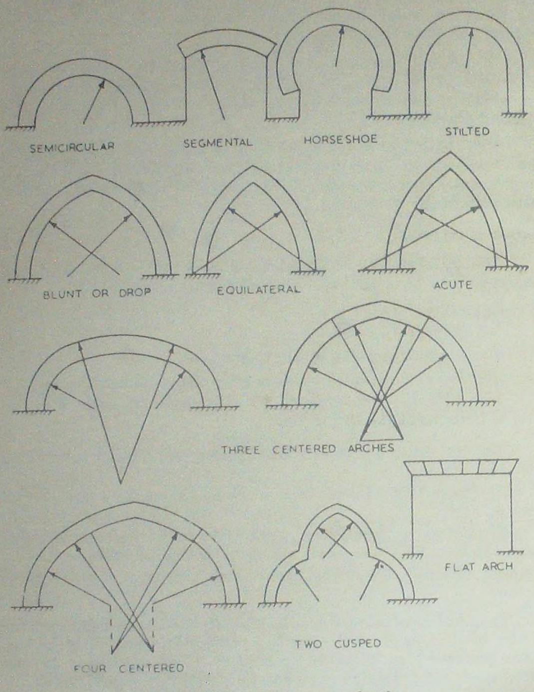
The other types of arches are :

(*i*) *Flat Arch* : In which there is no rise.

(*ii*) *Two Cusp Arch* : Which is used mainly for decorative purposes.

(*iii*) *Elliptical Arch* : Which has an elliptical shape for its intrados.

Some other types of arches, *e.g.*, a relieving arch which is used to take the major portion of the load coming over a lintel (*see* Fig. 484) are also used.



Figs. 472-483. Various types of arches.

Brick Arches

Brick arches may be divided into the following types :

(*i*) Gauged arches.
(*ii*) Axed or rough cut arches.
(*iii*) Rough brick arches.
(*iv*) Brick flat arches.

Primarily this classification is based on the type of bricks used in the arch construction. The varieties of bricks which can be used are :

(*a*) Ordinary standard bricks.

(*b*) Ordinary bricks cut to a wedge shape.

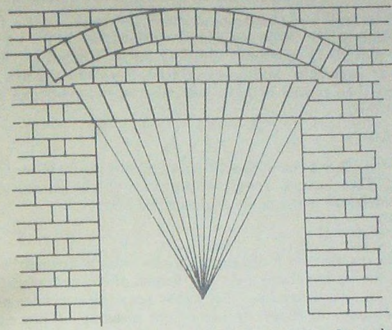


Fig. 484. A relieving arch constructed above a flat arch.

(*c*) Purpose made bricks. These are special bricks of different sizes suitable for various types of arch work.

(*d*) Soft bricks. These are made of diatomaceous earth and can be sawn and rubbed to the desired shapes.

Gauged Arches :

In this type of arches, bricks are cut and accurately dressed to a wedge shape so as to conform to the various voussoir sizes. Truly radial joints are present and they can be made as thin as possible. In order that the bricks are correctly shaped, a full scale drawing of the arch showing the various voussoirs and the joints is

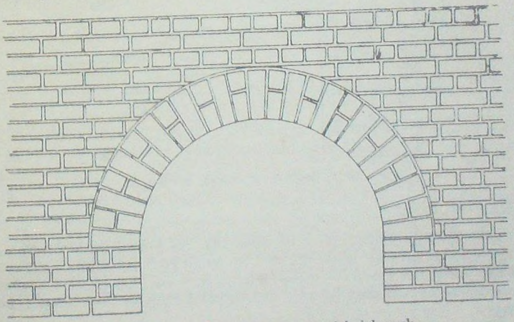


Fig. 485. Semi-circular gauged brick arch.

prepared and metallic templates are cut corresponding to each voussoir. The voussoirs are cut to this shape accurately.

The centering of the arch, as described later on, is erected and each voussoir fitted in its position with mortar. When all the voussoirs are placed in position, the key stone is fitted and hammered slightly. If very thin joints are desired, the voussoirs are dipped in mortar and then placed in position otherwise mortar can be applied with a trowel.

Axed Arches :

The bricks are cut with a bricklaying axe to form wedge shaped voussoirs. They have a rough appearance at the joints. The construction procedure is the same as described above.

Rough Brick Arches :

These are made of ordinary bricks which are neither cut nor dressed to the wedge shape. As the length of the extrados is greater than that of the intrados, the joints near the extrados are wider. The appearance of these arches is not pleasing. They are mostly constructed in half brick rings so as to reduce the thickness of the joints. (*See* fig. 488).

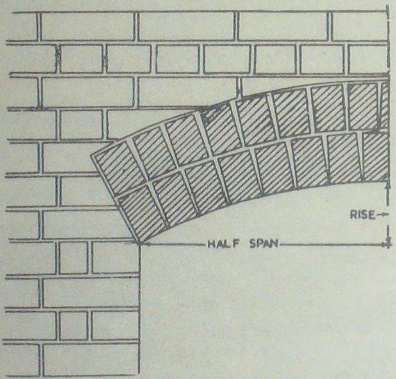


Fig. 486. Segmental rough brick arch.

Brick Flat Arches :

These are constructed of specially cut bricks made to wedge shape and arranged in a manner so as to have flat under surface. All the joints are made to radiate from one common point. Either one brick thickness may be used or half brick may be used for thicker arches.

Whenever loads are excessive, segmental or semi-circular arches can be built above the flat arches so as to reduce the loads on the latter. (*See* fig. 484).

Flat arches can also be used for facework and part of the wall thickness can be supported by a horizontal wooden section (lintel).

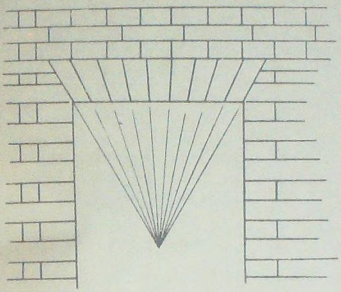


Fig. 487. Flat arch (gauged).

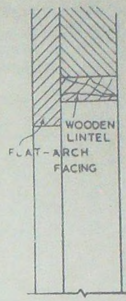


Fig. 488. Flat arch facing.

Stone Arches :

Ashlar and rubble masonry work can both be used for arch construction.

Ashlar arches are made of fully dressed stones cut to wedge shapes. They are constructed with the aid of templates as described under brick gauged arches. Ashlar arches can also be made to give flat arch appearance. The joints are joggled or rebated. Relieving arches can be built for excessive loads.

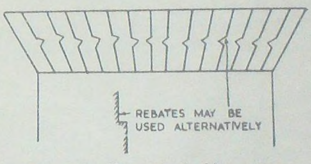


Fig. 489. Flat arch of ashlar masonry.

Rubble arches are made of roughly dressed stones arranged and fitted into a definite arch shape. On account of unevenness of individual stones, the joints are thicker. These arches have lesser strengths than the ashlar arches.

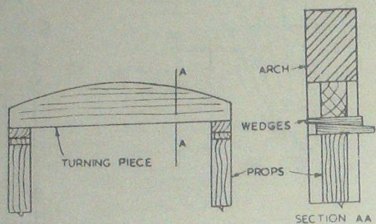
Concrete Arches :

Cement concrete blocks are frequently used these days for arch construction. The blocks are similar to stone voussoirs and are of precast type. These arches are suitable where stones are not available and concrete work can be carried out easily. Arches of reinforced cement concrete are rarely used in buildings. They are used for carrying suspended floors or improving the appearance of very big buildings.

Centering for Arches

A temporary structure is necessary to support the arch till it develops strength. For very small works, mud masonry, made to the shape of the soffit of the arch is built and plastered, over which archwork is constructed. The temporary masonry work can be dismantled later on.

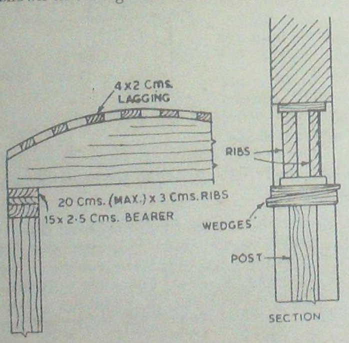
A timber centering is commonly used for arch construction as it is easier to erect, dismantle and can be re-used for a number of arches.



Figs. 490-491. Arch centering for 10 cm. wide soffit arches.

The simplest type of arch centering used for a 10 cm. wide soffit is shown in figs. 490-491. It consists of a thick wooden plank which is shaped to the underside curve of the soffit and is supported by vertical timber posts (called props) at the ends. Wedges are used to tighten or loosen the centering.

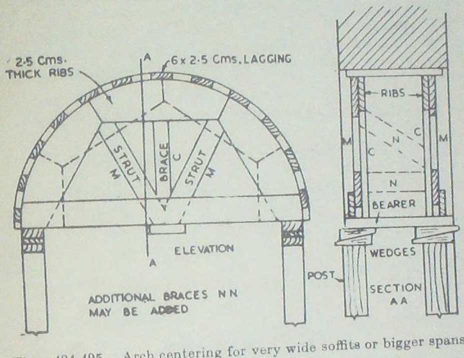
For soffit thicknesses greater than 10 cm., two ribs suitably shaped and connected at the top by 4×2 cm. wooden sections called laggings are used. These are supported by bearers, wedges and posts as shown in the figs. 492-493.



Figs. 492-493. Arch centering for wider soffit arches.

For large spans and very wide soffits, a built up centering of cut wood ribs joined together and shaped to the soffit are used. They are connected by braces and strutted. They are in turn supported on bearers which rest on posts and wedges. Lagging is used to connect the ribs together at the top and also to support the bricks.

After the arch develops strength, the wedges are slightly loosened and the posts and centering removed. For heavy arches, it is necessary to support the posts on boxes containing sand. A hole



Figs. 494-495. Arch centering for very wide soffits or bigger spans.

is kept plugged into the box. When the plug is removed, sand flows out and the post sinks slowly thereby relieving the arch centering.

Lintels

Arches are not preferred these days for bridging openings over doors and windows of a building, because they require strong abutments (walls) to withstand the arch thrust. Instead lintels are commonly built to span the openings and they support the superincumbent load by beam action. They are easy to build and the supporting walls need not be very strong. However, a proper bearing for lintel ends is very necessary. At least 10 cm. length of bearing is minimum and if the span exceeds 1.2 m, the end bearing may be increased to 15 cm. For very long spans, the bearing for the lintel end should equal at least its depth.

As a thumb-rule, the depth of lintel may be kept as $\frac{1}{12}$th of the span or 15 cm. whichever is greater. The depth may be adjusted to course heights of brick or stone.

The following type of lintels are commonly used :

(i) *Wooden lintels* : These are the oldest type of lintels. The opening is spanned by a wooden member over which the masonry is built. Wooden lintels cannot take greater load, are costly wherever timber is not available and are subjected to decay in course of time. They are also not as sound as other types.

(*ii*) *Stone lintels* : Stone slabs are also used for lintel construction. They are not widely used as the type of stone needed for this work is not available at all places.

(*iii*) *Reinforced concrete lintels* : These are most commonly used these days. They consist of a rectangular concrete section, strengthened with steel rods. For small spans, one or two rods at the bottom are sufficient. For larger spans, some of the bars are taken to top at the ends and vertical bars (stirrups) are used in addition. (*See* fig. 497). They may be cast in place or precast R. C. lintels may be used with advantage to accelerate the progress of work.

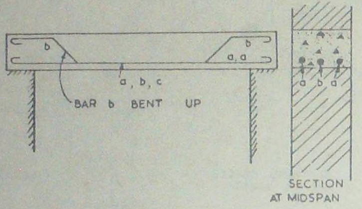
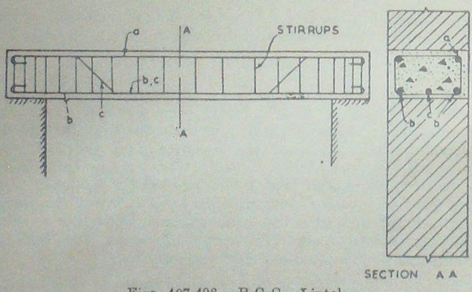


Fig. 496. R.C.C. Lintel.



Figs. 497-498. R.C.C. Lintel.

Reinforced brick lintels : These are used for comparatively small openings and consist of bricks laid in mortar and strengthened with steel bars. Ordinary brick masonry is not capable of taking loads over openings.

QUESTIONS

1. What is meant by the term "arch"? Briefly illustrate with sketches the various types of arches used in masonry construction.

2. What are the various types of brick arches? Briefly describe the construction of a 3 metre span segmental arch for 40 cm. thick wall.

3. Define voussoirs, key stone, soffit, rise of the arch, extrados, skew-back and haunch. Illustrate your answer with sketches.

4. What are the different types of lintels used? Sketch a Reinforced concrete lintel to span an opening 2 metre clear in a masonry wall.

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8

DAMP PREVENTION

Dampness is the presence of hygroscopic moisture. It leads to unhygienic conditions affecting badly the health and comfort of the inhabitants and seriously deteriorating the stability of the building. Protection against damp should form an essential feature for any type of construction.

Sources of Dampness

The sources which create dampness in a building are :

(*a*) Geological and climatic causes :

(*i*) Rain penetration.

(*ii*) Ground moisture rise.

(*iii*) Condensation in buildings due to moisture in the atmosphere.

(*iv*) Drainage of the site.

(*v*) Orientation of the building.

(*b*) Structural causes :

(*i*) Water introduced in the structure during construction.

(*ii*) Defective construction.

(1) *Rain Penetration* : The climate of a country has a great bearing on the extent of dampness in a building. Some of the buildings can withstand a heavy rain shower of a short duration whereas most of the buildings fail to withstand continuous down-pour of rain for a number of days. Wherever such climatic conditions occur, dampness in the building is inevitable.

Direct penetration of rain through the entire area of the wall is rarely seen. Properly constructed walls offer considerable resistance to the penetration of moisture but a rapid penetration of moisture takes place through the capillaries between the mortar joints and the bricks or stones used to construct the wall. Porous external renderings prevent rain penetration to a large extent whereas dense renderings usually crack and are, therefore, sources through which damp can pass. Projecting features of a building arrest water on them and transmit it inside.

Rain penetration is common on the roof components such as valley gutters and dormer windows. Similarly parapets and chimneys collect water. Leakage occurs through flat roofs also and water in this case may penetrate at a crack or at a joint. Hence inspection of the entire surface is essential in this case.

(2) *Ground Moisture Rise* : The soil on which the building is constructed is an important factor for causing the damp or its prevention. Gravel and sandy soils allow water to pass through them very easily whereas soils of clayey nature create damp conditions due to heavy capillary rise. Further if a clayey stratum is covered by a sandy layer it is difficult to drain such soil.

Dampness in floors is primarily due to this reason. The rise of water also causes the soluble salts to be brought up and they get deposited on the walls at the floor level. A sort of darkened surface with irregular patches is created for some height above the floor level.

(3) *Condensation in a building due to moisture in the atmosphere* : Except under very cold climates, condensation is not prevalent in in this country. In the case of dampness due to condensation usually the whole area of walls, ceilings and floors is affected. Deliquescent salts cause condensation, *e.g.*, if sea water containing sodium chloride is used in the construction of a building during humid climate, the surfaces present a damp appearance. Similarly nitrates and chlorides of alkali metals cause dampness.

(4) *Drainage of the Site* : The elevation of a building site has a correlation with the sub-soil conditions and the strata beneath. Houses built on a higher ground can be drained easily and are hence less liable to dampness. Low lying sites cannot be easily drained and present somewhat water logged conditions if impervious soil is present underneath the building. While deciding upon the location of a building, it should be ensured that the site can be drained off easily.

(5) *Orientation of the building* : Every building has some walls which are subjected to a constant splash of water and also some walls are getting less of direct sun's rays. This is due to geographical conditions which create rain falling at a place mostly in one particular direction. The walls which are in this direction and those which also get less sunshine during the hotter part of the day are liable to get damp.

(6) *Water introduced in the building during construction*. Walls while being built are in a very damp condition. This persists for a long period after the wall has been constructed. While the walls get dried, efflorescence of soluble salts results. If this dampness persists, it is to be rectified. Similarly if wet timber is painted, it cannot get dried and hence is liable to be attacked by vermin.

Dampness due to Structural Causes

- Floors
  - Porous concrete laid in base course (Damp rises due to capillary action)
  - Pressure of subsoil water (Rise in water table)
  - Poorly drained subsoil
- Walls
  - Below ground
    - Defective or no D.P.C.
    - Poorly drained earth retained
  - At doors, windows etc.
    - Bedding or pointing of frames defective
    - Shrinkage of wooden frames permitting an entry of rain
  - absence of suitable throating
  - Absence of water bar
  - Porous sill being used
  - General areas
    - Porous materials used
    - Defective finishing
  - Top of wall
    - Defective rain water gutters
    - Defective throating of copings or bad eaves
- Roofs
  - Bad workmanship in plumbing
  - Defective pointing of tiles
  - Insufficient lap of covering material
  - Very flat slope
  - Excessive vegetation on top
  - Use of porous materials
- Chimneys
  - Use of Porous bricks
  - Inefficient jointing near roof

(7) *Defective construction* : Improper construction of the various parts, *e.g.*, fixtures in a building, joints in the roofs, throating of sills and coping, proper jointing of walls, etc., creates dampness by transmitting water. In every component of a building, there are specific points where damp is liable to find its way and it is essential that enough care is taken to see that proper construction is carried out. In the following chart various types of defective constructional causes for some important structural members are described. The extent of dampness along with the time of occurrenee is shown in the table on page 178.

Structural element	*Extent of dampness*	*Timing of occurrence*	*Sources of damp*	*Other causes*
Wall, partitions, ceilings, floors	(*a*) Completely spread	After a certain rise in temp. and humidity of the outside air or of rooms only	Air	Condensation
	(*b*) In patches	During high humidity	Air	Condensation aided by deliquescent salts
	(*c*) One patch	—	From plumbing fittings	Leaking pipes or condensation or cold pipes
Walls	From floor level to some distance above	At all times of the year	Due to ground moisture movement	Absence or defect in D.P.C.
Chimneys	(*a*) From roof downwards	After rain	Moisture penetration.	Absence or defective D.P.C.
	(*b*) Patches with brown colour	Whenever chimney is used	Condensation in side flues.	—
Ceilings	(*a*) Patches	After rain	Leakage in roofs.	—
	(*b*) Wide spread	During cold weather	Condensation	—
Ground Floors	(*a*) Patches	Whenever ground is wet	Ground moisture movement	Defective base
	(*b*) Around edges	—Do—	—Do—	D. P. C. not effective

Effects of Dampness :

(1) Corrosion of metals used in the construction.

(2) Plasters get crumbled and softened.

(3) The floor coverings loose adhesion with the floor bases.

(4) Timber, when in contact with damp gets rotten.

(5) The paints get blistered and bleached. Further they get disfigured.

(6) The stones, bricks, etc. are disfigured on account of a coating of salts which collect on them.

(7) All electrical installations get deteriorated.

(8) Causes unhygienic conditions for the occupants of the building.

Prevention of Dampness

There are various methods of preventing damp. Different types of materials are used for reducing the occurrence of dampness. The methods of damp prevention may be classified as under :

(1) Use of water proofing mixtures or Integral treatment.

(2) Application of water proof surface treatment.

(3) Interposing a water proof membrane.

(4) Use of special constructional devices.

These are described below :

1. *Water proofing mixtures or Integral Treatment* :

Synthetic compounds are available which can be added during the process of mixing of the constructional materials. Substances such as chalk, talc or fuller's earth fill the pores in the concrete or mortar mix and make it denser. The other type of chemicals are silicates, chlorides and sulphates which react chemically and fill the pores. Soaps and other fatty acid compounds such as calcium, sodium ammonium stearates and oleates and petroleum oils are used as admixtures in concrete to make it water repellent. The water soluble soaps are not water repellent in themselves but they react with hydrated lime to form insoluble compounds. Some compounds are available in commercial patented forms like Pudlo, Impero, Cico, etc. Some of them are used after diluting with water.

2. *Water-proof surface treatment* :

Surface treatments can be either external or internal, the former are considered to be more effective in preventing dampness. While the latter cannot eliminate dampness but can only reduce it to an acceptable degree.

External surface treatments consist of pointing joints in brick-work or stone masonry and plastering over brick walls. The inner walls are normally plastered. Paints, oils, waxes, soaps and silicate solutions, etc. can also be applied on the surfaces for treatment against damp. These, however, need renewals after a few years.

A thin film of a water proofing material can be applied to the surface of concrete after it is laid. These materials consist of silicates of aluminium, potassium, barium hydroxide and magnesium sulphate in alternate applications, soft soap and alum, lime and linseed oil, coal tar, bitumen, waxes, fats, etc. Some of these covering materials give a durable resisting surface to the concrete while others afford only a temporary protection. However the tars and asphalts render the surface black which is not desirable.

3. *Interposing a water proofing membrane* :

This method consists of introducing a layer of water repellent material against the travel of damp. These are called Damp Proof Courses (D.P.C.). The materials used for the damp proof courses are :—

(*i*) Flexible materials like bituminous sheet, plastic sheet, metal sheet etc.

(*ii*) *Semi-rigid materials* : Like mastic asphalt.

(*iii*) *Rigid materials* : Like slates, bricks, stones, dense cement concrete, etc.

For selection of the material for D. P. C, the following rules should be applied :

(*i*) The material should be durable and impervious.

(*ii*) It should be capable of withstanding the dead load of the wall and other superimposed loads without disintegrating itself.

(*iii*) It should not allow any movements in itself so that the walls resting on it do not crack.

(*iv*) For walls of 30 cm. thickness any of the types described above may be used.

(*v*) For thicker walls or wider areas, a D.P.C. which has least number of joints should be used.

(*vi*) When water under pressure is to be retained, a jointless D.P.C. is desirable to prevent leakage.

(*vii*) For bridging cavities or joints, flexible materials should be used.

A brief description of some of the types of membrane damp proofing agents is given below :

(*a*) *Concrete layers* : Cement concrete layer of 1 : 2 : 4 mix with water proofing agents is used as D.P.C. It does not permit the rise of water by capillary action but allows the water to pass through the cracks which occur in this layer due to shrinkage or minor settlement of the building. This can be used wherever damp is not excessive. For preventing the damp effectively, a layer of concrete at least 4 cm. in thickness painted with two coats of hot bitumen are used. This type of D.P.C. is used as a horizontal plinth D.P.C.

(*b*) *Mortar* : This can be used as a bedding layer for other types of D.P.C. and is made up of cement sand mix in the ratio of 1 : 3 with a slight addition of lime to increase the workability. For

(3) The floor coverings loose adhesion with the floor bases.

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(*b*) *Mortar* : This can be used as a bedding layer for other types of D.P.C. and is made up of cement sand mix in the ratio of 1 : 3 with a slight addition of lime to increase the workability. For vertical D.P.C. a plaster of 1 : 3 cement sand mortar, at least 2 cm. in thickness covered with two coats of hot buitmen is used.

(c) *Bricks* : Dense bricks which absorb less than 4½% of their weight of water are suitable for D.P.C. wherever the damp is not excessive. They should not be used for downward passage of damp prevention. The joints should be left open.

(d) *Stones* : Dense stones, *e. g.*, granite, trap, slates, etc. ere used as D.P.C. and should be laid in cement sand mortar. Two layers are at least used with joints breaking vertically.

(e) *Hot laid bitumen* : This material is used on a bedding of concrete or mortar and should be applied so as to have a thickness of at least 3 m. m.

(f) *Mastic Asphalt* : This provides a semi-rigid impervious D.P.C. Special care is needed in its laying.

(g) *Metal Sheets* : Lead copper and aluminium sheets are used for D.P.C. Lead is to be protected from corrosion with an application of bitumen coating. This can stand distortion and can be suitably lapped. At least 12 kg. of lead per square metre should be used. Copper sheets are also quite durable and damp resistant but may stain the external wall surfaces. The copper sheets are not less than 3 m. m. in thickness. Aluminium sheets have to be protected with a layer of bitumen.

While laying a D.P.C. the following points should be kept in view :

(*i*) The D.P.C. should cover the full thickness of the wall and should not be recessed into the wall.

(*ii*) The mortar bed upon which the D.P.C. is laid should be even.

(*iii*) Each D.P.C. should be placed in correct position with another D.P.C. so as to provide a continuous protection.

(*iv*) Whenever D.P.C. are to be used to cover angle projection they should be laid continuously.

Use of membranes in the prevention of damp at various positions in a building.

Basement : Vertical D.P.C. is applied to the enclosing walls of a basement. The horizontal D.P.C. is applied to the flooring of basement. There are various methods of applying vertical D.P.C. The horizontal D.P.C. of the flooring may be continued to the top (*See* fig. 499) so that a sort of waterproof tank is formed. This prevents water from passing through the floors and walls adjacent to the earth and also intercepts the water which walls would absorb directly from the ground. Asphalt mastic or asphalt felt may be used along with concrete surfaces of the basement. The D.P.C.'s may be laid on the inner surface or on the outer surface of the walls or else they may be incorporated into the wall thickness.

The bottom layer of concrete is covered with a 2 cm. thick asphalt mastic laid in two coats and a second layer of concrete is laid over it. The mastic is continued as a vertical D.P.C. A 10 cm. outer wall is constructed from the horizontal D.P.C. to a little above ground level. The joints are raked out on the inner surface and

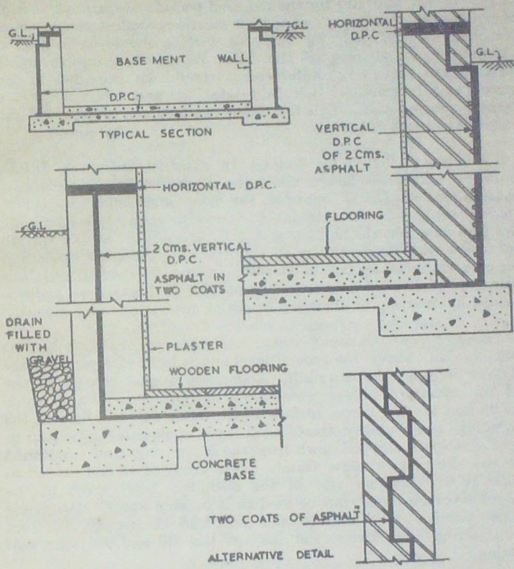


Fig. 499-502. Various methods for damp-proofing of basement.

asphalt layer is applied. After some time a second layer of asphalt is laid in such a manner so as to cover the joints of the first layer. Then the inner wall is built. In case excessive pressure of water is encountered, a drain can be laid outside the wall junction with bottom concrete. (*See* fig. 500).

If the asphalt treatment is to be given on the outside of the basement, the wall is built, joints are raked out on the exterior surface and two coats of asphalts applied as described above. The joint with the horizontal D.P.C. above the ground level is made perfect and the vertical D.P.C. is made inside the wall for a height between the horizontal D.P.C. for the ground floor and the ground level (*See* fig. 501). This prevents an ugly appearance on the exterior.

Floor : The concrete floors can be treated with waterproofing layer of mastic asphalt or fibrous asphalt felt. This treatment is necessary when the subsoil water table is high and moisture is likely to rise through the flooring by seepage aided by capillary action of the soil. A bedding of concrete of 10 cm. in thickness is laid and allowed to set and dry for the required period. A priming coat of hot liquid asphalt is given and asphalt mastic is applied in two coats. If asphalt felt is used, the concrete surface should be levelled so as to prevent the tearing of the felt. Whenever excessive uplift pressures are expected, reinforcement should be provided in the concrete and the mastic or felt laid later on and covered with a concrete wearing coat. This treatment can be given to ground floors as well as to basement floors.

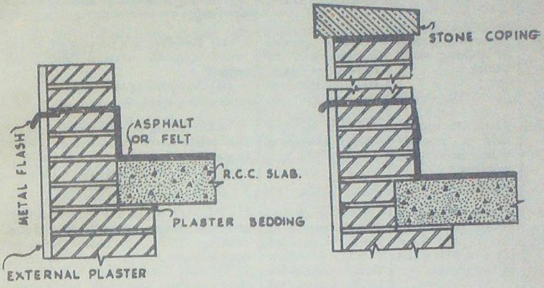
Horizontal D.P.C. for Walls : In external walls the D.P.C. should be laid about 20 cm. above the ground level. It is essential to have a vertical D.P.C. between the floor level and the D.P.C. level on the inside of external walls in this case. Some building codes prescribe that the horizontal D.P.C. should be at the plinth level below the flooring. In an internal wall, the D.P.C. is laid in level with the upper surface of concrete in the finished floor. The continuity of D.P.C. between the internal and external walls is obtained by inserting bitumenised bricks or cement concrete blocks.

Damp proofing in cavity walls : A horizontal D.P.C. is laid at about 20 cm. above the ground level and is built of separate inner and outer slabs for the two walls. Dampness is also caused at the head of openings if proper protection is not afforded. Water which finds its way to the inner surface of the outer wall will drip on the opening, if not suitably treated. A layer of asphalt felt or lead or copper sheeting is stepped down from the inner wall and continued over the door or window frame. This covering should extend to at least 10 cm. on either side of the opening. Lead sheet in the form of a trough should not be used as it collects water. Dampness can also occur at the window sills and lead or asphalt felt can be introduced in between the face of the sill and the inner wall covering.

Parapets : Water drains on the inner side of the parapet and finds way to the interior of the building. A D.P.C. just above the junction of the roof with the parapet wall gives an effective protection. Materials which form a continuous sheeting are preferred and flexibility is desirable. D.P.C. should extend through the full thickness of the wall including any plaster etc. A metal flashing may be provided on the exterior surface to improve appearance. A D.P.C. underneath the coping may be necessary where the bricks are not of good quality and are liable to get damaged on account of sulphate action. To reduce the number of joints in the coping, it should be cast monolithically. If any projection is present on a parapet, it should be protected by suitable flashings. Whenever it is anticipated that the plaster is going to crack, the plastering should be done on the interior surface only.

(4) *Special constructional devices* :

(*i*) Cavity wall construction : For preventing the external walls from carrying damp inside, cavity wall construction can be adopted. The details are described in Chapter VI.



Figs. 503-504. Prevention of damp along parapets.

(*ii*) For solid walls at least 1½ brick thickness should be used if lot of damp is anticipated.

(*iii*) The face bricks should be of best quality which can absorb very little moisture.

(*iv*) Openings and walls in general should be protected by the use of cornices, string courses, sills, plinth courses and canopies. These elements should be sloped away from the building and should have throating to prevent the water dripping on the surfaces.

(*v*) Roofs should be given an adequate slope to drain off water easily.

(*vi*) All plumbing fixtures, *e.g.*, down water pipes should be suitably fixed and it should be ensured that the water does not leak at their connections.

(*vii*) Special attention should be paid to the construction of joints and also to the junction of the roofs with parapet walls.

Treatment of Damp

Before starting any treatment for the dampness occurred at any place, the cause of the damp should be thoroughly investigated. The following table is recommended for the treatment of damp in the various parts of a building.

No.	*Location of damp*	*Causes*	*Treatment*
1.	Above openings in wet weather.	Ineffective lintel or coping or absence of D.P.C.	(*i*) Throating may be corrected. (*ii*) The D.P.C. can be introduced by cutting a recess at the top of the opening.
2.	Around the sides of opening (solid walls).	Due to porous brickwork in the reveals or defective pointing of the frame.	(*i*) Rendering a plaster of water proof cement around the jamb reveals. (*ii*) Repointing the frame.
3.	Along the underside of wooden sills in wet weather.	Defect in the design or setting of the sill.	A throating on the underside of the sill should be formed. Good slope should be given on the top surface of the sill outside. The sill should be rendered with plaster.
4.	Permanent dampness at or about the inside floor level on the walls of the rooms.	Absence or inadequateness of the horizontal D.P.C. or ineffective resistance to the horizontal movement of damp due to water getting collected on ground outside.	A D.P.C. is to be provided by suitably openin g the wall. If the existing D.P.C. is inadequate, a double layer D.P.C. should be laid. To prevent the appearance of damp on the surface, the plaster is broken and the brick workis given a coating of neat cement slurry suitably water proofed and plaster applied.
5.	On walls and floors below ground level.	(*i*) Site may be undrained ; (*ii*) Floor is laid on sloping clay bed.	Disconnecting the floor from subsoil will help. A new thick layer of sandy soil is laid below the floor. The foundation of the floor may be built of rubble packing and then floor suitably finished. Suitable weep holes may be set in the walls. Special renderings can be given by stripping off the concrete topping and relaying it over the water proofing layer.
6.	On ceiling appearing suddenly in bad weather.	Bad eaves or choked rain water gutter.	Cleaning of gutters and repairing of eaves.
7.	In front of fireplaces at ceilings.	Defective lead work around chimney stacks.	Renewal of gutter lead work and constructing suitable fillets.

QUESTIONS

1. What are the various causes of dampness in a building ? Give a detailed answer.

2. Describe briefly how dampness can occur in walls, chimneys, ceilings and floors of a building. What are the timings of their occurrence ?

3. Write a short note on dampness due to structural causes. What are the bad effects of dampness ?

4. Write a detailed note on the prevention of dampness by interposing a water proofing membrane in a structure.

Name the various materials which can be used for this purpose.

5. A basement of a building is 4 metres deep and rectangular in plan of 6×10 metres in size. There is likelihood of dampness occurring in the inside of the basement. As the building is not yet constructed,ebxplain briefly the various methods of damp prevention if the walls are to be built in brick masonry and a concrete floor is to be used.

6. Write short notes on the prevention of dampness in cavity walls and along parapets.

References

1. **National Building Organisation :** *Dampness in Buildings.*

2. **Dawes S.B. :** *Dampness in Domestic Buildings.*

3. **Capital Project Chandigarh :** *Building Bye-Laws.*

4. **British Standard Specifications No. 743 of 1951 :** *Materials for Damp Proof Courses.*

5. **British Standard 1097 of 1947 :** *Mastic Asphalt for Damp Proof Courses.*

6. **British Standard 1418 of 1947 :** *Mastic Asphalt Damp Proof Courses and Tanking.*

7. **Blake E.G. :** *Damp Walls.*

9

WOOD WORK JOINTS, FASTENINGS AND TOOLS

Different pieces of timber have to be connected together in order to develop a framework which may be used in the construction of a building. Timber, being a natural product available in abundance in India, is used for the construction of doors, windows, roofs, partitions, beams, posts, etc. To increase the structural stability, enhance the architectural beauty, economise timber and to facilitate construction, joints form a very important part of carpentry.

It is well known that the joint is the weakest part of any structural member, hence it is desirable that utmost attention is paid to the construction and finishing of joints. The forces acting on wooden members can be of the following nature :

(*i*) *Tensile* : This force will move the two parts of a joint apart.

(*ii*) *Compressive* : A force of this nature will try to crush the fibres of the component parts.

(*iii*) *Shear* : This will try to tear off the wooden fibres at right angles to their line of growth.

(*iv*) *Torsion* : Any force trying to twist a member will tear it off crosswise.

Keeping in view these forces, the following points about the joints should be noted :

(*i*) The joints should be as simple as possible to save labour in construction. Further complicated joints present numerous surfaces or angles which can lodge verms and cause timber to decay.

(*ii*) The joint should be cut in such a way so as to weaken the connecting members as little as possible.

(*iii*) Each face abutting [with the other should be cut in such a way that the face is perpendicular to the line of pressure acting on it.

(*iv*) Each part should be safe to withstand compressive forces acting on it. This means that the area of members being connected should be in proportion to the forces acting on them.

(*v*) The fastenings should be proportioned in such a way that they equal in strength to the members which they connect.

(*vi*) The fastenings should be placed in such a manner that there is sufficient resistance to the failure of a joint by the fastenings getting sheared or crushed through the timber.

Definitions

(*i*) *Chamfer* : Arris (edge) of timber plained off flat to form an angle usually 45°.

(*ii*) *Bevel* : If the angle of chamfer is not 45°, it is called bevel.

(*iii*) *Stopped Chamfer* : When the chamfer is not continued to the end of the wooden piece but ends in another chamfer or slope, it is called stopped chamfer.

(*iv*) *Moulding* : Process of shaping various units of construction by hand or machine to produce a moulded section.

(*v*) *Bead* : Moulding consisting of a semi-circle and a quirk or bead returned ; three quarters of a circle with quirk at each end.

(*vi*) *Bead jointed* : Term applied to two units of timber fitted at their sides, with a bead worked on one unit to cover the joint.

(*vii*) *Groove* : Recess formed in board or a piece of wood. The shapes may be hollow, V-shape, semi-circular, etc.

(*viii*) *Rebating* : Cutting rectangular portion from a plank to receive another plank similarly cut.

(*ix*) *Mitring* : Joining two boards at an angle.

Types of joints

Joints may be classified as under :

(1) *Lengthening joints* : These connect members lengthwise in order to make use of small members.

(2) *Bearing joints* : These are the transverse joints.

(3) *Oblique shouldered joints.*

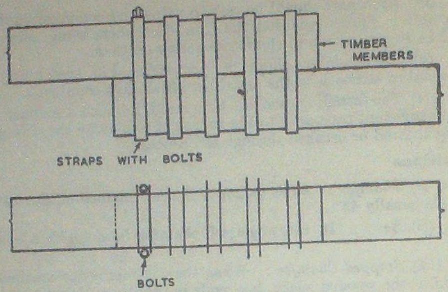
(4) *Side or widening joints.*

(5) *Angle joints.*

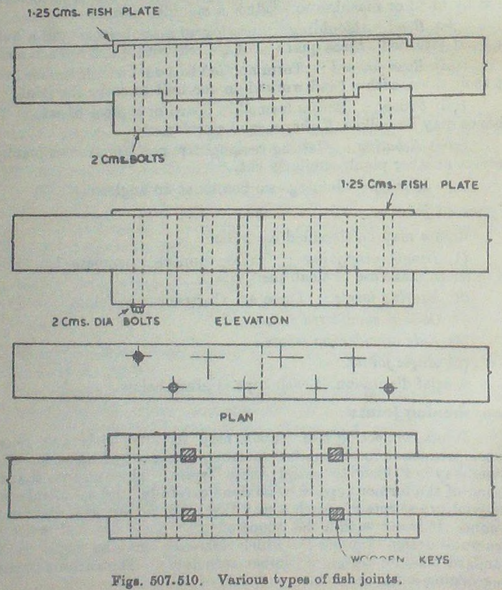
A brief discussion of each type is given below.

Lengthening Joints

Joints connecting two timbers may have to withstand tension or compression if the connected members are stressed likewise. Some joints may not have to stand these forces. This means that the design of the former type is to be done carefully and all members at the joint are selected in such a way that the forces are distributed evenly. It is not within the scope of this book to deal with the structural design of joints for which reference may be made to any standard book on design of timber structures. The various types of lengthening joints are :



Figs. 505-506. Plan and elevation of a lap joint with iron straps having bolt ends.

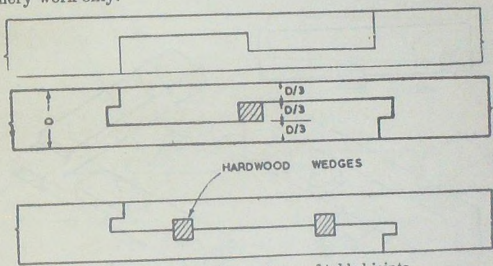


Figs. 507-510. Various types of fish joints.

(*i*) *Lap Joint* : Method of joining two members by lapping one over the other and bolting the same is called lap jointing. Sufficient number of bolts are provided to withstand the forces. In this type of joint, the timbers are not cut but wrought iron straps are placed over them and the pieces are bolted. As the timber is not cut, a hundred per cent efficiency could be achieved. The joint is satisfactory for temporary construction.

(*ii*) *Fish Joint* : This type of joint is more effective for transmitting only tension. The timbers are cut and iron plates are bolted to them. These plates are called 'fish' plates. The strength of the joint depends upon the bolts and the fish plates. To increase this strength, keys are provided in the joint as shown in Figure 510. As an alternative the plates may be bent as shown in Figure 507.

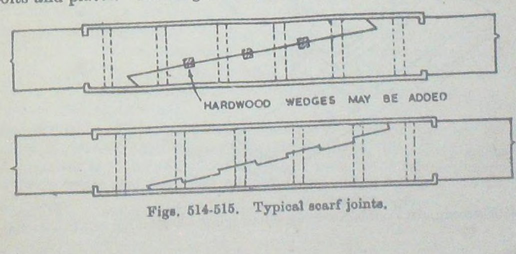
(*iii*) *Tabled Joint* : The members of wood are cut with the shapes shown in Figures 511-513 and joined suitably. This joint is not very efficient as lot of material is cut. This joint is used in joinery work only.



Figs. 511-513. Various types of tabled joints.

(*iv*) *Scarf Joint* : These are used where strength as well as the shape of the joint are equally important. Different types of scarf joints are shown in Figures 514-515.

The simplest scarf joint depends entirely upon the strength of bolts and plates. Bending of the plates into the timber may also be

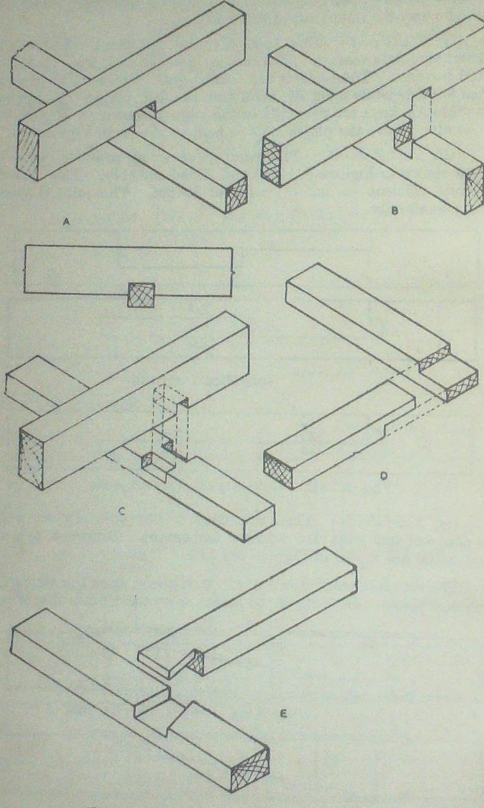


Figs. 514-515. Typical scarf joints.

helpful. Using notched splays and hard wood keys strengthen the joint but are difficult to construct. These are very strong types of joints.

Bearing Joints

When two members have to be joined at right angles to each



Figs. 516-520. Various types of bearing joints.
(A) Notching, (B) Double Notching, (C) Cogging, (D) Halving, (E) Dovetailing.

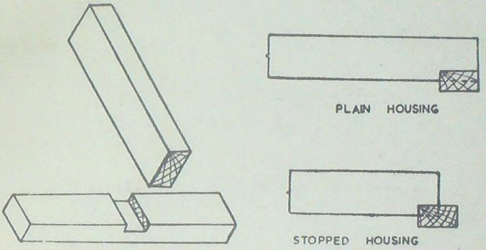
other, it is essential that they should have sufficient strength at the connection. Various types of joints are used depending on the nature of members to be connected and the forces acting on them. Some of them are described below.

(*i*) *Notching* : One member may be cut as shown in Fig. 'A' and the other fitted with it. The shoulders thus created help in the prevention of any displacement of the joint. If both the members are cut, double notching is formed (*See* figures 516-520B).

(*ii*) *Cogging* : When the entire depth of the timber is to be utilised, the members are to be connected as shown in Figs. 516-520C.

(*iii*) *Halving* : Timbers that cross each other and are required to be flush on one or two faces are cut to meet as shown in Figs. 516-520D.

(*iv*) *Dove-tailing* : Wedge shaped pieces are cut from members and the timbers are fitted into the projections of each other.



Figs. 521-523. Typical housed joints.

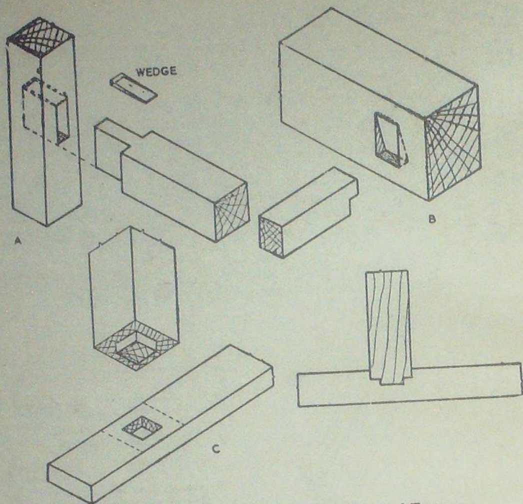
(*v*) *Housing* : When the entire end or thickness of a member fits into the notch of another, a housed joint is formed.

(*vi*) *Mortice and Tenon* : In the ordinary type of this joint, the end of one timber is cut so as to form a projection which is called Tenon. The other member is morticed to correspond to the dimensions of the tenon and the latter fitted into the former. This joint is commonly used. The two members may further be prevented from displacement by driving wedges or pins into the joint.

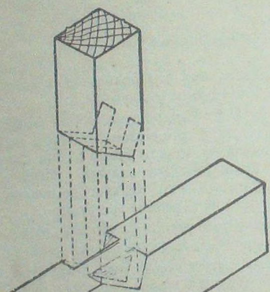
(*vii*) *Chase Morticing* : This is used when subsidiary members are connected to the main members which have been fixed earlier.

(*viii*) *Joggle Tenon* : This is used for members which rest on each other and displacement between the two is undesirable, *e.g.*, a wooden post resting on a sill.

(*ix*) *House and Dovetail Tenon* : When the ordinary tenon is insufficient to develop the necessary bearing strength, the entire end of one member is fitted or housed into the recess made in the other and further a tenon and morticed joint is built.



Figs. 524—526. Beaving Joints. (A) Mortice and Tenon. (B) Chase Mortice, (C) Detail and Elevation of stub tenon.



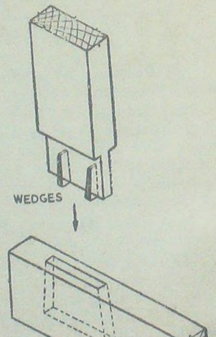


Fig. 528. Fox-tail Wedging Joint.

If the tenon is made of the shape of a dovetail and the mortice is cut in a similar fashion to suit the tenon, a dovetailed joint is formed.

(*x*) *Tusk-Tenon* : When members of equal depth meet each other at right angles, this type of joint is used.

Pins may be driven to prevent the lateral movement of the joint.

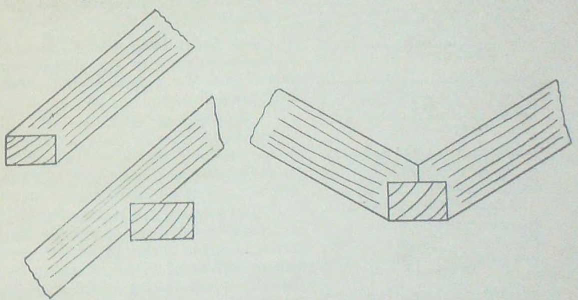
(*xi*) *Fox-tail Wedging* : This joint is used when the back side of the morticed member is not accessible. In this case the mortice is cut to a lesser depth than the member and is also slightly dovetailed. The tenon is cut and two sockets are made in the tenon in which wedges are inserted. The entire assembly is forced into the mortice.

(*xii*) *Bridle* : In this, the members are slotted and tenoned as shown in Fig. 527. These joints are used in wooden trusses at the junction of struts and ties.

Oblique Shouldered Joints

(*i*) *Mitre* : When two planks are to be joined at an angle, a mitre joint is formed. For right angled junctions, the two members are cut at 45° and joined. To prevent light from being seen through the widening of the joint, a wooden piece is fitted in the centre of the members and this is called mitred and feather joint.

(*ii*) *Bird's mouth* : The oblique member of this joint is cut in such a way so as to form a notch and into this fits the other member.



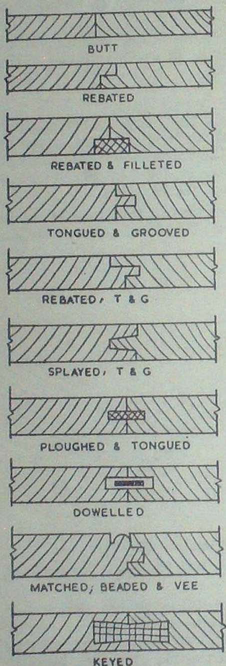
Figs. 529-531. Typical Bird's mouth joints.

One or two oblique members may join and rest on other members in this manner.

(*iii*) *Halving and Dovetailing* : When it is desired that one or both sides of the connected members are to be in flush on one or both sides, this type of joint is used. It is constructed by cutting a depression in one of the members and fitting the other member into it. However, one or both of the cut surfaces of this depression and the corresponding tenon are made inclined so as to form a dovetail.

(*iv*) *Oblique Tenon* : For joining bigger sized timber members at an angle, this type of joint is commonly used. The tenon of the inclined member fits into the corresponding mortice made into the horizontal member. On account of the inclination of one of the members, the meeting surfaces are cut in a manner that the force from the inclined member is at right angle to the cut surface. Examples of this type of joint are the joints between the tie beam and the principal rafter of a roof truss or inclined members and horizontal beams of wooden partitions.

(*v*) *Bridle* : This joint is also used mostly for connecting inclined and horizontal members. It is the reverse of the mortice and tenon joint. A sort of a mortice is cut in an inclined member and a corresponding projection or bridle left in the horizontal member. This joint is also used at the end of the principal rafter being connected to a tie beam.



Figs. 532-541. Different types of side joints.

Side or Widening Joints

These are used for laying planks in floors or in battened doors. The following types are commonly used :

(*i*) *Butt* : The two members are simply joined side to side.

(*ii*) *Rebated* : In this, depressions are cut in both the members and are joined lapping mutually.

(*iii*) *Rebated and filleted* : A small depression is made in the connecting ends of both the members and other small piece fitted in.

(*iv*) *Tongued and Grooved* : A depression (groove) is made in the side of one member and a corresponding projection (tonque) is cut in the other member. They are fitted tight.

(*v*) *Rebated, Tongued and Grooved*: In addition to forming a tongue and groove, a rebate is also given by cutting an additional width on one side of the tongue and making a similar shape for the other member.

(*vi*) *Splayed, Tongued and Grooved* This joint is similar to the joint (*iv*) except that the tongue has got one side cut at an angle.

(*vii*) *Ploughed and Tongued* : In this both the members have got similar grooves and a small wooden piece is fitted tight in between.

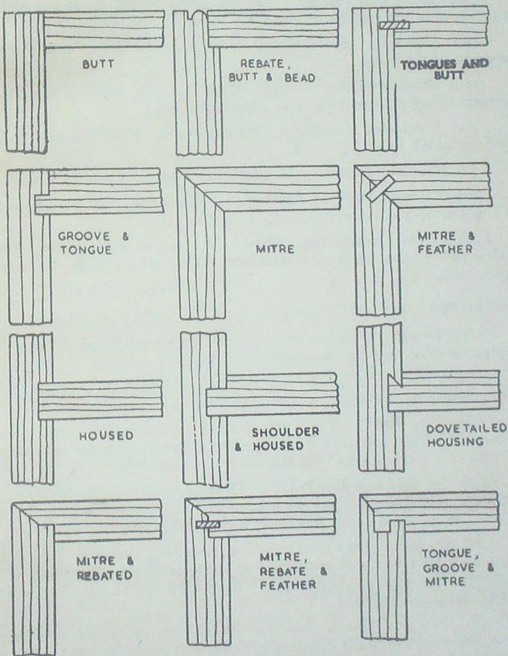
(*viii*) *Dowel* : This is similar to the above type except that the additional small member may be of any other material (dowel) and may not fit tight.

(*ix*) *Matched, Beeded and Vee :* This has got a tongue and groove arrangement and in addition has special moulding on one side and a V-shaped depression on the other.

(*x*) *Keyed* : A dovetailed shaped key is used to fit in the depressions in the connecting members which are fitted tightly.

Angle Joints

These joints are generally used for connecting members parallel or at right angles to their grains. The following types are generally used:



Figs. 542-553. Various types of angle joints.

(*i*) *Butt* : The members are connected by just joining them together.

(*ii*) *Rebate, Butt and Bead* : A rebate is formed in one of the members and the other member is fitted in it. To give it a better appearance, a moulding in the form of a bead is used.

(*iii*) *Tongued and Butt* : In this, the members are butted against each other and a small piece of wood is fitted into the corresponding depression of the two members.

(*iv*) *Tongue and Groove* : The members may be joined by fitting a projection of the two members.

(*v*) *Mitre* : The members aie cut at an angle at the joint and fitted.

(*vi*) *Mitre and Feather* : An additional small wooden member is inserted in the middle of the mitre joint.

(*vii*) *Housed* : One member is completely fitted into the depression of the other.

(*viii*) *Shouldered and Housed* : Part of one member fits into a corresponding depression of the other members.

(*ix*) *Dovetailed Housing* : One member is fitted into the other by dovetailed joint.

(*x*) *Mitre and Rebate* : In addition to mitre, a rebate is used.

(*xi*) *Mitre, Rebate and Feather* : A feather is used in addition to the joint described above.

(*xii*) *Tongue, Groove and Mitre* : A tongue and groove joint with a part of the connecting members jointed at an angle is sometimes used.

Fastenings

(*i*) *Dowels* : These are small wooden pieces fitted in between two connecting members to keep them in one plane.

(*ii*) *Pins* : The joints of door and window shutters are strengthened by driving small wooden pieces called pins.

(*iii*) *Wire nails* : These are circular, elliptical or rectangular in section. They are used for connecting different wooden members. They have a tendency to split the wood in some cases.

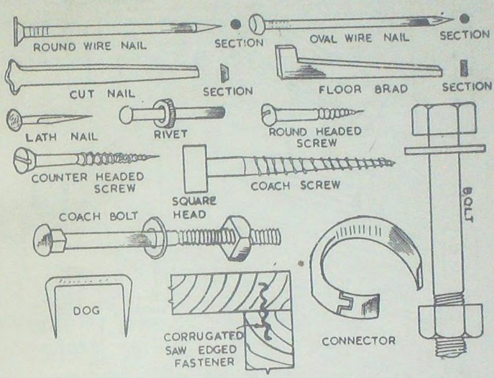
(*iv*) *Cut nail and floor brads* : They are thin nails rectangular or trapezoidal in section having a head on one or both sides. They are used wherever a small sized nail hole is required.

(*v*) *Screws* : They are used for fastening wooden members which may have to be disconnected at times or where vibrations will not permit the nails to stay longer. They may be round headed or counter sunk headed.

(*vi*) *Bolts and Coach Screws* : Whenever spikes or ordinary screws cannot offer much resistance, bolts have to be used. They ar**e** generally used for connecting large sized members.

(*vii*) *Connectors* : Thin metal rings or corrugated sheet pieces can be driven into the members after abutting them. They have sufficient strength and do not damage the timber.

(*viii*) *Dogs* : These are wrought iron U-shaped pieces with pointed ends. They are driven to connect the members.



Figs. 554-567. Fastenings.

Tools for Carpentry Work

Following are the types of tools used in carpentry work :

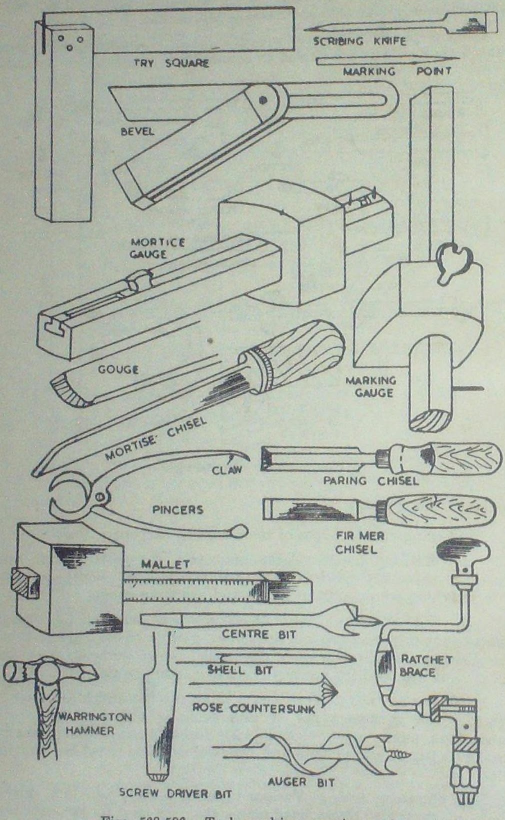
(*i*) *Marking tools* : These are used for setting out and adjusting carpentry work. They are try square, bevel, scribing knife, marking point, mortice gauge and marking gauge.

(*ii*) *Cutting tools* : These are chisels and saws. The type of chisels commonly used are mortice chisel, paring chisel, firmer chisel etc. Crosscut saws, tenon saws, dovetailed saws, compass saws and coping saws are used for various types of cutting work.

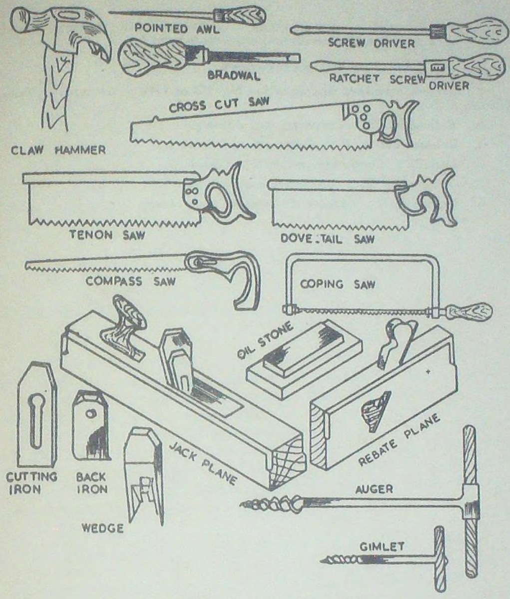
(*iii*) *Boring tools* : For driving holes ratchet and brace may be used to which various types of bits such as centre, shell, rose-countersunk, auger, screwdriver bits are used to get different shapes of holes. Augers and gimlets and bradwal are also used for driving holes.

(*iv*) *Planning tools* : Various types of planes, *e.g.*, jack plane, rebate plane, trying plane, bead plane, etc., are used for smoothening the wood face or for creating small mouldings.

(*v*) *Hammers and Screw drivers* : Various types of these tools are shown in figures 568-604.



Figs. 568-586. Tools used in carpentry work.



Figs. 587-604. Tools in carpentry.

QUESTIONS

1. What are the various types of lengthening joints ? Describe briefly how a scarf joint is made up so as to connect two members.

2. Write short notes on :

(*i*) Notching.
(*ii*) Cogging.
(*iii*) Dovetailing.
(*iv*) Halving.

3. Illustrate with sketches how a mortice and a tenon joint is made ? What is meant by a chase mortice joint ? When is fox-tail wedging used for a mortice and tenon joint ?

4. Write short notes on :

(*i*) Mitred joint.
(*ii*) Bird's mouth joint.
(*iii*) Oblique tenon joint.
(*iv*) Bridle joint.

5. What are the various types of side joints used for joining wood planks ? Illustrate with sketches.

6. What are the various types of fastenings and fixtures used in carpentry work ? When are dowels and connectors used ?

References

1. **British Standard Specification No. 565 of 1949** : *Glossary o ;Terms Applicable to Joints.*
2. **Telling M. T.** : *Carpentry and Joinery.*
3. **Bridgewood A. E.** : *Carpentry and Joinery.*
4. **Audel's** : *Carpenters and Builders Guide.*
5. **Dougles W. B.** ; *Carpentry and Joinery.*
6. **Emery A. S.** ; *Advanced Carpentry and Joinery.*

10

DOORS AND WINDOWS

Location of Doors and Windows

Doors :

Doors are provided to give an access to the inside of the room of a building. Hence they should be so located that freedom of movement in and out of the room is ensured keeping in view the maximum use of accommodation in the room and privacy of the occupants. Doors should preferably be placed in the corner of the room. In case a room has more than one door and they are to be located in the opposite walls of the room, the doors should face each other. This would provide a good ventilation and also create least interference with the inside arrangement of the room.

Windows :

Distribution and control of day light, desired vision of outside, privacy, ventilation control and heat loss are some of the factors which have to be considered in the location of windows. The pattern of air movement inside a room depends to a large extent on the angle at which air enters and leaves the room. It is desirable that the movement of air is downwards and across a room for proper ventilation. This means that windows should be located opposite to each other wherever possible. An attempt should be made to get the maximum amount of light into the room. Windows located on the northern side would be highly effective in this respect. Wherever windows have to be located in residential buildings situated just near public places, *e.g.*, a shopping centre or a cinema, privacy of the rooms on the ground floor is necessary. For this, the windows should be kept at a higher level say about two metres above the ground level outside. On similar considerations, the windows of bath rooms should be located at a higher level. Windows provide an effective means of getting a prospect of the outside surroundings. It is desirable to locate the windows above the floor level of a room in such a manner that the residents can conveniently look outside. A height of 0.75 to 1 metre for the window sill above the floor level is recommended.

Sizes of Doors and Windows

Doors :

Internal doors of residential buildings should not, as a rule, be less than 0.9×2 metre. However the size of doors leading to bath rooms can be reduced to 0.75×2 metre. It should be aimed that two persons walking shoulder to shoulder should conveniently pass through the door. A size of 1.0×2 metre would be an average recommended standard. Doors in public places should be of larger size and their height increased accordingly. A common criterion for the sizes of the doors, used in India, is :

$$\text{width} = (0.4 \text{ to } 0.6) \text{ height}$$

Doors of garages should as a rule, be not less than 2.5×2.25 m.

The following further points may be noted regarding the location, hanging and size of the doors :—

(*i*) *Width* : The aggregate clear width of doorways serving as exit for more than 40 persons shall not be less than 55 cm. per hundred persons accommodated.

(*ii*) *Hanging of doors* :

(*a*) The doors shall be so hung and arranged that when opened, they shall not in any way diminish or obstruct the required width of passageway, stair or other means of exit.

(*b*) Buildings constructed facing streets should have door opening outside (*i.e.*, towards the street).

(*c*) Exit doors leading from rooms occupied by 15 persons or more shall be hung to swing in the direction of exit.

(*d*) No exit door shall open immediately on a flight of stairs, but a landing the length and width of which are not less than the width of such door shall be provided between the door and the stairs. No riser should be located within 30 cm. of an exit door.

(*iii*) *Door fastenings* : Fastenings required on exit doors shall be such that the door can be readily opened from inside.

Windows :

The size of windows would be governed by the total area of window space needed. The following criteria may be kept in view while designing a window.

(*i*) Breadth of window $= \frac{1}{8}$(width of room + height of room).

(*ii*) There should be one square metre of window space for every 30 to 40 cubic metre of inside content of the room.

(*iii*) Glass area in the windows should be at least 15% of the floor area of the room. However, it is a good practice to provide 20% of the floor area as the total glass area of the windows. Continuous sash or one large opening in a room provides better distribution of light than a number of small windows.

Materials

Doors :

(*i*) *Wood* : Wood is used in several forms for the construction of doors. Doors may be made of solid planks or built up of small individual pieces. Since wood is one of the most commonly available building materials in India, it is largely used for this purpose. Moreover, it can also take a good polish and can be given different type of mouldings to produce an attractive appearance. However, its life is less as it is easily attacked by vermin especially when in contact with walls built of mud masonry.

(*ii*) *Glass* : This is used in panels of doors to admit light. Big openings in doors fitted with thick glass sheets give a very good appearance. Coloured glass, frosted glass, and beaded glass can be used for ornamental appearance.

(*iii*) *Ply-wood* : This material is very useful for doors which have to be made flush.

(*iv*) *Metals* : Steel framed doors are gaining popularity these days. Cast metal doors are relatively high priced. They are used mostly for monumental structures. Hollow metal doors made up of a metal frame and covered with sheet metal are selected for greater rigidity, life and fire resistance.

(*v*) *Concrete* ; Reinforced cement concrete frames can be used for doors in areas where there is a danger of disintegration of wooden frames by vermin.

Windows :

The above-mentioned materials can also be used for the construction of windows. Use of metal in windows is progressively increasing. Aluminium and steel are mostly used. However bronze, stainless steel and galvanised steel are used for specific type of buildings.

Definitions

(*i*) *Frame* : A group of members assembled and placed along the top, bottom and sides of an opening so as to form an enclosure and a support for a door or a window shutter.

(*ii*) *Sill* : The horizontal member forming the bottom of the frame.

(*iii*) *Shutter* :	Planks panelled or otherwise which fit in the frame.
(*iv*) *Style or Stile* :	Upright or vertical outside members of a shutter or framework.
(*v*) *Top rail* :	The topmost horizontal member of a shutter or framework.
(*vi*) *Lock-Rail* :	Middle horizontal member of a shutter or framework wherein lock and bolt are fixed.
(*vii*) *Bottom-Rail* :	The lower-most horizontal member of a shutter or framework.
(*viii*) *Mullion* :	The vertical member running through a shutter or a frame.
(*ix*) *Jamb* :	Vertical face of a window or door opening which supports the frame.
(*x*) *Reveal* :	External jamb of a door or window opening at right angles to the face of the wall.
(*xi*) *Sash bar* ;	Light weight units of a frame which carry the glass within a window or a door-frame.
(*xii*) *Sash-door* :	Door whose upper part is glazed.
(*xiii*) *Panel* :	The area included between the rails.
(*xiv*) *Hanging or* : *Hinged Style*	The styles of a door, which is hung on one side, are called Hanging or Hinged styles.
(*xv*) *Cross-Rail* ;	Additional horizontal member connecting the two styles of a shutter or framework.
(*xvi*) *Transom* :	Horizontal dividing member in a window or a door frame.
(*xvii*) *Threshold* :	Wooden fixture fixed to the floor under a door-frame, thus enabling the door to be cut short enough to clear floor coverings on the inside.
(*xviii*) *Rebate* :	Depression cut in the frame to receive the door.
(*xix*) *Louver* :	An inclined piece of wood fixed in a frame-work.

General types of Door Movements

(*i*) *Swinging doors* : The shutters are hung to the door frame on hinges or butts fixed to one side of the shutter so that they swing on a vertical axis. These types are mostly used in residential buildings. The frame of these doors may be laid in flush with the outside or inside face of the wall so as to minimise the obstruction created by the opened shutter. They may be of either single swinging or double swinging type.

(*ii*) *Sliding doors* : In these, the shutters can slide either upward, downward or sideway. These doors do not create obstruction in movements.

(*iii*) *Rolling shutter doors* : This is an improvement on the sliding doors. They are generally made of steel and have the advantage of easy opening and closing. Moreover, they do not require much space. These doors are specially useful for garages or shops where large openings have to be provided.

(*iv*) *Revolving doors* : These doors are used in places where frequent opening and closing of a door is to be avoided, *e.g.*, fish market. These doors hang on a central pivot and can rotate, whenever used, so as to close the opening automatically. Single shutter or double shutter revolving doors are also used in public places, *e.g.*, hotels. These doors revolve about one side of the shutter and get automatically closed whenever pushed and left. They are suitable for air-conditioned buildings as they do not admit heavy draught of air when opened.

(*v*) *Folding doors* : These doors may be of wood or metal. They can be constructed cheaply. They are used for large openings.

(*vi*) *Collapsible doors* : They are made of light steel sections, mostly channels. They roll in small channels fixed at top and bottom wherein small rollers have been kept.

(*vii*) *Telescopic doors* : They are used for very large openings. They are made up of five to fifteen leaves, generally centre parting. When opened, the shutters are stacked in pockets at the ends. These are operated by two motors located in the end pockets. The central leaves are driven by an endless chain operated by the motor. The other leaves are moved by a series of cables attached to the powered central leaf and arranged in such a way that all leaves arrive or close simultaneously.

Door Frame

(*a*) *Wooden door frame.* External doors are fixed to "frames". A door frame consists of two vertical pieces (posts) and one horizontal piece at top (head). Sometimes a horizontal member is added at the base also and this is called sill. The size of the members depends on the size of the door to be hung. Mostly they are 12×7.5 cm. in section. They have a rebate of about 1.25 cm. depth wherein the door shutter fits and one groove where the plaster abuts. The joints between the head and the post may be any one of the following :

(*i*) Closed Mortised and tenoned joint.

(*ii*) Haunched mortised and tenoned joint.

(*iii*) Pin and tenoned joint.

(*iv*) Double tenoned joint.

These are illustrated in the diagrams below.

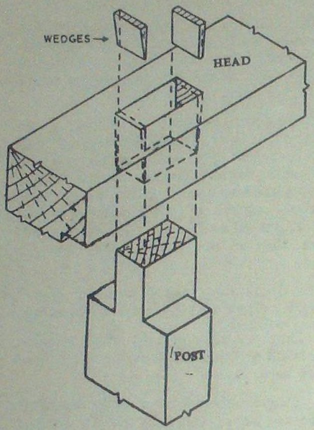


Fig. 605. Closed mortice and tenon joint between door frame head and vertical member.

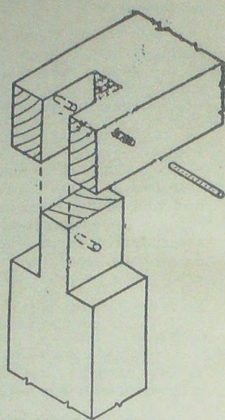


Fig. 606. Detail of pin and tenon joint.

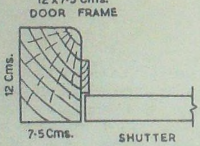


Fig. 607. Additional stop fixed to door frame for resting of the shutter.

Construction. The sections of suitable size are selected and plained. Rebates of required size are cut. The tenon and morticed joints are framed. The frame is temporarily fitted to check the correctness of the joints. The frame is opened and glue is applied at the contact faces of the joint. Pins of 1 cm. diameter are inserted and cut to shape. In addition, wedges may also be inserted if desired. The frame is finally plained and smoothened with the aid of a sand paper.

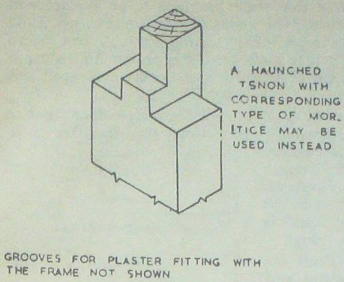


Fig. 608.

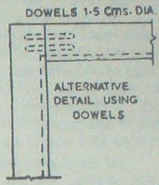


Fig. 609. Dowelled joint for door frame.

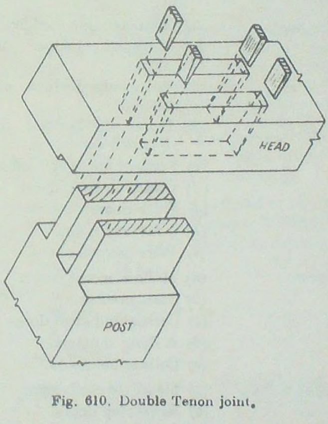
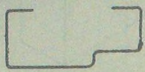


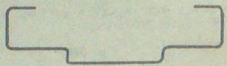
Fig. 610. Double Tenon joint.

Fixing: (*a*) *Before or during the contruction of wall.* The frame is erected vertical in plumb and secured tightly before any masonry around it is built. To ensure the proper fixing inside the wall, the head is projected beyond the frame dimensions (known as horns). In addition to this or as an alternative iron straps known as holdfasts of suitable dimensions are fixed to the frame.

To enable taking out of the frame for repairs or replacement after the building is constructed the wooden horns are not used. Hold fasts (Iron straps) which have got bolts running through the frame are used. The nut of the bolt is sunk into the frame and covered with putty. Any time removal is desired, the putty is scraped and the nut opened out.

(b) *After the construction of wall.* For expensive door frames which would get damaged during construction, the door frame is fixed into the wall after construction. Plugs of suitable size are driven into the wall as the masonry is constructed. They are sawn off true to the face of the jamb. The door frame is erected and nailed to these plugs.





Figs. 611-612. Steel door frames.

(c) *Steel door frame.* These are made of steel channel sections and have depressions wherein the door shutter can fit in. These are welded at corners, and have suitable attachments, *e.g.*, fixing lugs, hinges, rubber shock absorbers, etc.

Types of Doors

(1) *Wooden doors* :
- (a) Battened and Ledged doors.
- (b) Battened, Ledged and Braced doors.
- (c) Battened, Ledged and Framed doors.
- (d) Battened, Ledged, Braced and Framed doors.
- (e) Framed and Panelled doors.
- (f) Glazed or Sash doors.
- (g) Flush doors.
- (h) Louvered doors.
- (i) Wire-gauged doors.

(2) *Metal doors* :
- (a) Hollow metal doors.
- (b) Steel plate doors.
- (c) Corrugated steel doors.
- (d) Rolling shutters.
- (e) Collapsible doors.

(3) *Composite doors* :
- (a) Metal covered doors.
- (b) Revolving doors.
- (c) Sliding doors.
- (d) Telescopic doors.

Battened and Ledged Doors

This is the simplest type of wooden doors and is used for narrow openings and where cost is the main consideration. It consists of vertical battens fixed with horizontal members called "ledges". The size of vertical battens varies from 10 to 20 cm. and their thickness ranges from 2 to 4 cm. The battens are joined together in various ways. The type of joint to be given depends on the desired appearance. Some of the commonly used joints between the battens are shown in figs. 618-624.

Square joints in battens should be avoided as they open out and give a very unsighty appearance. If they have to be used, square joints should be grooved to enhance their appearance.

Ledges are normally three in number. The bottom ledge and the middle ledge are wider than the top ledge. The section of ledges may be taken as under :

Top ledge : 10×2.5 cm. to 10×4 cm.

Middle and bottom ledges : 15×2.5 cm. to 20×4 cm.

These ledges may be bevelled to prevent water standing against them if the door is fitted on the exterior face of the building.

Construction : The battens after being plained, grooved and cut to proper size are assembled on the working platform. One ledge is fixed temporarily on one side. The second ledge is also fixed in a similar manner. The middle ledge is then properly fixed with nails or screws to the battens. The other two ledges are also fixed permanently thereafter. If nails are used, they should be sufficiently long so as to project beyond the ledges. While fixing the nails, small pieces of wood are placed below the ledges to avoid damage to the surface of the ledge. The nails are then bent over the ledges. However, it is better to use screws. The side of battens should be painted after grooving and before fixing as otherwise when the joints open, a bad appearance is created.

Hanging of door : The door is fitted to the frame with garnet hinges, which are generally 25 cm. long and three in number.

Fittings : The following fittings are generally used.

Bolts : 2 Nos. of 25 cm.

Handle : 1

Aldrop bolt and pack-lock : 1

Hooks : 2

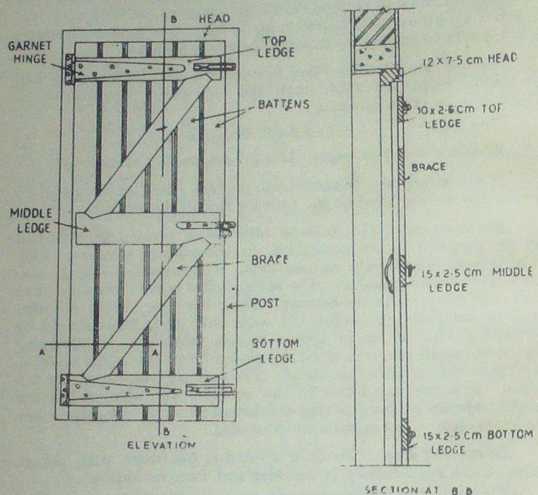
Door stop : 1 No.

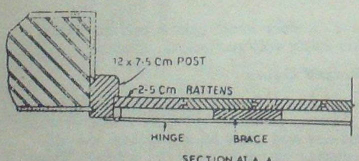
A very cheap type of a door would need a bolt on inside, a thumb latch and a hasp and staple with padlock on outside.

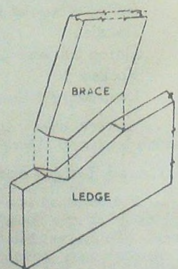
Battened, Ledged and Braced Doors

The battened and ledged door, described above, has a tendency to droop at the 'nose'. This is particularly so in the case of wide doors. To prevent this tendency and also to strengthen the door, it is customary to insert sloping braces between the ledges. These braces must incline upwards from the hanging edge or else they will not be useful in preventing the droop. The position of the middle ledge should allow the braces to have the same inclination. The width of braces varies from 10 to 15 cm. and are usually 2.5 to 4 cm. thick.

Construction : This door is made in a manner similar to the battened and ledged door. The joint between the ledge and the brace is shown in Figure 616.





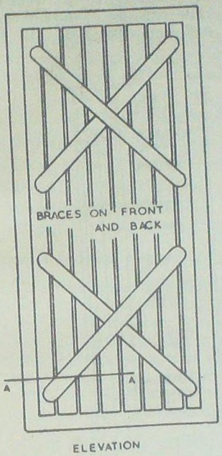


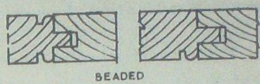
Figs. 613-615. Elevation, Vertical and Horizontal sections of a battened, ledged and braced door.

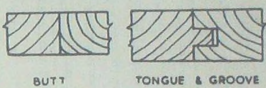
Fig. 616. Joint between brace and ledge.

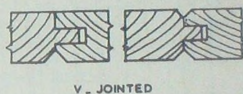
Hanging of the door : This is hung by garnet hinges 20 to 25 cm. long and three in number for a single leafed door and six for double leaved door.

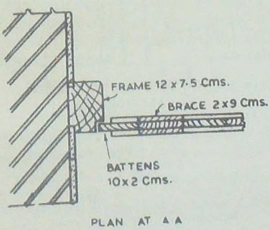
Fittings : Same as in the battened and ledged door.

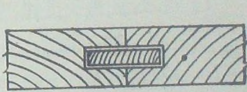












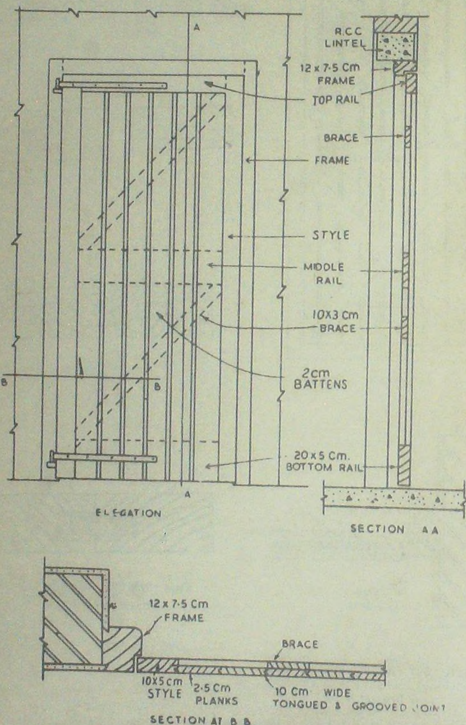
Figs. 619-625. Joints between battens of doors.

Figs. 617-618 Elevation and Sectional plan of a battened and braced door.

Sometimes doors with battens and cross braces only are used to give a better appearance than a battened, ledged and a braced door (as shown in Figs. 617-618).

Battened, ledged and framed Door

This is superior in strength and appearance to an ordinary battened and ledged door. It consists of a framework of two vertical styles, bottom rail, top rail and one middle rail. The battens are fixed in this framework. The styles are, generally, 10 cm. wide and 4 cm. thick. The top and bottom rails are also of the same size. The middle rail is about 20 cm. wide and 4 cm. thick as the lock



Figs. 626-628. Elevation, vertical and horizontal sections of a framed, ledged and braced door.

fittings are fixed to it. Battens are from 10 cm. to 12.5 cm. wide and about 1.5 to 2 cm. thick.

The middle and bottom rails are mortised and tenoned into the styles. The upper and lower ends of the battens are let into the rails and the side battens are tongued into the styles.

Construction : The rails are fitted loosely into the styles. The battens are accurately fitted and slipped into the grooves of the styles and rails. The tenons are wedged and pinned firmly.

Hanging of the door : This is hung with heavy garnet hinges. Sometimes strap hinges or a Narmadi is used.

Fittings : The usual fittings are :

Strap hinges : 3 Nos.

Bolts : 2 Nos. of 25 cm.

Aldrop with padlock : 1 No.

Handle : 1 No.

Battened, ledged, braced and framed door

This door is stronger than the battened, ledged and framed type. In addition to the members of that door, cross braces inclining upwards from the hanging side are used. The middle and bottom rails are mortised and tenoned into the styles and the braces are either housed into the rails at about 4 cm. from the style or taken into the corners and tenoned into the styles. The size of braces is $1{\cdot}5 \times 12$ cm. Generally the thickness of the top rail or the styles is equal to that of the braces and the battens together.

An improved type of this type of door is one in which the bottom rail, middle rail and the braces are equal in thickness to that of the head minus the thickness of battens. This means that the battens will run over the bottom rail, middle rail and braces. If such a door is used on exterior side of a building, the water collecting otherwise on the projection of the bottom rail, is not there and does not rot the door.

This is a strong type of door and at the same time is also cheap.

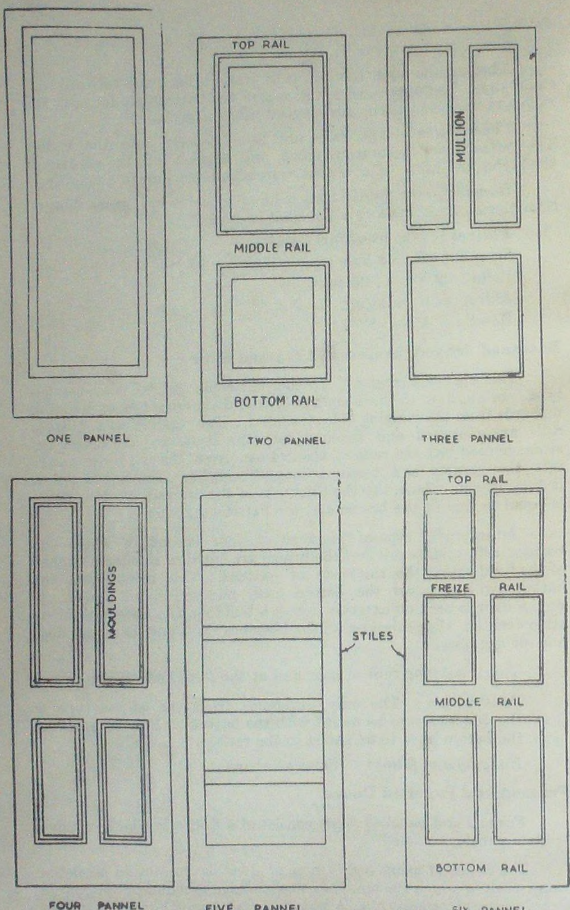
Construction : The only difference from the above type is that the braces are to be nailed with the battens. For the modified type, the batten have to be nailed to the rails.

Hanging and fittings : Same as above.

Framed and Panelled Doors

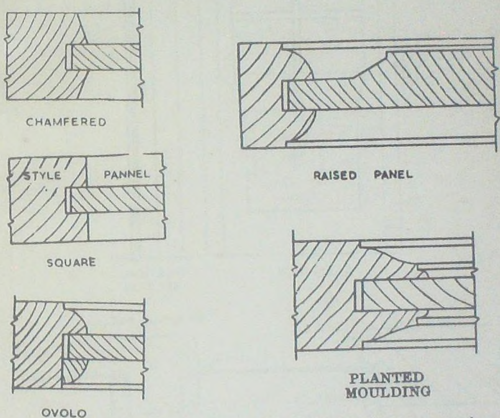
Framed and panelled doors consist of a frame in which wooden or glass panels are fitted.

The object of using such a type of door is to obtain skeleton frame work in which the tendency to shrinkage is reduced. Moreover a very pleasant appearance is obtained by panelling. A panelled door consists of a frame which is grooved on the inside edges to receive one or more panels. The styles are continuous from top to



Figs. 629-634. Types of panelled doors.

bottom. The top, middle, intermediate and bottom rails are joined to the styles. The mullions are joined to the rails. The thickness of the shutter frame is dependent on the size of the door, the situation of the door, the type of lock to be fixed, the thickness of panels and the size of panel mouldings. They are generally 4 to 5 cm. thick. They may be divided into a number of panels depending upon the size of the door and the nature of appearance desired. The panels range from one to six or even more in number (Figures 629-634). The size of the individual panel is one's own choice. However, it must be ensured that the styles are at least 10 cm. wide and the bottom rail and lock rail are 15 cm. wide. In order to enhance the beauty of the door the panels are given architectural mouldings as shown in figures 635-639.



Figs. 635-639. Various types of mouldings used for door panels.

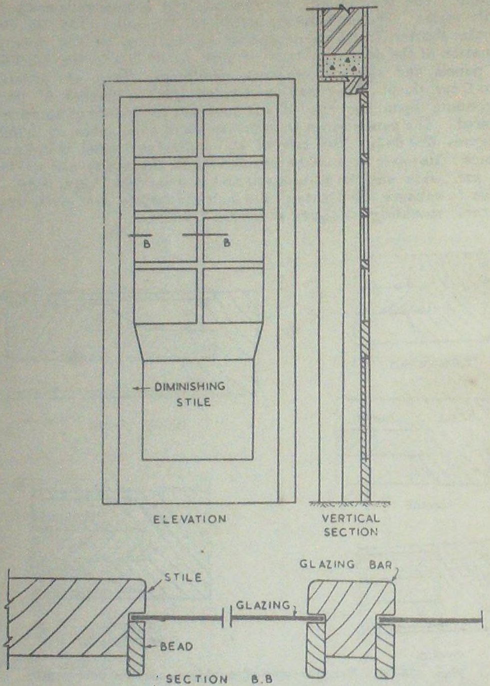
These figures show the junction of the panel with the style in section. As is clear from these figures, the panels can be of raised or flush type. They may be made of solid or laminated wood. Doors free from intricate mouldings are easy to clean and construct.

Construction :

The joints of the door shutter frame may be :

(*i*) *Mortised and Tenoned Joint* :

The width of each tenon is 5·0 cm. Grooves are formed along the inner edges of the frame to receive the panels The depth of the grooves is made equal to the thickness of the panel and shall not be less than 1·25 cm.



Figs. 640-642. Elevation, vertical and horizontal sections of a glazed and panelled door with diminishing style.

(*ii*) *Dowelled Joint* :

The dowels are machine made and are of hard wood. Mostly they are 1·5×12·5 cm. long and are placed at about 5 cm. centres. The ends of the rails are bored and glue is applied to the edges of the rails and the inside of holes. Similar treatment is given to the style. Glued dowels are inserted into the rails and both of them are fitted into the styles. This type of construction is considered to be not very durable but is an essential feature of door construction with machinery since the usual type of joints cannot be made with machines easily.

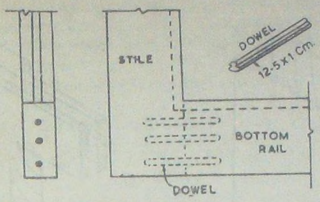
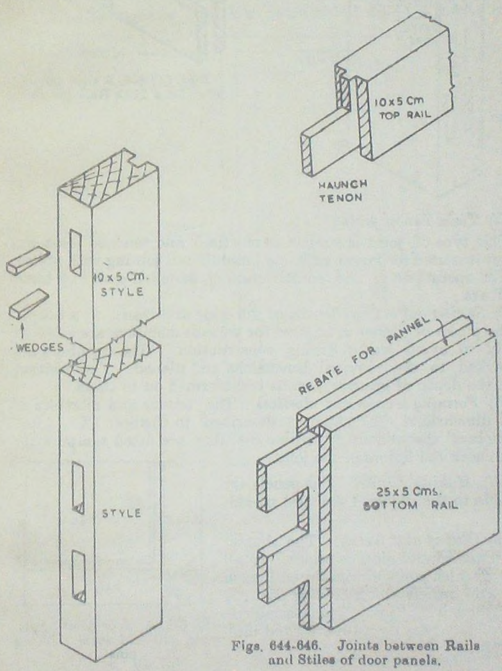
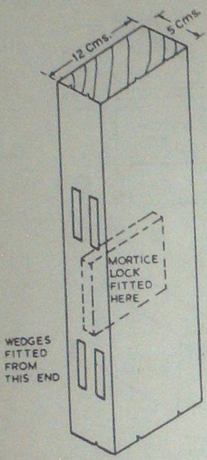
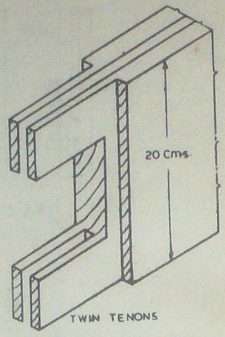


Fig. 643. Dowelled joints.



Figs. 644-646. Joints between Rails and Stiles of door panels.





Figs. 647-648. A twin tenon joint for a Lock Rail and Stile.

(*iii*) *Twin Tenon joint* :

This type of joint is similar to mortised and tenoned joint except that it is used for larger rails, *e.g.*, middle rail joining with styles.

The operations in the construction of panelled doors by hand method are :

(*i*) *Setting out* : The details of the door are drawn on a board. Then the pieces of timber to be used for various members are selected carefully to avoid waste during construction. The members are then marked to the required dimensions and planed. The position of rails, the depth of grooves, etc., is transformed on to them.

(*ii*) *Forming tenons and mortices* : The tenons and mortices of correct dimensions are made as described in Chapter IX. After the corners of the tenons have been cut, they are fitted temporarily so as to check the fitness of the joint.

(*iii*) *Making Panels*. The penels are next made to the required size and mouldings.

(*iv*) *Gluing and fixing*. The shutter frame is opened and glue is applied to all the places which come in contact with each other. The panels are placed in position and the frame is immediately re-assembled. Wedges or pins (*See* fig. 649) are fixed into the joints.

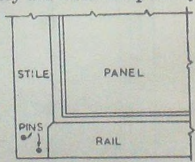


Fig. 649. A door joint between rail and style showing pins.

(*v*) *Cleaning.* All the projections which are in excess to the required dimensions are sawn off. The shutter thus prepared is finally cleaned with a sharp plane follower by sand paper.

Hanging of the door :

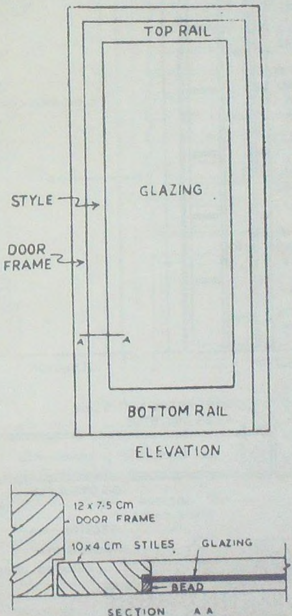
These doors are hung with the aid of butt-hinges or rising-butt-hinges.

Fittings : The following fittings are used :

Hinges	3 on each leaf
Bolts	3 Nos. of 25 cm.
Handles	3 Nos.
Door stops	2 Nos.
Aldrop and Padlock or mortise lock	1 No.

Glazed or Sash Door

When light is desired to be admitted inside a room through a



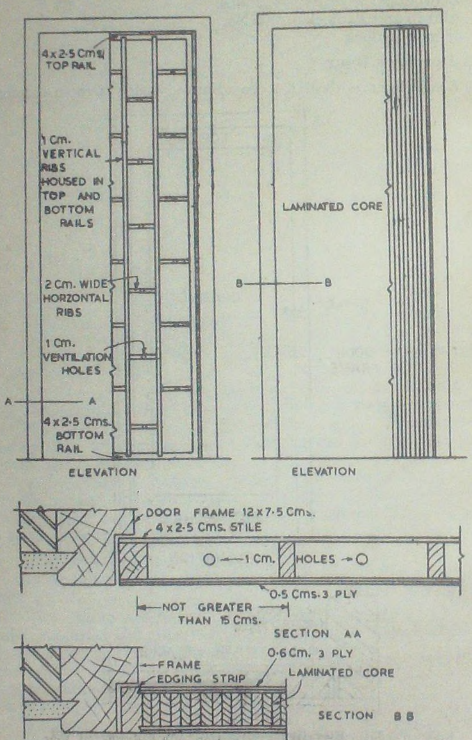
Figs. 650-651. Elevation and section of a fully glazed door.

door, its upper part may be glazed and the lower part panelled. These are called partially glazed doors. The latest trend is however, to provide fully glazed doors. Usually 5 to 8 mm thick polished plate glass is used. Special kind of glasses, e.g., reinforced with wire mesh or toughened are being used to avoid shattering.

The glasses are fixed in the rebates of sash bar and they are secured with putty or by wooden beads fixed to the frame. The sash bars do not add to the strength of the door.

Flush Doors

This type of door provides a clean surface and is extensively



Figs. 652-655. Details of flush doors.

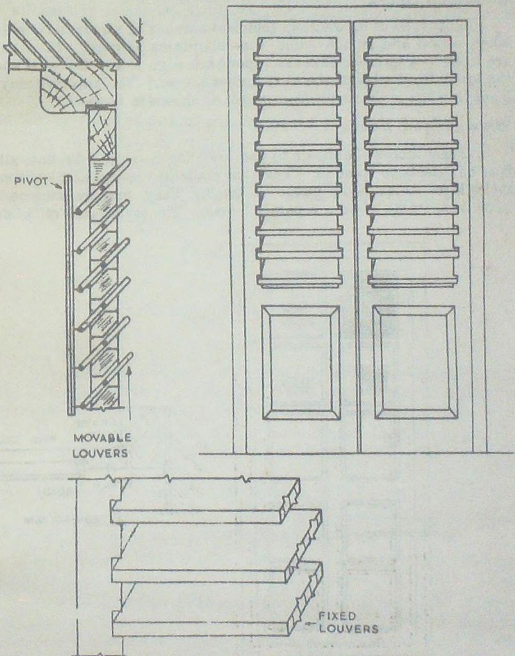
used these days. The flush surface, when polished gives a beautiful appearance.

They are of two types :

(i) *The solid or laminated core type* :

(*See* fig. 653 and for section see fig. 655).

The laminae are 1.5 cm. thick and joined together in pieces. On the outside 0.6 cm. plywood (3 plys) are fixed to the laminae. Edging strips are fitted, as shown, on the sides. This door is quite strong and sound insulating than the one described below. Sometimes instead of wooden laminae light weight material such as cork board, perforated wood resin boards and strips of compressed straw boards may also be used as a filling.



Figs. 656-658. Elevation and details of louvered doors.

(ii) *Skeleton framed type* (See figs. 652 and 654) : This door consists of very light members. The styles, top and bottom rails are 4 × 2.5 cm. in size, and 1 cm. wide vertical and horizontal ribs are fitted into them. Each side is covered with 0.6 cm. thick plywood. Special hinge blocks 15 × 4 × 2.5 cm. in size are fixed. This type of construction is cheaper and saves wood.

Construction : In the laminated type, all the components are glued together. In the skeleton framed type the vertical ribs are housed 3 cm. into the outer rails. The horizontal ribs are glued to the vertical ribs and styles. Ventilation holes are provided as shown for durability.

Hanging and fitings : As for panelled type.

Louvered Doors

This type of door allows sufficient amount of air circulation even when closed and at the same time maintains privacy. The louvers are fixed in a series so that the upper back edge of any louver is above the lower front edge of the next higher louver. The louvers may be fixed into the style or made movable as shown in figure 656.

Wire-gauged Doors

These doors enable air to pass into the room and do not allow flies or insects to come in. They are made of vertical and horizontal styles into which wire gauge is fixed. They may be hung on the same door frame or on a separate frame. The styles and rails shall

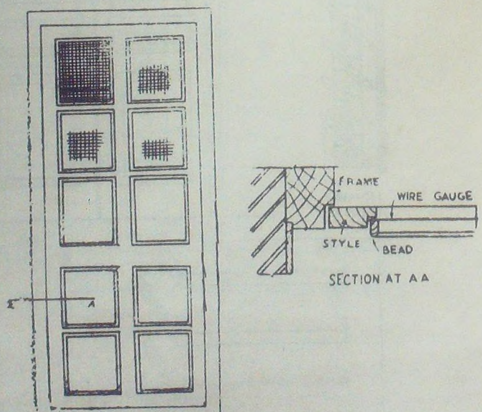


Fig. 659.660. Elevation and section of a wire gauge doors.

be of the same size as that of the other door. Wire gauge shall be of best quality woven wire webbing. The entire area of the wire gauge within a panel shall not have any joint. Wire gauge is fixed to the leaf by rails and 2×2 cm. heads are fixed. Double leaf wire gauge door shall close with the meeting styles abutting against each other. The leaves may close to such an extent that the junction projects outside from the face of the frame. The top of the frame and the sill, if any, shall have a wedge-shaped wooden projection.

Clearance under the doors

A 1.25 cm. clearance may be kept between the door and the flooring so that bottom of the door leaf clears off any carpet or other furnishing laid on the floor. This is done either by hanging the door on rising butt hinges or fixing a wooden threshold to the flooring. As an alternative a concrete flooring may be raised and sloped both ways under the door.

Door Casings

In important buildings internal doors are fixed to casings, or linings which provide a suitable finish to the openings. Following are the types of casings generally used :

(a) *Plain Casings* : They are made of plain thick wooden boards (about 4 cm.). The door leaf is fixed in rebate cut in this plank or a stop is fixed to the casing as shown in fig. 661. The top casing is grooved to receive the vertical sides. This type of casing is suitable for walls not greater than 20 cm. thick.

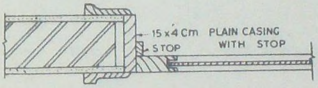


Fig. 661. Plain Casing.

(b) *Skeleton Casings.* This consists of vertical members to which thin boarding is fixed. Horizontal pieces are also fixed at intervals to give strength. These are used for thicker walls.

(c) *Framed Casings.* This is made of panelled jamb and top member and is used where architectural beauty is the main consideration.

Fixing of Casings. The methods of fixing are as under :

(i) *With Pallets.* 1 cm. thick pallet pieces are fixed at regular intervals into the masonry and to this is attached the casing.

(ii) *Plugs.* Hard wooden plugs are fitted into the wall and casing is fixed to them.

(iii) *Ground work.* These provide continuous means of fixing the casings. The jamb grounds are fixed with plugs to the wall and cross pieces, which act as packing for wide casings, are fitted to these jamb grounds.

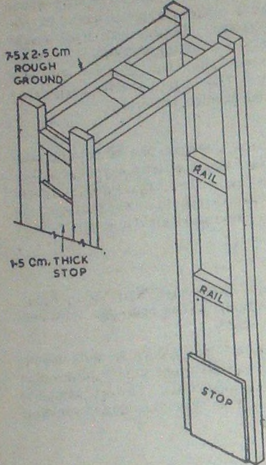


Fig. 662. Skeleton Casing.

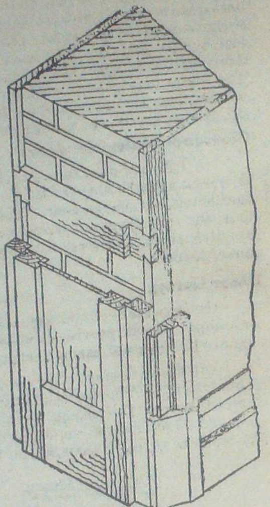


Fig. 663. Framed Casing.

Metal doors

(a) *Hollow metal doors.* They are made of furniture steel and are shaped as wooden doors in appearance. The rails, styles and places where hinges, locks, etc., are fixed are strengthened by welding small T or I Sections inside. The styles are filled with some insulating material so that there is not much noise when they are opened or closed.

(b) *Steel plate doors.* Whenever a stronger door is needed, a framework of angle or channel steel sections is built. On this, steel plates of required thickness are welded.

(c) *Corrugated steel doors.* A frame-work of angles and channels is built up with suitable bracings. On this corrugated steel sheets are fixed vertically. If a stronger door is desired, an additional sheet can be placed and the gap between the two being filled with asbestos or any other fire-proof material.

(d) *Rolling shutters doors.* These are commonly used, these days, for entrance to the garage, show-rooms and shops, where the door width is large. They are available in varying widths, upto 6 m. The shutter rolls up and causes no obstruction to the floor space.

Their operation is also easy. They are sufficiently strong and can be used in exposed situations.

(e) *Collapsible door.* These doors have the advantage that they do not require any frame or hinges to hang upon. These metallic doors are made from small rolled steel channel sections and strips. They are fitted with rollers at the bottom which slide in rails provided in the floor. When opened, they collapse to the sides. They are normally provided at the entrance of residential buildings, godowns or public buildings.

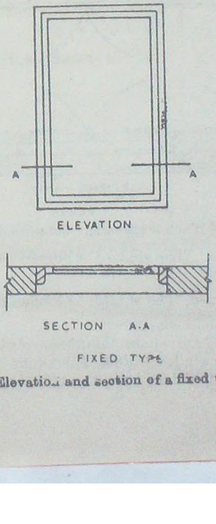
Composite Doors

Metal covered doors. They consist of cores of seasoned non-resinous timber covered with a tight fitting sheet metal, *e.g.*, furniture steel, galvanised steel, cold rolled copper, sheet bronze, tin and lead combination (terne plate), etc. The cores are made of two or three layers of 2.5 cm. boards and about 20 cm. wide. One layer should be vertical and the other horizontal. The covering is made of 35×50 cm. sheet preferably with double joint. The three-ply doors are very strong and two-ply doors give a moderate degree of protection.

In case cheaper doors of this type are needed, the same can be made by making a framework of wooden styles and rails and the inner spaces being filled with asbestos or other fire-proof material. This type has got considerable fire resistance qualities.

WINDOWS

Windows comprise of two parts, one frame which is fitted in the opening in the wall and the other sashes which are small shutter



Figs. 664-665. Elevation and section of a fixed type window

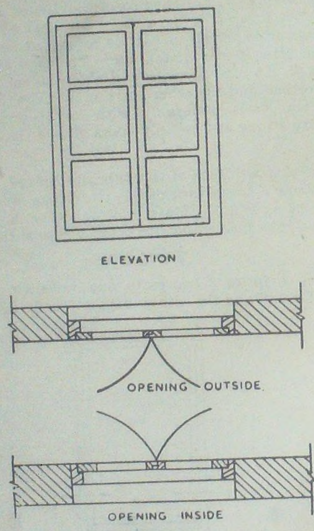
frames containing the glass and attached to the frame by hinges or retained by grooves. The type of window is determined by the type of window movement.

Types of Window Movements

(*a*) *Fixed type.* This consists of a framework in which the panel or glass is fitted and the framework cannot move.

(*b*) *Opening outside.* In this the shutters open towards outside of a building.

(*c*) *Opening inside.* Here the shutters open inside the building.



Figs. 666-668. Window Elevation and opening arrangements.

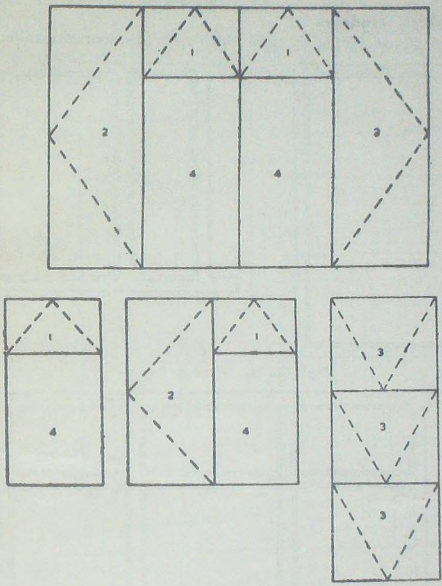
(*d*) *Top-hinged.* The shutter is hinged at the bottom and can be moved outside.

(*e*) *Bottom-hinged.* The shutter is hinged at the bottom and can be moved inside.

(*f*) *Pivoted.* These window shutters rotate about a pivot which may be fixed to the window frame. The windows can rotate horizontally or vertically depending upon the position of the pivot.

(*g*) *Sliding*. In this type, the shutters can move inside the walls horizontally or vertically.

(*h*) *Double hung*. One shutter goes up and the other moves down.



Figs. 669-672. Various types of window movements.
1. Top hung. 2. Side hung. 3. Bottom hung. 4. Fixed.

Types of Windows

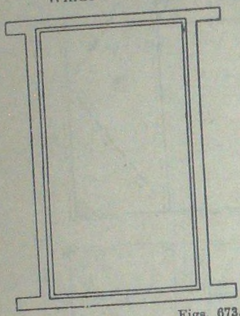
(1) Wooden Windows :
- (*a*) Casement Windows.
- (*b*) Double Hung Windows.
- (*c*) Sliding Windows.
- (*d*) Pivoted Windows.
- (*e*) Louvered or Venetiated

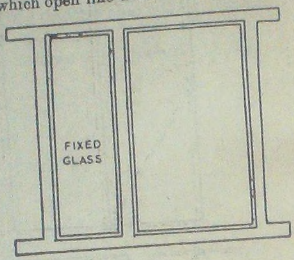
(2) Metal Windows :
- (*a*) Solid Section Metal Windows.
- (*b*) Metal Covered and Hollow Metal Windows.

(3) Miscellaneous Windows : (a) Composite Windows.
(b) Bay Windows.
(c) Clere Storey Windows.
(d) Corner Windows.
(e) Dormer Windows.

Casement Windows

Windows having shutters which open like doors are called case-





Figs. 673-74. Window frames.

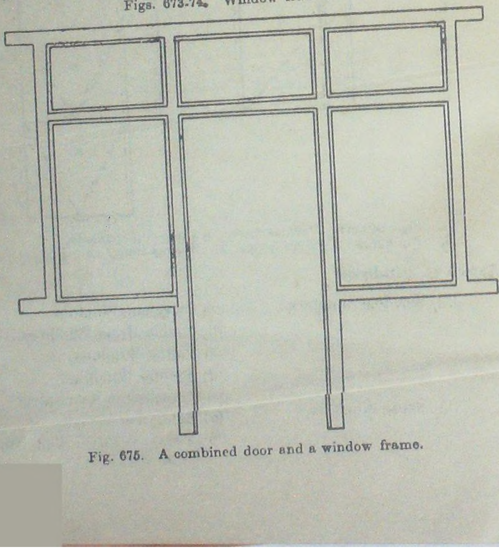
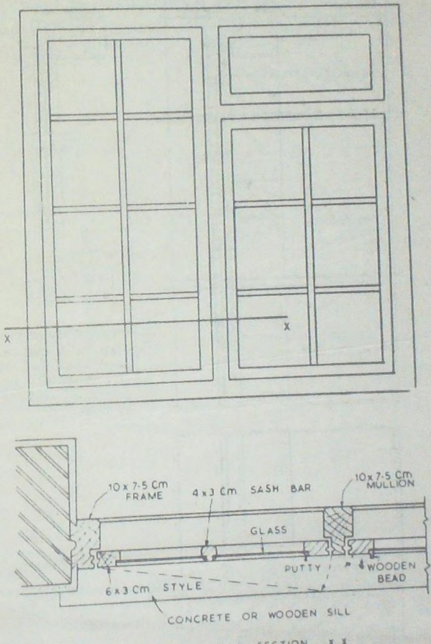


Fig. 675. A combined door and a window frame.

ment windows. This has a frame consisting of styles, top rail and bottom rail. The window frame is made in the same manner as a door frame except that it has a sill at the bottom. However, it may have an additional central vertical member which is called mullion. Additional horizontal members known as transomes may also be used. The wooden frame can be made as one unit with the door frame.

Heads, mullions and transomes are generally 10×6 cm. to 12×7·5 cm. in section. The size of sills may be more. The joints and the construction of the window frames is similar to the door frame.

The window frame is provided with iron bars or welded iron grills, particularly on the ground floor, as a safety measure against

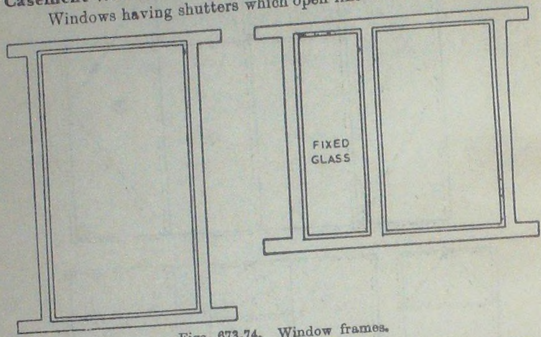


Figs. 676-677. Elevation and plan of a casement window.

(3) Miscellaneous Windows : (a) Composite Windows.
(b) Bay Windows.
(c) Clere Storey Windows.
(d) Corner Windows.
(e) Dormer Windows.

Casement Windows

Windows having shutters which open like doors are called case-



Figs. 673-74. Window frames.

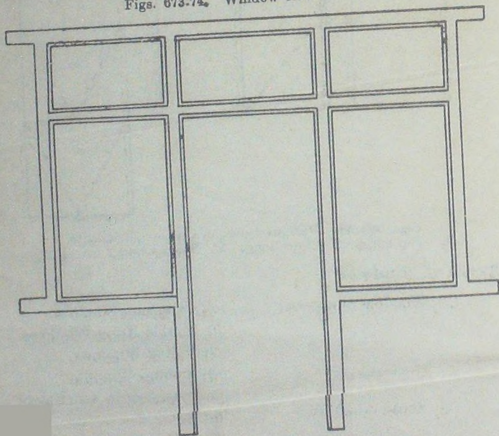


Fig. 675. A combined door and a window frame.

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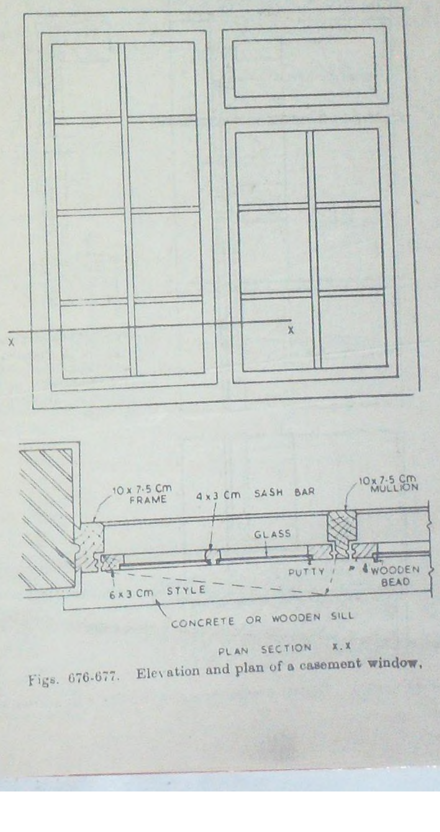
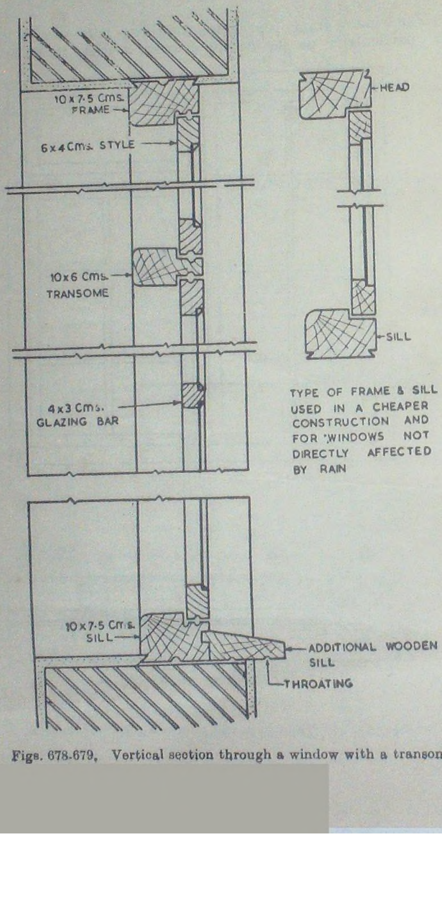


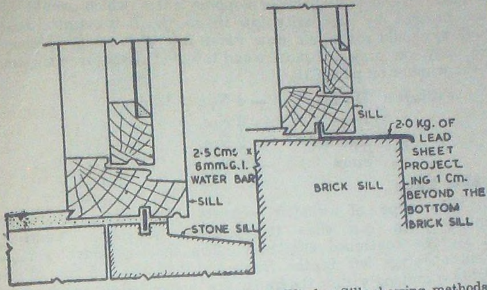
Figs. 676-677. Elevation and plan of a casement window.

burglars. Wrought iron bars varying in diameter from 1·5 to 2 cm. and spacing of 10 to 15 cm. centre to centre are used in ordinary buildings. However, the present trend is to provide welded grills with beautiful patterns.

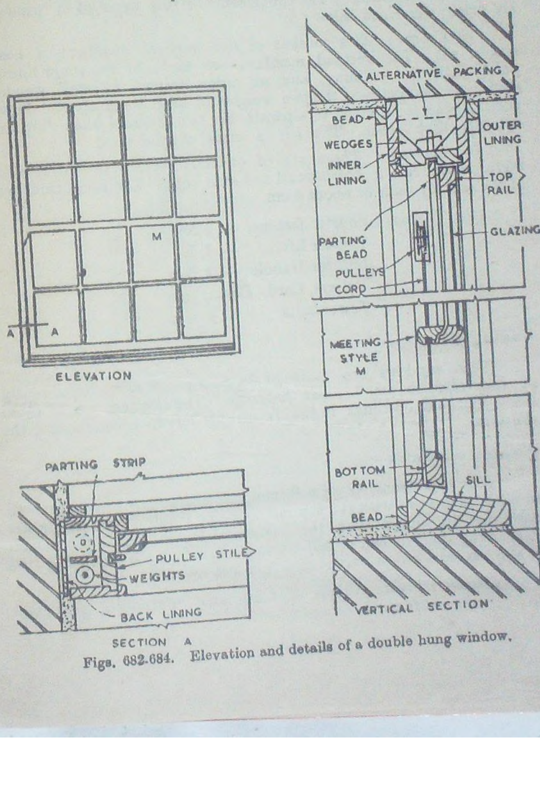
Sash or shutters which comprise of vertical and horizontal sash bars are also similarly constructed. Each shutter should not be greater than $0{\cdot}6 \times 1{\cdot}2$ m. in size. The sash bars have a size 4×3 cm. or $4 \times 3{\cdot}5$ cm. Small grooves are made in the frame and



Figs. 678-679. Vertical section through a window with a transome.



Figs. 680-681. Different arrangements of Window Sills showing methods of preventing entry of water.



Figs. 682-684. Elevation and details of a double hung window.

the rails. These are capable of stopping water which would otherwise proceed by capillarity into the room. It is essential that the windows should not admit rain water into the room. Hence the sills may be projected outside and throated as shown in the section of the window on page 231.

Fittings :	Hinges	— 4 Nos. of 10 cm.
	Bolts	— 3 Nos.
	Handles	— 2 Nos.
	Stops	— 2 Nos.

Double hung

This type of window consists of a pair of shutters both of which can slide to facilitate cleaning. Ventilation can also be controlled effectively. The shutters move vertically within openings left in the frame and the walls. A pair of metal weights contained within the frame are connected to each shutter by means of cords or chains after being passed over pulleys which are fixed to the frame. The components of this type of a window are briefly described below :

(*i*) *Frame* : This consists of two vertical members, a head and a sill. The vertical members are made of an inner lining, pulley style, back lining, and an outer lining. A small wooden section is used between the two weights to keep them apart. Small parting bead is provided to separate the two shutters when they are opposite each other. The sill is made of solid wood.

(*ii*) *Shutters* : These are of ordinary type with two vertical styles, a top rail, a bottom rail and sash bars. The usual thickness of the shutter shall be about 5 cm.

(*iii*) *Fittings* :	Shutter fastener	— 2 Nos.
	Shutter lift	— 1 No.
	Shutter Handle	— 2 Nos.
	Pulleys, Cord, Chains, etc.	
	Tower bolts	— 4 Nos.

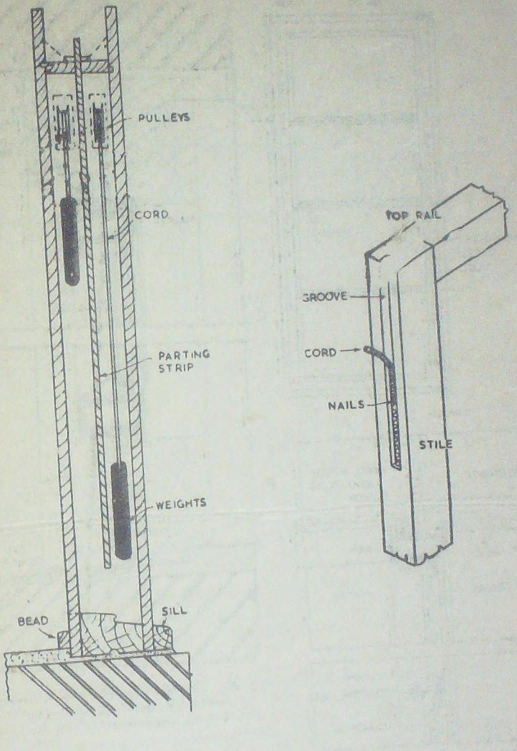
Sliding windows

These windows are made of shutters which move horizontally or vertically on small roller bearings. The shutters are of usual size. Suitable openings in the frame are left to accommodate the shutters.

Pivoted windows

This type consists of a frame and a shutter which is pivoted to allow it to open with the top rail swinging inside. The pivots are fixed slightly higher than the horizontal central line of the shutter so that the shutter can be self-closing. The frame is similar to that of a casement window except that it is not rebated.

Fittings : Pivots, Cleats, Latches and Ventilating gear, etc., are used.



SECTION THROUGH JAMB

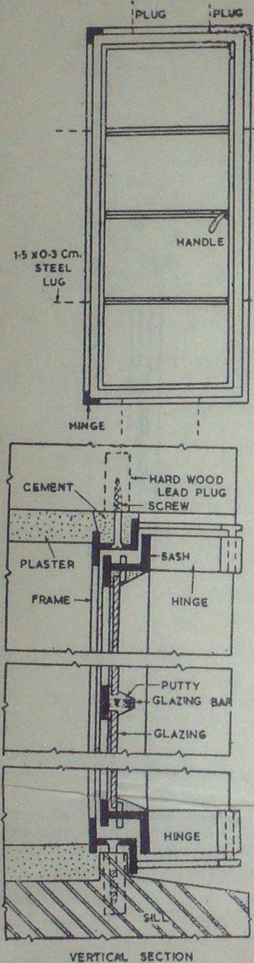
Figs. 685-686. Double hung window detail.

Louvered or Venetiated windows

… well as enough air is desired, louvered windows are used. These may be of fixed or moving type. The construction is similar to that of louvered doors.

Solid section metal windows

They are made of light rolled steel sections which act as a frame. The glazing is fitted into this frame. The shutter containing



Figs. 687-688. Elevation and section of steel window.

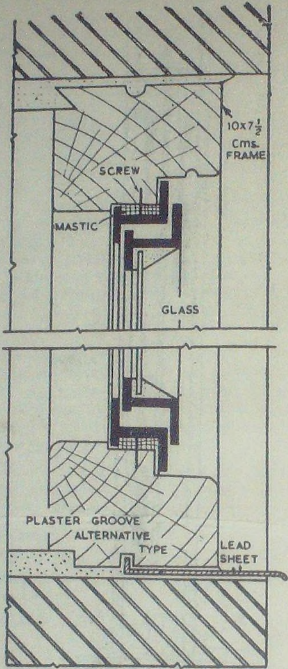


Fig. 689. Section through a steel window showing the use of an additional wooden frame surrounding it.

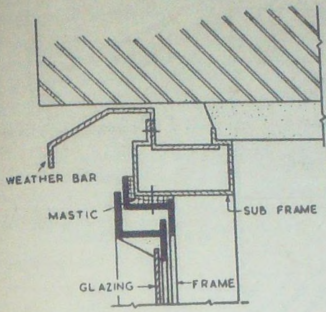


Fig. 690. Section through a steel window with a metallic subframe and a weather bar

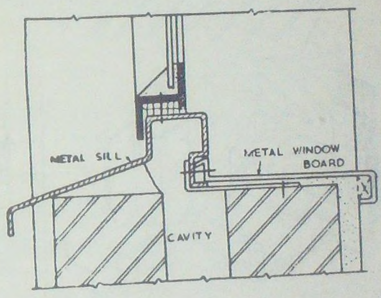


Fig. 691. Section through the sill of a steel window showing the use of metallic sills and window board.

the glass can have various types of movements, *i.e.*, it may be hinged at bottom, top, side or pivoted to move in a horizontal or vertical direction. Similarly horizontal or vertical moving shutters or double hung types are possible. The frame is fastened into the masonry in a groove with cement grout. Teak wood frame and sill can also be used to fit in the steel shutter to enhance the appearance.

Continuous windows which can be operated mechanically are used for big openings and are pivoted suitably at top.

Steel windows should receive one coat of primer before being installed. Then they should be painted with another coat of a durable paint and repainted after the glazing is fixed. The materials used for metal windows may be steel, bronze, aluminium, stainless steel, etc.

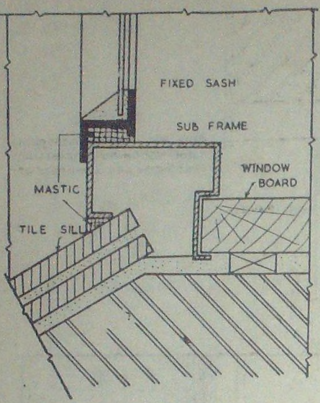


Fig. 692. Section through a steel window showing metallic subframe and tiled sill.

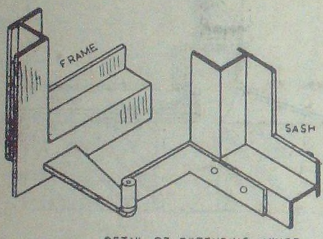
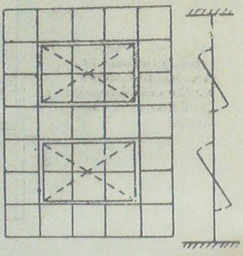


Fig. 693. Hinge for a steel window



Figs. 694-695. A typical industrial steel window.

Metal covered and Hollow Metal Windows

Metal covered windows are more fire resistant and durable than the wooden windows. They are more attractive than solid section steel windows. However, they are more expensive. Their construction is similar to that of the metal covered doors and metallic coverings described therein can be used.

Hollow metal windows are made of blue annealed steel, galvanised steel, bronze, copper or nickel steel. They are generally, double hung type or casement type. These are more fire resistant than the metal covered and the wooden windows.

Composite Window

Different type of movements can be obtained in the same window. This type of window can be adopted for a small room where only one large window is used. This can control movement of air and at the same time provide maximum light.

Bay Window

This is a window which projects outward from the face line of the wall or a building. This gives extra floor area to the room and at the same time provides an additional space for admitting light and air into the room. A number of these windows might increase the architectural beauty of the entire house.

Clere-Storey Window

It is fixed above the lean to roof but near the main roof and is of pivoted type. The shutter can be operated by a cord passing round a pulley. This window provides ventilation to the room whose front is blocked by a verandah roof.

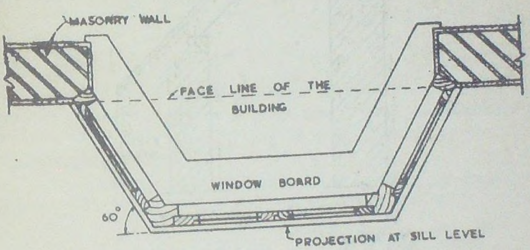


Fig. 696. Bay Window.

Corner Window

This is placed in the corner of a building so that light and air can come from the two directions.

Dormer Window

This window is provided on the sloping roof of a building. The object is to provide light and air to the room built up within the roof slopes.

Ventilators

They are provided for ventilation purposes and can be combined with a window or a door frame. They may, as an alternative, be located near the ceiling of the room if the height of the room

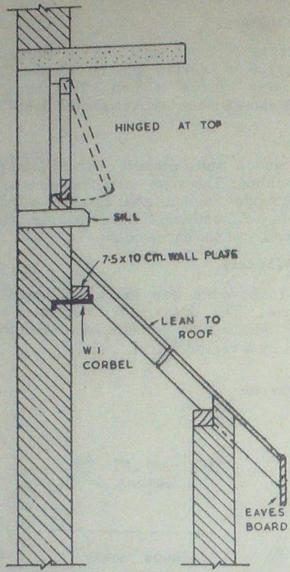


Fig. 697. Clere-Storey Window.

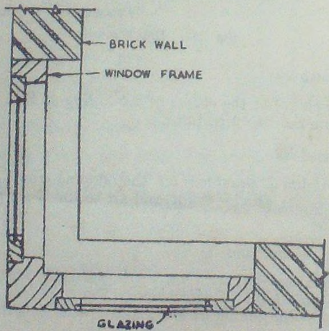
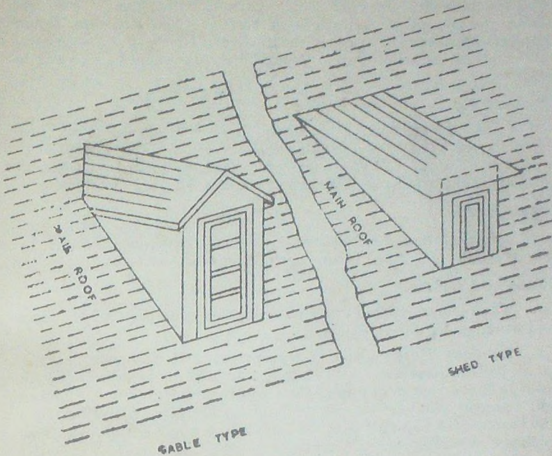


Fig. 698. Corner Window.

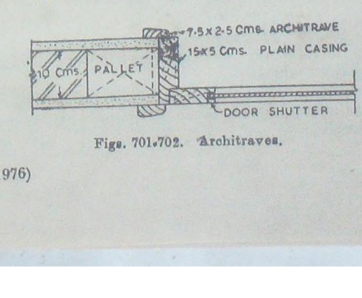


Figs. 699-700. Dormer Windows.

permits. They are usually pivoted type and can be operated with a pulley and a cord or have self-closing small bolts.

Architraves

These are used to conceal joints between the door frames or casings and the plaster at the door. They consist of two vertical



Figs. 701-702. Architraves.

and one horizontal member which have mitred angle. These are nailed to the plugs and edges of casings. The size and design depends on the size of opening, the quality of timber and the general architectural effect desired. Generally they are about 10 × 4 cm. to 6 × 2 cm.

Picture Rails

These are generally fixed at the top level of architrave and have various types of mouldings and finishes. They are fixed to the walls by plugs. They are used for hanging pictures or photographs. They are made of wood and are about 7·5 × 2 cm. in section.

Angle Beads

External angles of plaster are protected from damage by wooden beads 1 or 2 cm. in size fixed to plugs in the walls.

Glass and Glazing

The various types of glass used in the construction of doors and windows are described below :

(*a*) *Plate Glass* : This is transparent and flat glass having plain polished surfaces and showing no distortion when objects through it are viewed at any angle. Show windows, picture windows and exposed windows in costly buildings are fitted with this glass. The thickness of plate glass varies from 3 to 6 mm., however 6 mm. thickness is usually used for windows.

(*b*) *Clear Window Glass.* This is transparent, relatively thin flat glass having plain and smooth surface but small waviness of surface is present which is visible when viewed at an angle. The thickness varies from 2·5 to 7·5 mm.

(*c*) *Obscured glass.* One side of this glass is patterned while rolling which obscures direct vision but does not obstruct light. Figured glass or rough cast glass are examples of this type.

(*d*) *Processed Glass* : These are of three kinds, *i.e.*, ground-glass, chipped one process and chipped two process. There are many patterns and some provide true privacy with a uniform diffusion of light while others give maximum transmission of light.

(*e*) *Wired-Glass* : Rolled flat glass having wire mesh embedded in it is called wired glass. This is used where slight degree of fire protection or safety against breakage is desired.

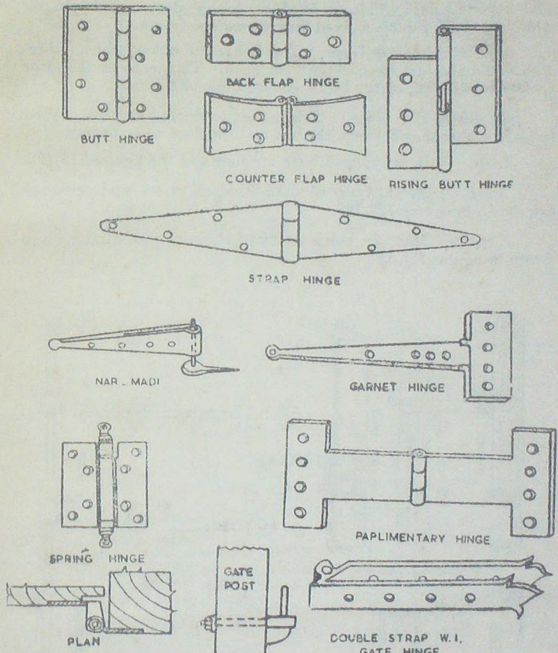
(*f*) *Prism Glass* : This has prism shaped ribs for deflecting light. The prisms with different angles are available to suit various needs.

(*g*) *Active Glass* : This reduces heat and a large percentage of glare. Also it transmits lesser amount of ultraviolet rays which bleach some coloured fabrics.

(*h*) *Quartz Glass* : This transmits ultraviolet rays and is used in hospitals where maximum benefit from sun's rays is desired for the health of the patients.

(i) *Bullet-proof Glass* : This is made of laminated plate glass which may break under impact but will not shatter.

Glazing : The process of placing glass within sash bars is called glazing. Rebates of about 6 mm. depth are provided on one side of the sash bars to support the glass. After the glass is placed, it is kept in position by means of putty, glazing beads, strips or moulds of wood. Windows are sometimes provided with two thicknesses of glass with an air space between them. This is called "Double Glazing" and is adopted in air-conditioned buildings.



Figs. 703-714. Different types of hinges for doors.

Fittings for Doors and Windows

(a) *Hinges* :

(*i*) *Butt hinges* : These are commonly used on doors and windows and are screwed to the edges of the shutters and rebates in the frame.

(*ii*) *Back-flap hinge* : This is used where the shutters are thin and butt hinges cannot be fixed. These are fixed to the back side of the shutter and the frame.

(*iii*) *Garnet hinge* : This is fixed to ledged and braced doors.

(*iv*) *Strap hinge* : This is also used on ledged doors.

(*v*) *Narmadi* : This is fixed on heavy doors. The pin on which the strap rotates is fixed into the wall or frame.

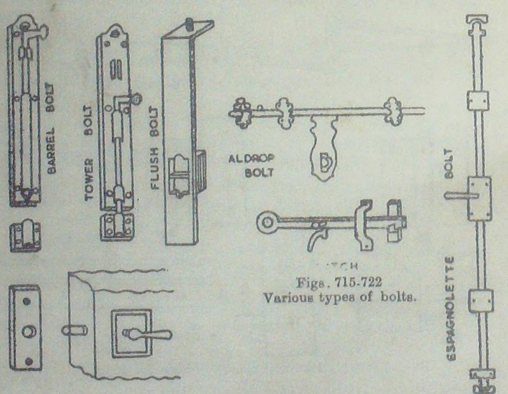
(*vi*) *Parliamentary hinge* : This is fixed to a door which otherwise would obstruct the passage when open. This enables the door shutter to rest against the longitudinal profile of the wall.

(*vii*) *Rising Butt hinge* : This is used on doors which are desired to leave a clearance between the leaf and the floor when opened.

Bolts. Various types of bolts are shown in the figures 715-722.

Locks. Different types of locks fitted on doors and windows are shown in figures 723-727.

Handles. Handles which are fitted to doors and windows are shown in figures 728-731.



Figs. 715-722
Various types of bolts.

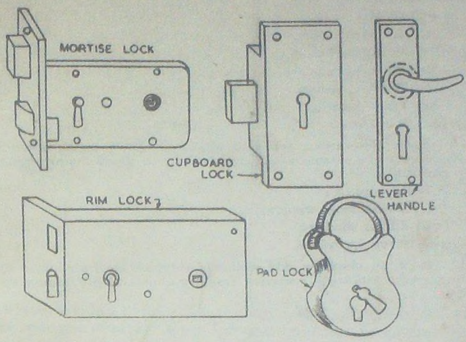
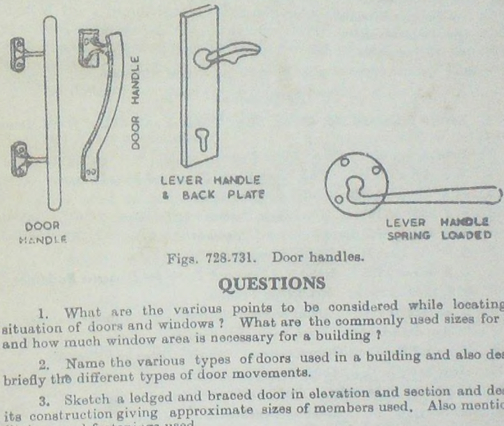


Fig. 723-727. Door Locks.



Figs. 728-731. Door handles.

QUESTIONS

1. What are the various points to be considered while locating the situation of doors and windows ? What are the commonly used sizes for them and how much window area is necessary for a building ?

2. Name the various types of doors used in a building and also describe briefly the different types of door movements.

3. Sketch a ledged and braced door in elevation and section and describe its construction giving approximate sizes of members used. Also mention the fittings and fastenings used.

4. Write short notes on :

(*i*) Ledged door.

(*ii*) Various types of panelled doors.

5. Draw detailed sketches to show the constructional joints of a panelled door shutter. Roughly sketch the various types of door mouldings.

6. What are the advantages of flush doors. Draw a section of a flush door with skeleton frame as the interior support.

7. Write short notes on :
   (*i*) Glazed doors.
   (*ii*) Louvered doors.
   (*iii*) Wire gauge doors.
   (*iv*) Plain casings.
   (*v*) Skeleton casings.
   (*vi*) Framed casings.
   (*vii*) Door frame.

8. Name the various types of windows. Draw an elevation and a vertical section of a casement window showing in detail the arrangement of water proofing.

9. Write notes on :
   (*i*) Double hinge windows.
   (*ii*) Sliding windows.
   (*iii*) Pivoted windows.

10. Draw an elevation and section of a typical steel window. Also show an arrangement for using a wooden frame or a metallic sub-frame with these windows.

11. Write short notes on ;
   (*i*) Bay window.
   (*ii*) Clere-storey window.
   (*iii*) Corner window.
   (*iv*) Dormer window.
   (*v*) Architraves.
   (*vi*) Picture rails.
   (*vii*) Various types of glass used for doors and windows.

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1. **British Standard No. 459 of 1954.** *Panelled and Glazed Wood Doors (Part I).*
2. **British Standard 459 :** *Flush Doors (Part II).*
3. **B. S. 459 Part III :** *Fire Check Flush Doors and Metal Frames.*
4. **B. S. 459 Part IV :** *Match Boarded Doors.*
5. **B. S. 1567 of 1958 :** *Wood Door Frames and Linings.*
6. **B. S. 644 of 1951 Part I :** *Wood Casement Windows.*
7. **B. S. 644 Part II :** *Double Hung Sash Windows.*
8. **B. S. 990 of 1935 :** *Metal Windows and Doors for Domestic Buildings.*
9. **B. S. 1245 of 1945 :** *Metal Door Frames.*
10. **B. S. 1422 of 1948 :** *Metal Window Subframes and Window Boards.*
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11

FLOORS

Floors divide a building into different levels, one above the other for the purpose of creating accommodation within restricted space. Bottom-most floor of a building is called ground floor unless it is below the surrounding ground level when it is termed basement floor. The object of the ground floor is to have a clean, smooth, impervious level and a durable surface. The top floors, in addition to the above objects have to be sufficiently strong so as to withstand the loads which come over the floor.

Two distinct components of the floor are :

(*i*) A subfloor or sometimes termed as base course.

(*ii*) Floor covering.

The object of providing a subfloor is to give proper support to the covering and hence loads are taken by this part. Moreover the subfloor is used to carry the covering and to make the flooring, in general, water-proof and sound-proof. A thin layer of another material may be used in between the two components.

The materials used for ground floor construction are :

(*i*) Bricks
(*ii*) Stone
(*iii*) Wood
(*iv*) Concrete

The materials used for the finishes of ground floors are :

(*i*) Bricks
(*ii*) Stones
(*iii*) Concrete
(*iv*) Tiles
(*v*) Wood
(*vi*) Terrazzo
(*vii*) Mosaic
(*viii*) Asphalt
(*ix*) Rubber
(*x*) Linoleum
(*xi*) Cork
(*xii*) Magnesite
(*xiii*) Glass

Since ground floors rest directly on the soil, it is essential to have a proper drainage for the floor. This may consist of a system of drains suitably constructed below the floor and arranged to lead the water outside the building. However, this measure is not necessary in the normal type of construction. Generally a porous layer of an inert material is provided to prevent the rise of water into the floor. The material generally used is sand, crushed rock, gravel or cinder. In certain cases asphalt layers may assist in the general drainage of the surface.

To select a suitable type of floor construction in a building certain points have to be kept in view. These are discussed on pages 260-262 and apply mostly to upper floors. However, for ground floors, the selection of the type of the wearing surface is important and the various considerations governing the suitability of one over the other are given below :

(*i*) *Initial Cost* : The cost of the floor covering is a very important item. The expensive type of floor coverings are marble, rubber tiles and special clay tiles. Terrazzo, cork, tiles, linoleum, asphalt and slate form a less expensive group of floor coverings, whereas concrete and brick are the cheapest.

However, the type of base course used with a particular covering has an important bearing on the cost of the floor, *e.g.*, if a wearing surface is to be provided on a wooden base, the cost would be different for different coverings as special treatment would be needed to fix the covering with the base in each case.

(*ii*) *Appearance* : Colour, texture and decorative value with regard to the architectural beauty of a room are the factors which have to be taken into consideration while selecting a type of floor for a room. Terrazzo, tiles and marble give a good appearance whereas an asphalt covering has an unattractive look.

(*iii*) *Durability* : Resistance to wear is an important factor for a floor covering. Further, resistance to temperature changes, humidity, disintegration and decay have to be taken into account. Tiles, terrazzo, marble and concrete floor coverings offer good resistance to these forces of disintegration whereas linoleum and rubber give less satisfactory resistance while cork and asphalt coverings have very low resistance. Wherever heavy floor traffic is not anticipated, bricks, wood blocks and asphalt mastic can be used.

(*iv*) *Cleanliness* : A floor should be non-absorbent and capable of being easily cleaned. All joints should be simple so that they can be made as water-tight as possible. Terrazzo, tiles, marble and slates provide surfaces which can be easily cleaned.

In addition to general cleanliness, a floor covering should have an effective resistance against the absorption of oil and grease which would otherwise give a very unsightly appearance. Greasy substances are not absorbed by tiles but affect terrazzo, concrete, and bricks to some extent. Grease, oil and gasoline distinegrate asphalt and rubber floors to a considerable extent.

(*v*) *Dampness* : Resistance to damp is an important factor to be considered for ground floor construction. Wood, rubber, linoleum and cork coverings are not suitable in damp places wherease clay, tiles, bricks, concrete and terrazzo are suitable for use on floors which are subjected to dampness.

(*vi*) *Indentation* : It is desirable that indentation should not occur when loads are to be supported by a floor. In the case of lighter loads also, *e.g.*, chairs, tables, etc., care should be taken that the floor covering does not get any imprint. Certain floor coverings do not get any mark on account of loads but some of the floor coverings get imprints which are not visible after the load is removed. Examples of the first type are concrete and other hard floor coverings whereas asphalt and rubber surfaces belong to the latter type.

(*vii*) *Noiselessness* : While this is not an important factor for ground floor construction, however, care should be exercised to ensure that the floor is somewhat noiseless when travelled over. Wood, linoleum and asphalt are good in this respect whereas cork and rubber coverings are much superior.

(*viii*) *Maintenance* : To keep the surface in good condition, it is necessary to clean, repair and apply any other treatment from time to time. Tile, marble, terrazzo and concrete surfaces need less maintenance whereas wood blocks, mastics and corks may need frequent maintenance. However, concrete surfaces cannot be repaired easily while tiles of marbles or slates can be replaced quickly.

Types of floors

The various types of floorings used in ground floor construction are :

(*i*) Brick flooring
(*ii*) Stone flooring
(*iii*) Concrete flooring
(*iv*) Tiled flooring
(*v*) Wood-block flooring
(*vi*) Terrazzo flooring
(*vii*) Mosaic flooring
(*viii*) Asphalt flooring
(*ix*) Rubber flooring
(*x*) Linoleum flooring
(*xi*) Cork flooring
(*xii*) Magnesite flooring
(*xiii*) Glass flooring

A brief description of these is given below :

(1) **Brick flooring** : These are commonly used in cheap construction and where good bricks are available. Well burnt bricks of good colour and uniform shape are used. The filling, over which this floor is to be laid, should be well compacted. The level of the floor-

ing top being known, the filling is excavated to the desired depth. This depth of excavation depends upon the type of beddings to be provided for the brick bearing surface. Generally two types of beddings are provided. In the first type, after excavation the surface is levelled and rammed carefully. On this bed, 7·5 cm. layer of sand is spread over which a course of brick laid flat in mortar is built. This acts as a sublayer for the brick wearing course. As an alternative a lime concrete mix or lean cement concrete mix (one part of cement, six of sand and 18 of aggregates 3.75 cm. size) of 10 to 15 cm in thickness is laid on the compacted bed. The bricks for the wearing course are laid on edge breaking bond with each other. However, herring bone

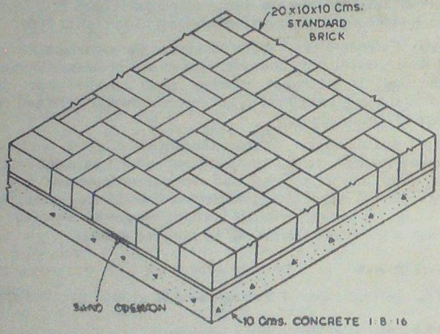


Fig. 732. Brick flooring.

pattern can also be used. The bricks are cemented by the use of cement or lime mortar and the joints are pointed to get good finish. For pointing, the mortar is raked out from the joints to a depth of 2 cm. and cement pointing carried out. The whole surface is cured with water for a suitable period. Whenever brick flooring is used just outside the building, the brick joints are simply grouted with dry sand, known as sand grouting.

(2) **Stone Flooring :** This type of work is also called paving. This consists of comparatively thin slabs of stone laid on concrete bedding. For damp and black cotton soil, a layer of sand or rubble is used as a cushion below the base. After excavating to the required depth, the earthen base is levelled, rammed and watered. Then a concrete layer 10 to 15 cm. in thickness is laid and rammed thoroughly. The stone slabs used should be of a hard, durable and even quality and of as uniform thickness as possible. They should be finely chisel dressed on surface and should have their edges true and parallel from side to side. In laying the slabs, work is started from two diagonally opposite corners and brought up from both sides. At the corners, two slabs are laid on mortar about 2.5 cm. thick and securely

pushed so as to conform to the level of the floor. A string is stretched from the top of one slab to the top of other and all intermediate slabs are laid in a manner so that their tops touch the string. Each slab is firmly bedded on stiff mortar and tapped with a wooden mallet. However, when a slab gets lowered than the floor level, it is not raised by inserting small stone chips from below but is relaid on fresh layer of stiff mortar. The joints between the individual stones should not exceed $\frac{1}{4}$ cm. but considerably thin joints can be put in better quality of work. After the slabs of stone are laid, the mortar in the joints is raked out to a depth of about 1 to 2 cm. and the joints

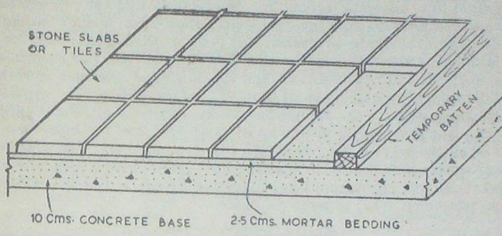


Fig. 733. Stone flooring.

are pointed flush with cement mortar (1 : 3). For the flooring of this type, a slope of 1 in 40 has to be given for proper drainage. Polished stone slabs are laid to a definite pattern, breaking joints with each other. It may be necessary to rub this flooring with carborundum stones and to apply a suitable wax polish for giving a final finish to the floor.

(3) **Concrete Flooring :** Concrete floors are most commonly used these days in residential, commercial and public buildings. The two components of a concrete flooring are :

(*a*) a base and

(*b*) a wearing surface.

The flooring can be constructed either monolithically, *i.e.*, base layer is laid and then immediately a concrete topping is provided or non-monolithically the topping is laid after the base has set. Monolithic construction has got certain disadvantages, which are :

(*i*) The topping is likely to get damaged due to subsequent building operations.

(*ii*) It is likely to develop hair cracks on account of small settlements which may occur in the base course immediately after it is laid.

(*iii*) When the surface of the topping gets damaged, it is very difficult to repair it.

(*iv*) The progress is slow since the topping can be laid only after the base course has sufficiently set to allow the workman to lay the top layer.

However the advantage of monolithic construction is that a smaller thickness is needed as the bond between the base course and the topping is good.

The type of floor finish generally used for the topping is either an ordinary concrete finish or a granolithic finish which is concrete made up of specially selected aggregates. The thickness of granolithic concrete should not be less than 1.25 cm. When the thickness is between 1.25 cm. to 4 cm., the finish should be laid monolithic with the base. When it is greater than 4 cm., this may be laid either monolithically or after the base concrete has hardened. Expected wearing of the surface and the nature of the base surface will determine the thickness of topping. If the thickness of topping is not greater than 4 cm. for non-monolithic construction, the topping may be laid in one layer otherwise in two layers, the top layer being laid when the bottom layer is still in plastic condition. The grading of aggregates should be such that the floor should give a granolithic appearance. A typical grading suggested by the National Building Organisation (N.B.O.) is given as under.

I.S. Sieve	Corresponding B.S. Sieves	%age by weight passing each Sieve
12 mm.	$\frac{1}{2}''$	100
9 mm.	$\frac{3}{8}''$	85-100
No. 480	$\frac{3}{16}''$	0-20
No. 240	No. 7	0-5

Generally hard fine grained granite, basalt, limestone and quartzite stones are suitable for coarse aggregate. Preferably crushed aggregates should be used to get a granolithic finish. Granolated metal is sometimes used as coarse aggregates. The fine aggregates used are the natural or crushed sands and a suitable grading as suggested by N.B.O. is given below:

I. S. Sieve	Corresponding B.S. Sieve	%age by weight passing I.S. Sieve
9 mm.	$\frac{3}{8}''$	100
No. 480	$\frac{3}{16}''$	90-100
No. 240	No. 7	75-100
No. 120	No. 14	55-90
No. 60	No. 25	35-59
No. 30	No. 52	10-30
No. 15	No. 100	0-10

For ordinary concrete finish, the proportions of the concrete mix should be 1 : $1\frac{1}{2}$: 3. However, under controlled mixing conditions, 1 : 2 : 4 ratio with carefully selected aggregates may be used. For granolithic finish a mix of 1 : 1 : 2 is suitable but a careful selection of aggregates is essential.

Before laying the topping, the base concrete which may be about 10 cm. in thickness is laid. The top surface of this base is finished roughly so as to get the desired bond between the base course and the topping. This concrete is generally of lean proportions and lime concrete is mostly used. For laying the topping, the surface of the base is cleaned and the work is planned in such a way that pouring can be done with ease. Whenever monolithic construction is desired, the wearing coat is placed within 45 minutes to 4 hours after placing the base.

For non-monolithic construction, the surface of the base concrete is brushed with a stiff broom and cleaned thoroughly. It is wetted the previous night and surplus water is brushed off. The floor is laid in rectangular panels made with the help of battens set on mortar beds. The panels used are not greater in size than 2×2 m. Generally in exposed floorings 1×1 m. panels are used. These battens are laid to the desired level and slope. The concrete is poured into these bays after a grout of cement sand mix is applied to the base course. Concreting of alternate bays is done at one time and the intermediate bays are not laid earlier than 72 hours. This enables most of the initial shrinkage to take place. As soon as the layer of concrete is even, the surface is rapidly compacted by ramming or beating and screeded to a uniform level and line. This is followed by trowelling. The trowelling is done to give a level surface just after the laying of concrete. Further trowelling is done when the mix has stiffened to a point where a solid well compacted surface can be obtained without bringing up the slurry. Dusting of the surface with neat cement to facilitate trowelling or the application of a cement slurry to the surface should not be permitted.

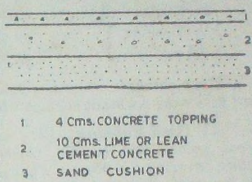


Fig. 734. Concrete flooring.

The floor thus laid is protected from sunlight, wind and rain for at least 12 hours but preferably 24 hours. It is then kept wet by spreading a layer of wet sand for a period of at least 7 days. As an alternative, special membranes can be used for curing. In the case of granolithic finish, the surface may be rubbed to get a better finish. The grinding is delayed sufficiently to prevent displacement of the aggregates. Power operated machines, fitted with abrasive stones, can be used for rubbing the floor surface. The surface is kept wet while it is rubbed. Any holes or depressions appearing on the surface are finished with an application of a thin cement grout which is allowed to set for a period of 3 days and then rubbed again.

Non-slippery surfaces can be obtained by incorporating suitable abrasives, *e.g.*, silicon carbide, carborundum, aluminium oxide in granular form at the rate of 3 to 6 kg. per square metre of the surface depending on the thickness of the topping.

For surface hardening, three coats of sodium silicate are given, each being applied after the previous has dried.

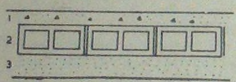
In ordinary type of concrete flooring, the topping is replaced by only a thin coat of cement mortar 1 : 1 mix rendered on the base course which is generally of cement concrete. On lime concrete bases, thicker rendering is needed.

For getting a coloured finish, either coloured cements are used or to get the different colours, pigments as specified below may be used for every cubic metre of concrete in the topping.

Red colour	$\frac{1}{10}$ cu.m. red oxide of iron powder.
Terra-cotta colour	Burnt yellow ochre.
Black colour	$\frac{1}{30}$ cu.m. of manganese dioxide.
Buff colour	$\frac{1}{25}$ cu. m. of yellow cochre.

Floor paints in various colours are available and these give a hard and wear resistant surface which is also water-proof.

(4) **Tiled flooring**. Clay tiles of various shapes, sizes, thicknesses, colour and surface finishes are manufactured for use as surface covering for floors. Flooring tiles are set on a concrete base with mortar. Special bedding made up of emulsified asphalt and Portland cement is available for use over wood, steel and concrete bases. The concrete bedding is generally of 15 cm. in thickness and is laid evenly with a slight rough surface at the top. After a period of 2 to 3 days, a mortar layer of 1 : 1 mix is spread on the concrete bed and the tiles are set truly and evenly with a thin paste of cement applied to their sides. They are slightly tapped till the cement oozes out through the joints to the top surface. This extra cement is wiped off and the joints are cleaned with saw dust. After 2 to 3 days, these joints are rubbed with carborundum stone to chip off all the projecting edges or surfaces. The whole surface is then polished with a very soft carborundum stone followed by a pumice stone. Finally the surface is washed with soap. This process of rubbing with carborundum stone is not suitable for tiles which have a glazed surface.



1 5 Cms. CONCRETE TOPPING

2 HOLLOW TILES

3 SAND CUSHION

Fig. 735. Hollow tiled flooring with concrete topping.

Floors may be built of hollow tiles which act as a base and the same are covered with a layer of concrete. This type of floor ensures freedom from damp. A cushion of sand should be given below the tile layers.

(5) **Wooden flooring**. This type of floor construction is not extensively used but is popular for special purpose floor, *e.g.*, in auditoriums, hospitals, etc. The various types of wooden floorings used are :

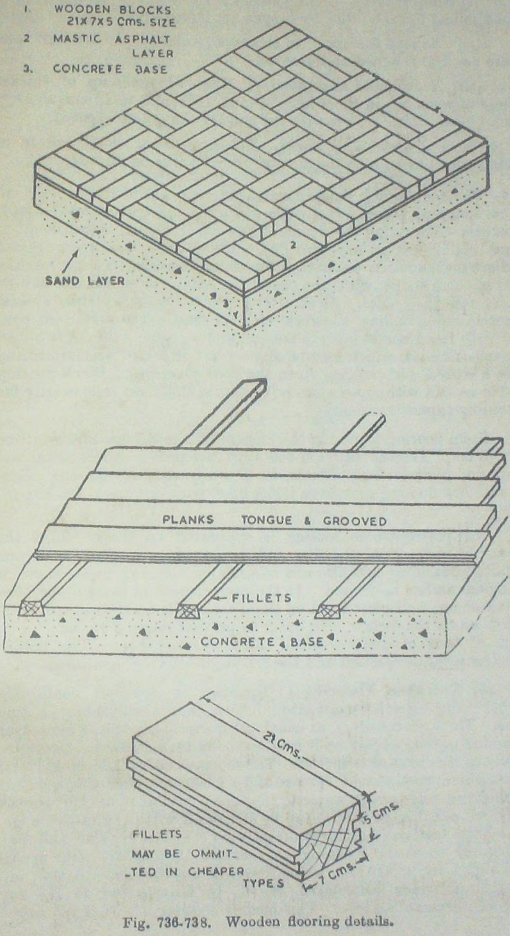


Fig. 736-738. Wooden flooring details.

(*i*) *Strip flooring.* This consists of narrow and thin strips of wood joined to each other by tongue and groove joint.

(*ii*) *Planked flooring.* In this type, wider planks are used and these are also tongued and grooved.

(*iii*) *H-avy wood block flooring.* These are made up of thicker pieces of wood cut in short lengths ranging from 5 to 10 cm. so as to form blocks which are set with the ends of the grains exposed.

(*iv*) *Fabricated wood blocks.* These consist of small square or rectangular blocks with tongue and groove joints on all sides.

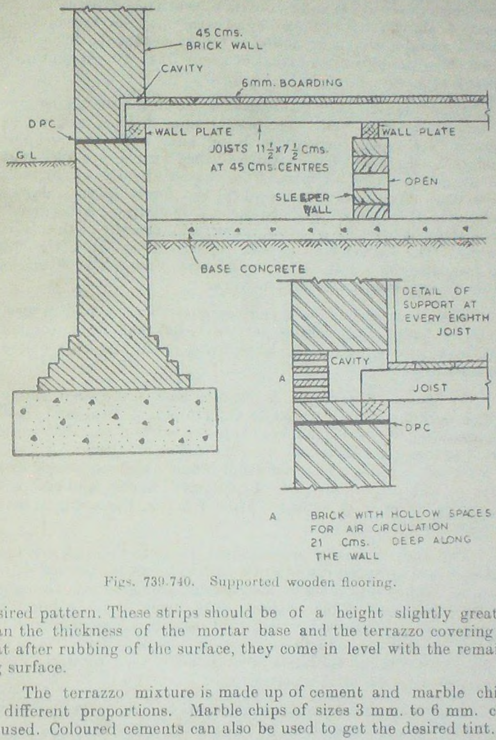
Wooden flooring should have a concrete base or should rest on joints spanning across dwarf walls which are constructed at suitable intervals. For fixing the wooden floors on concrete slabs, longitudinal nailing strips are provided. These have a bevelled section and are embedded in concrete at suitable intervals. To increase the hold of these strips with the concrete, nails or other fixtures can be driven into their sides. As an alternative to nailing strips, special concrete called nailing concrete may be used. The surface in contact with the concrete layer is treated with an application of bitumen or asphalt mastic which may be applied hot or cold. Special flooring nails are used for nailing down the floor coverings. Plank flooring should be laid with metal spacers 1 m.m. in thickness temporarily for providing expansion joints.

Strip flooring is used in thicknesses of 2 to 2.5 cm. and width of 6 to 10 cm. Thicker floors of this type are used in warehouses, factories and gymnasiums. Planks for flooring are about 20 cm. wide. Wood block flooring may have joints filled with bitumen for expansion.

For places where flooring is supported on dwarf walls, the intermediate space is left hollow. This provides an effective means of damp prevention and also can be used for dancing halls where a springing action is desired. In the construction of these floors, the joists rest on wall plate fixed on the dwarf walls and the boarding is nailed on to the former. In order to prevent damp a 15 cm. thick layer of lean concrete is spread on the earthen base. The hollow space between the ground and the floor is effectively ventilated.

(6) **Terrazzo Flooring :** Terrazzo is concrete containing marble chipping as an aggregate. The surface is rubbed to a fine finish. The base course is, as usual, of concrete. On this, a thin layer of sand is spread evenly and is covered by tarred paper. Over this a layer of rich mortar is spread. The mortar base should be at least 3 cm. thick and should consist of 1 : 3 cement sand mixture. It should have only enough water to produce a mortar of as stiff consistency as possible so that it can be struck off with a straight edge. The mortar base can be placed directly on the concrete slab and can be bonded to it by cleaning the surface thoroughly. But in this case, slight irregularities, which develop in the base course on account of minor settlement would be transmitted to the top layer of terrazzo mixture. This mortar bedding is struck off about

1 to $1\frac{1}{2}$ cm. below the finished floor level. Metal dividing strips of 20 gauge in thickness are inserted into the mortar base to form the



Figs. 739-740. Supported wooden flooring.

desired pattern. These strips should be of a height slightly greater than the thickness of the mortar base and the terrazzo covering so that after rubbing of the surface, they come in level with the remaining surface.

The terrazzo mixture is made up of cement and marble chips in different proportions. Marble chips of sizes 3 mm. to 6 mm. can be used. Coloured cements can also be used to get the desired tint.

A uniform surface is absolutely essential and hence thorough mixing of the ingredients is desirable. The chippings should be thoroughly mixed dry followed by the addition of cement and remixing the ingredients. The materials should not be heaped so as to cause segregation but should be spread evenly on a made up platform. The amount of water added should be such so as to produce a plastic mixture which will stay without segregating if heaped.

After the mortar base has hardened, the terrazzo mixture is placed to the top level of the dividing strips. It is screeded by running a straight edge over it and the surface is rammed to consolidate the terrazzo and to obtain a level surface which is finally trowelled slightly. Additional aggregates may be spread on the finished surface while compacting or rolling so that the final surface is covered with chips to an extent of about 70 to 80 per cent of the exposed area.

After the terrazzo mixture has hardened, the surface is ground by hand or by a machine. The first grinding is done with a coarse carborundum stone, the surface being kept profusely wet while grinding. All pores or holes, which become visible, are filled with a fine identically coloured mix. This is kept slightly above the rest of the floor. The surface is again kept wet for at least 5 days and finally ground with a fine grained carborandum disc. After grinding, the surface is washed with hot water and cleaned with soft soap solution. The washed floor is wax polished to prevent the chippings from absorbing dust. The new terrazzo floor is washed and wax polished every week for several months.

This type of flooring is more expensive and is used where an attractive, clean and durable surface is desired. It is commonly used in hospitals, public buildings, living rooms and bath rooms of residential buildings.

(7) **Mosaic Flooring :** A concrete base is prepared and over it lime surkhi mortar is spread to a depth of 5 to 8 cm. and levelled. The area over which this is spread is restricted to a suitable working period so that the mortar may not get dried before the floor is finished. A layer of cementing material about 3 mm. thick consisting of two parts of slaked lime, one part of powdered marble and one part of puzzolona material is spread. After 4 hours, the laying of marble pieces or tiles is started.

The tiles or marble pieces should be cut to the desired shapes and sizes and arranged into definite outline to get the desired pattern. They are broken into cubes or wedges and hammered into the mortar at the outer line of the pattern. The inner area is filled with coloured pieces of marble in the desired fashion. A stone roller about 30 cm. in diameter,. 45 to 60 cm. long is passed over the surface gently, water being sprinkled every now and then to work up the cement between the marble pieces.

The surface, thus prepared is allowed to set for 24 hours and is rubbed with a pumice stone $20 \times 25 \times 7$ cm. fitted to a long wooden handle. The object is to polish the surface and to make it smooth and level. The floor is dried for about two weeks before use.

(8) **Asphalt Flooring** : Asphalt floors are of two types :

(*a*) *Asphalt tiles* : These are made from asphalt, asbestos fibres and inert materials under pressure. They are square and vary in sizes from 20 to 45 cm. and in thickness from 3 to 6 mm. They are used as a covering for wooden or concrete floors. On wooden floors, an asphalt saturated felt is first fixed to the wooden surface and the tiles are cemented to it. As an alternative, a mastic layer can be used for fixing. On concrete floors, the tiles are directly cemented to the floor. These tiles are resilient, non-absorbent, moisture-proof and relatively cheaper. They are used in schools, offices and hospitals.

(b) *Asphalt mastic* : Asphalt mastic is a mixture of fine aggregates (sand) and natural or artificial asphalt. It can be mixed hot and laid in continuous sheets or pressed into blocks which can be used as a flooring. As an alternative it is mixed with a mineral oil and asbestos and applied cold.

For hot mix construction, the asphalt is broken into pieces of not more than 250 gm. in weight and put into an iron pot which can be heated from underneath. While heating, the asphalt is stirred thoroughly so that the layer at the bottom may not get burnt. When the whole quantity is fused, sand or grit equal to twice the volume of asphalt is added gently and mixed thoroughly. This mixture is then ready for laying.

An ordinary concrete or wood base may be used for laying this mixture. If the wooden base is used, a tarred paper layer is introduced. Gauges are erected at the sides of the portion which is proposed to be laid with mixture. The mix is poured and spread by means of trowels into uniform thickness. Straight edges are used for giving a levelled surface. A thin layer of sand is spread over this and rubbed with a trowel. At the end of the day's work, the joints in the mastic are lapped as shown.

Generally 2·5 cm. thickness is sufficient for ordinary floor construction.

In the cold process, the ingredients are mixed without heating and a fluxing mineral oil is added to obtain a soft consistency suitable for laying. Pigments may be added for improving colour.

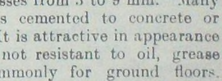


Fig. 741. Joint in mastic flooring.

(9) **Rubber Flooring** : Rubber flooring is made of pure rubber mixed with fillers such as cotton fibre, granulated cork or asbestos fibre and desired coloured pigments. Suitable patterns can be incorporated. It is used in thicknesses from 3 to 9 mm. Many colours and patterns are available. It is cemented to concrete or wood in the same manner as linoleum. It is attractive in appearance and elastic. However, rubber floors are not resistant to oil, grease and gasoline. They are not used commonly for ground floors. Rubber flooring can be made in sheets or tiles of suitable size and thickness.

(10) **Linoleum Flooring**. This is used as a covering for wood and concrete floors. Plain and printed varieties of linoleum are available in thicknesses from 2 to 6 mm. and in rolls which are about 2 m. to 4 m. wide. Linoleum tiles are also available for specific uses. The patterns made on the linoleum surface are durable

but when they get tarnished sufficiently, the covering should be varnished. Linoleum coverings are laid on concrete and wood with a layer of saturated felt in-between to act as a cementing material. If cemented directly to the flooring, there is a liability of its getting torn on account of the movement in the floor boards due to expansion or contraction of the planks. Moreover, depressions which appear on the surface of the linoleum boards shrink and give an unattractive appearance. Plywood boards, if used, as a sub-base for the linoleum flooring, the depressions caused otherwise are not visible. Linoleum coverings are attractive, resilient, durable, cheap and can be cleaned very easily. Varnishing and waxing the surface would give a longer life and help in the cleaning of the surface. Linoleum, however, is not used for basements.

(11) **Cork Flooring** : These are suitable for use in churches, theatres, public libraries and other places where noiseless floor covering is desired. This should not be used in basement or floors where dampness prevails. They are available as cork carpet and cork tiles. Base may consist of a concrete floor or wooden flooring. The cork flooring is fixed in a manner similar to the linoleum floor covering. It may also be fixed directly to wooden floors. Cork tiled flooring is available in various shades and is made up of cork shavings compressed in moulds to a thickness of about 12 mm. and baked subsequently for effective cementation of the individual components.

(12) **Magnesite Composition Flooring**. These are patent type of floor materials available for use on special occasions. Magnesite composition flooring consists of a dry mixture of magnesium oxide, asbestos or other inert material and a pigment. Liquid magnesium chloride is added on the job to form a plastic material which is trowelled to a smooth finish. This mixture sets to a hard surface in a few hours. Flooring of this type is generally 12 mm. thick. Thicker floors are laid in two layers. The lower layer is of fibrous nature whereas the upper layer is harder. Base of wood, concrete or steel plates can be used for supporting this composition. For wooden bases, a foundation of metal lath is necessary to increase the hold of the composition on the smooth wooden surface. This type of flooring is not very attractive and is less durable than clay tiles, terrazzo and marble. However it is less noisy than these floors. It is used in schools and in office buildings.

(13) **Glass Flooring**. Glass floors are used wherever it is desired to admit light into the basement through the top flooring. The glass blocks are fitted within frames of various types. They are of special shapes, if it is desired to transmit light at an angle to the farther areas in a room. Structural glass is available in the form of tiles or slabs and in thicknesses from 12 to 30 mm. The framework is spaced close apart so that the glass can stand loads coming over it. Glass floorings are not commonly used.

UPPER FLOORS

Selection of a suitable type of construction for upper floors of a building depends upon a number of factors, some of which are detailed below :

(1) *Floor Loads* : Light loads can be taken by any type of floor construction whereas heavy loads need special types of floors., e.g., steel joist with thin slabs of stone over them are suitable for light loads whereas for heavy loads thick reinforced concrete slab and beam construction is necessary. The use of flat slab construction will not be advantageous if only light loads are to be catered.

(2) *General type of Construction* : If beams, girders and columns are of wood, the floor construction will also be of wood whereas for steel framed building, the floors may be of concrete or steel and concrete type. Concrete framed structures should have R.C.C. floors. If brick walls are used to take the loads, flat slab construction is not possible.

(3) *Plan of a Building* : If a building is divided into rectangular panels which are nearly square in size, flat slab construction is possible. For short spans, simple slabs are economical whereas for long spans ribbed slabs will be satisfactory.

(4) *Initial Cost* : The initial cost of construction is directly dependent on the type of floor construction. As far as the direct cost is concerned, the various types of floors may be arranged in the following order :

(*i*) Wooden single floors or R.C.C. battened floors.
(*ii*) Light steel joist with timber planks.
(*iii*) Double and framed wooden floors.
(*iv*) Steel joist with R.C.C. slab or jack arches :
(*v*) R.C.C. slab and beams.
(*vi*) R.C.C. ribbed slabs or flat slab construction.
(*vii*) R.C.C. ribbed slabs with clay tiles.
(*viii*) Hollow clay tile arches and steel beams.

However, wooden floors may be costlier at places due to the non-availability of timber and similarly concrete floors may cost more where wood or stone slabs are in abundance, *e.g.*, in hilly areas.

The indirect cost which accounts for the cost of the base course, special ceilings, increased cost of sub-structure to support a given flooring and the increased height of a building on account of the use of thicker floorings affects the type of floor to be selected. Examples are the use of special nailing strips for laying a wooden floor on a concrete surface. Wearing surfaces, *e.g.*, linoleum, cork, etc., need a smooth and strong base course of concrete or wood flooring. Tiles, marble and terrazo will need concrete bedding. Plastered ceilings are needed for floors which have large projections underneath. Flat slabs on other hand do not need any additional ceiling. Whenever metal lath and thicker plaster layers are used for the construction of ceilings, the cost gets increased. Heavier type of floors will need stronger supporting structure. The use of flat slabs as flooring provides maximum room height. Concrete slabs supported on beams reduce the clear available floor height. Increased height means increased cost due to the cubic content of walls getting increased, the height of stairs being increased and heavier foundations being needed to support the increased loads.

(5) *Function of the Building* : The use to which a building is to be put determines the general type of construction needed. This factor, as already described under item (2), has an important effect on the selection of a suitable flooring. Moreover, the type of flooring loads, need for fire-proof construction, use of ceilings and other architectural features will limit the type of flooring which can be used under the given circumstances. Monumental or palatial structures will need a very decorative type of a flooring and this may be the deciding factor for selection.

Types of Floors

The various types of floorings used for the construction of upper floors are :

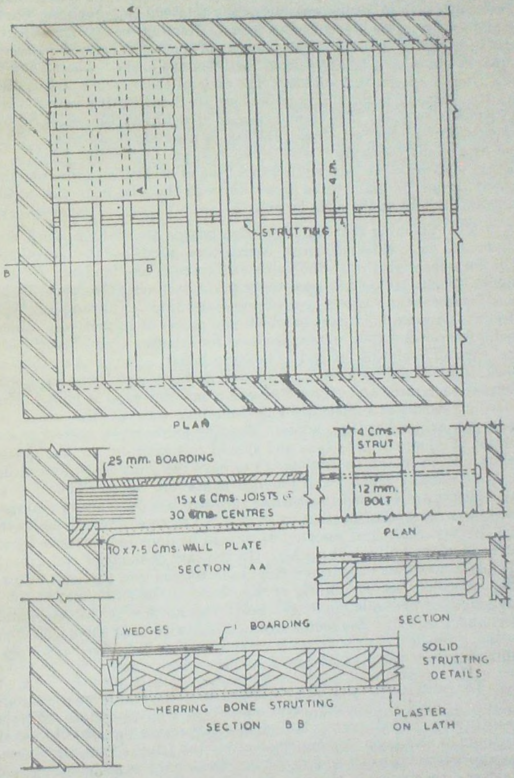
(1) Wooden floors.
- (*a*) Single joist.
- (*b*) Double joist.
- (*c*) Framed or triple joist.

(2) Steel joist and stone or precast concrete slabs.
(3) Jack arch floor of brick or concrete.
(4) R.C.C. slabs floor and steel girders and R.C.C. slab.
(5) R.C.C. beams and slabs.
(6) Flat slab construction.
(7) Beams and patent reinforcing slabs.
(8) Hollow tile ribbed floors.
(9) Hollow tile jack arch floors.

The details of each of them are given below :

(1) (*a*) **Wooden Floors ; Single Joist :** These are used for residential buildings where spans are short and the loads are comparatively lighter. They consist essentially of a set of wooden beams called joists and wooden boarding laid over them. These joists are spaced at about 30 cm. centre to centre, spanning the room in the shorter dimension. They are generally of sufficient width for rigidity. A minimum width of 5 cm. is taken as a guiding factor. The spans for this type of flooring are not generally greater than 4 metres. However in exceptional cases, spans up to 6 metres have been used.

The joists are supported on wall plates of 10×7 cm. to 12×7 cm. in size. The object of providing these wall plates is to distribute the loads from the joist to the wall below. Further they provide an easy means of bringing the upper edges of the joist to a horizontal plane for receiving the floor boarding. Wall plates are generally laid flush with the inner face of the wall and lengths as long as possible should be used. However if joints are a necessity, the same are provided by giving half lapped or scarfed joints. The joists rest on the wall plates with their ends nailed, cogged or notched. Single cogged or double cogged joint may be used. Corbels might be needed whenever the supporting width of the wall is not sufficient due to an adjacent flooring resting on it. Whenever joists of adjacent room run in the same direction, they may be overlapped and nailed to each other.



Figs. 742-743. Plan and Sectional details of single wooden flooring.

Joists for floors should not only be strong enough to support the loads for which they are designed but should also not deflect too much so as to cause the cracking of any plaster ceiling attached to them. A deflection greater than $\frac{1}{333}$th of the span is not permitted. The size of the joist is roughly calculated by the rule

$$\text{depth in cm.} = (\text{Span in metres} \times 4) + 5 \text{ cm.}$$

When the length of the joist exceeds 3·5 metres, strutting of the joist with each other becomes necessary to avoid side buckling which is prominent in the case of deep joists. Herring bone strutting is the best type of bracing. This consists of a pair of inclined pieces of timber which are tightly fitted between the joists. These vary in size from 5 × 3 cm. to 5 × 5 cm. The ends of these struts are nailed to the joist. At the end, joist wedges are incorporated between the joists and the wall. The second type of strutting is the solid strutting which is the simplest type and is used for cheap work. This consists of short lengths of wooden boards nailed to the joist in a continuous row. To strengthen this type of strutting, a circular rod about 12 mm. in diameter is passed through the joist near the strutting and is held at the ends by nuts.

The planking consists of wooden boards about 4 cm. thick and 10 to 15 cm. wide. Narrow boards are used as the shrinkage will not appreciably open the joints and there is less tendency for the planks to distort. Care has to be taken in fitting the joints of the boardstogether. Various type of joints are used. The simplest type of joint is a plain butt joint in which two pieces of boards just abutt each other. Rebated joints are used for a better class of work and are specially suitable for end or heading joints. For good quality of work, tongued and grooved or feathered and grooved joints are used. Rebated tongued and grooved type is a superior type of joint. The boarding should be sufficiently long from one wall to the other in order to avoid heading joints. Heading joints when necessary are formed of square or butt type and should rest entirely on the joists below. Each plank is cut so as to have the joint centrally on the joist. Generally rebated and tongued joints are used. The individual planks are jammed together as they are laid by flooring cramps. Each board is secured in position by 6 cm. screws screwed to each joist below. Nailing, if resorted to, should be done in a manner that the head of the nail is not visible. In the case of tongued and grooved joints nails can be driven from each tongue into the joist below. This is called secret nailing as the head of the nail is not visible. The length of the nails are driven below the surface by using a hammer and a punch. For secret nailing, oval wire nails should be used as they are less liable to split the tongues. Wherever gas pipes, cables, etc., are taken below the floors, screws are used.

For surfaces which are subjected to considerable wear, double planking is used. The first layer consists of a 2 cm. thick roughly sawn square edged planks laid diagonally across the joists to avoid the joints of this layer coming right below the joints of the top layer. The upper layer consists of 2 to 2.5 cm. thick hard wood planking and is laid at right angles to the direction of the joists.

On completion, the wooden floor planking is plained to a smooth and level surface. Hard wood floors are scraped and rubbed smooth with sand paper. They are finally waxed and polished.

False ceilings are fixed to the bottom of the joist so that the surface appears to be plain. If wooden ceiling is used, this can be directly nailed to the joists. However, in this method, the ceiling is liable to get opened at the joints due to vibration effect. Some joists can be made deeper than the other and the ceiling can be fixed to it but this method is also not very satisfactory as it increases the depth considerably. A better method is to incorporate separate ceiling joists which run at right angles to the main joist and the ceiling is fixed to it.

When metal lath is used, the spacing of the joist has to be chosen to suit the type of lath available because they are marketed in standard widths. These widths should form multiple of the joist spaces so that the joints in the lathing may come exactly below the joist.

Advantages :

(*i*) Single floors are easy to construct.

(*ii*) They are cheap.

(*iii*) As the joists rest on the wall at close intervals, the distribution of loads on the wall is better.

Disadvantages :

(*i*) For greater spans, deep joists are necessary which increase the weight and the cost of floor.

(*ii*) The joists are liable to sag and crack the ceiling.

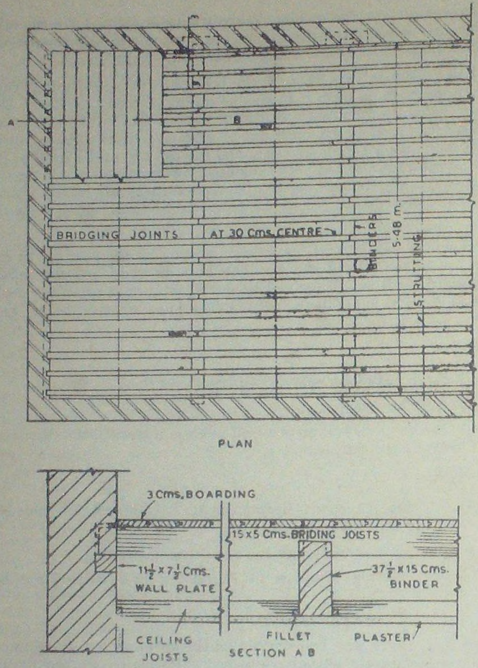
(*iii*) For making openings in the floor, lot of cutting is to be done.

(*iv*) They are not sound-proof.

(*v*) The loads are transmitted on the openings, *e.g.*, window or door lintel because the joists have to rest uniformally on the entire length of the wall.

(*vi*) They need wall plates for supporting the joists.

(1) (*b*) **Wooden Floors ; Double Joists** : Generally spans exceeding 6 metres are not suitable for single joist floors, hence intermediate supports are needed for supporting the bridging joists. These bridging joists can be of smaller sections than otherwise needed. The joists which are used to support the bridging joists are called binders. The spacing of binders is from 2 to $3\frac{1}{2}$ metres. They rest at their ends on stones or wooden bearing templates which are not less than 3/4 to $1\frac{1}{4}$ metres in length. Stone corbels can be fixed in the walls for this purpose. Binders increase the overall depth of a floor. To avoid this, the bridging joists are cogged to the binders. The depth of the sinking should not exceed $\frac{2}{3}$rd the depth of the bridging joist and their bearing should not be less than 2·5 cm. The cut-



Figs. 744-748 Plan and section of double wooden flooring.

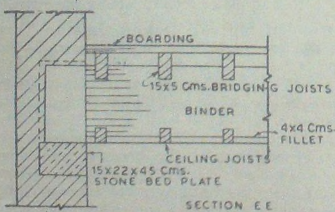


Fig. 749. Section at EE.

ting and notching of the bearing members should be restricted. Binders should not be embedded in the masonry of the wall. Free circulation around the ends of the binders is essential. It is not absolutely essential to provide strutting of the binders. Ceilings can be fixed to the bottom of the binders by fixing ceiling joist to the binders with the aid of small fillets which are nailed to them. The ceiling joists are notched to these fillets and nailed. Lathing is attached to the ceiling joist. As an alternative, the ceiling may be directly fixed to the bridging joists. Whenever the section of the binders becomes very heavy it may be economical to replace the wooden binders by rolled steel joists.

Advantages :

(*i*) The loads are transmitted at specific points and hence window and door openings can be avoided.

(*ii*) This type of flooring is more rigid and hence the plastered ceilings are not liable to crack.

(*iii*) An additional binder can be provided near the walls, thereby avoiding the use of wall plates which are liable to decay on account of their contact with masonry under damp conditions.

(*iv*) It is more sound-proof.

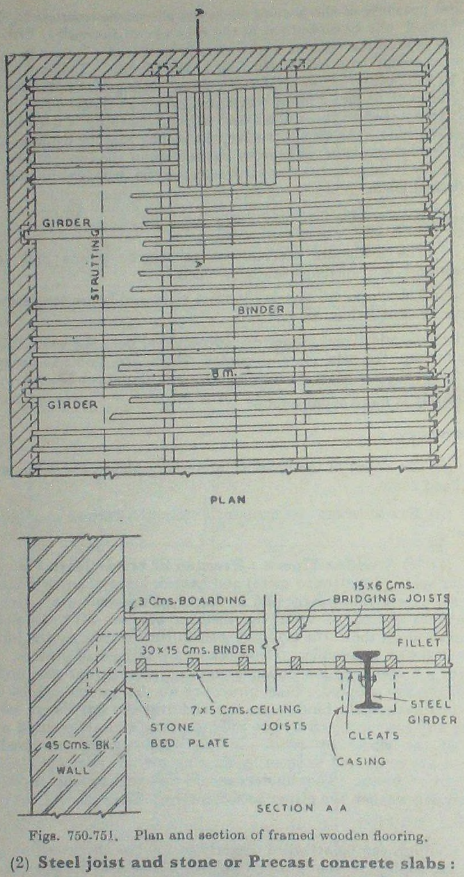
Disadvantages :

(*i*) The depth of the floors is increased which reduces the available head room.

(*ii*) Extra labour is needed to join the various members together.

(1) (*c*) **Wooden Floors : Framed or triple Joist** : For still greater spans (8 metres or more) and heavier loads, the size of binders becomes exceptionally large and is, therefore, uneconomical. Hence if beams are placed to span the distance between the walls and the binders rest on them, the bridging joist in turn resting on the binders some economy is possible. These beams are termed as girders. The spacing of these girders depends on the type of girder used and the size of binders adopted. Steel girders or wooden girders can be used. For steel girders, the binders are notched over the top flange of the girder and are supported by two mild steel angle cleats secured to the web of the girder by rivet. In case wooden girders are used, the binders are connected to them by forming special type of joints, *e.g.*, tusk tenon joints. The binders should not come against each other as this will weaken the girder considerably. They should be staggered.

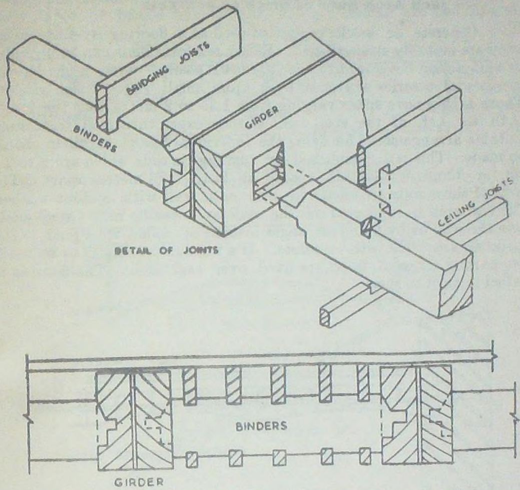
Ceilings can be attached directly to the binders or ceiling joists may be used. If the girders project below the binders also, the ceiling may be fixed to the binders and the girders suitably encased by covering with wood blocks (bearers, which may finally be finished with wooden lining or plastering).



Figs. 750-751. Plan and section of framed wooden flooring.

(2) **Steel joist and stone or Precast concrete slabs :**

Flagstone is available in abundance in certain parts of the coun-ry and is used for flooring. For small spans, steel joists are spanned n the shorter dimension of the room and are spaced at suitable intervals, depending on the availability of the maximum length of stones. Generally flagstone slabs are available in thicknesses of about



Figs. 752-753. Joint details of framed floors using wooden girders.

4 cm and widths of about 30 cm. These flagstones are inserted in the inter-space between the joists. They rest on the lower flanges of the joist. The portion above the flagstone is filled with light weight concrete made up of crushed brick or slag aggregate. If lime concrete is used, the steel joists should be encased in cement concrete so that it is not in direct contact with the lime which would cause disintegration of the joists. Instead of light weight concrete, any other suitable filling can be filled in the inter-space between the joists. However the top of these joists should be kept about 1 cm. lower than the concrete surface. A layer of suitable wearing coat may be laid as topping.

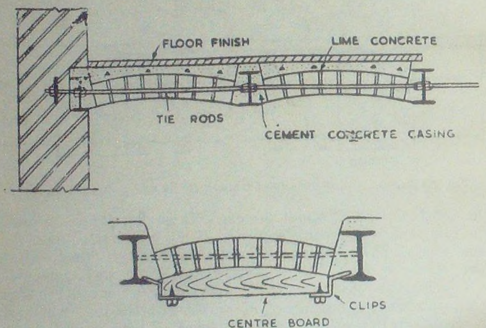
Instead of stone, precast cement concrete slabs of about 45 cm. length and 5 cm. thickness can be used in a similar manner.

For cheap type of construction, it may not be necessary to obtain flat surface at the bottom and hence the precast slabs or flagstone slabs can be laid on the top of these joists in such a way that all the heading joints come centrally over the joists. Wider joists are needed. The underside of these slabs is pointed with cement. The top may be suitably finished by laying a wearing coat of concrete or other suitable materials.

For larger spans, it is necessary to provide a few girders on which these steel joists can rest.

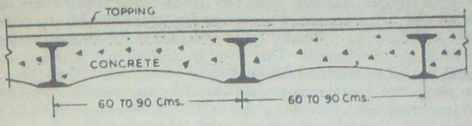
(3) Jack Arch floor of brick or concrete :

Concrete or bricks cannot be used as a flooring system unless they are suitably strengthened. Either reinforcement can be provided or arch action developed to bear the loads easily. Jack arch flooring consists of a series of arches built from small rolled steel girders. These arches have spans varying from 1.25 to 2 metre and the rise is $\frac{1}{12}$th to $\frac{1}{15}$th of the span. Since they exert thrust at their ends, suitable arrangements for tying the individual spans together should be made. This is accomplished by running tie rods which are 2 to 2·5 cm. in diameter and are spaced at 2 to 2·75 metre apart. The ends of these rods are anchored into each wall with a stout washer. The end arch is supported on the wall by encasing rolled steel joists into the wall or by fixing an angle instead of rolled steel joist. The spandrils are filled with concrete. If a wooden flooring is to be used, two nailing strips of wood are fixed over each arch. The flooring is nailed in turn to them.

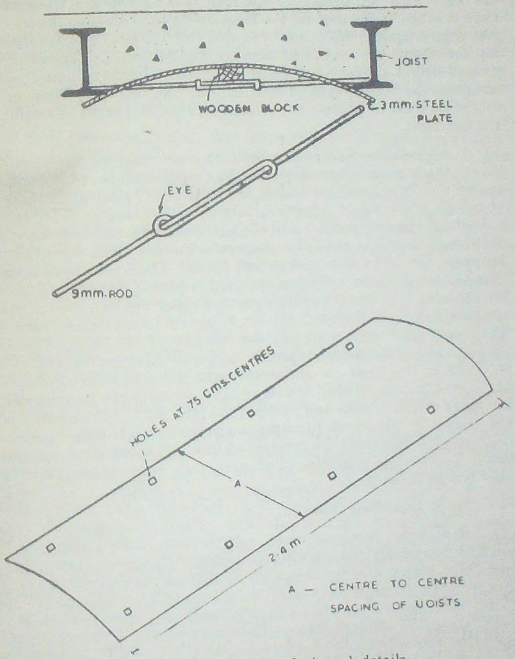


Figs. 754-755. Brick Jack arch details.

Brick jack arches are constructed by bringing up the arches against a concrete backing laid on the lower flanges of the joists. The centring for the arch consists of a segmental piece of wood 4 cm. thick with a chord length equal to the span of an arch and conforming to the soffit. The ends of the segment are cut off slightly. The bottom ends of the centre board rest on the lower flanges of the joist and the curved surface forms the top. Sometimes a bent iron strap is attached to its ends to form a hook by which the centring board is suspended from the rolled steel joist as shown in the figures 754-755. The brick arch is built over the centre board. In constructing the arch, the mason will sit on a plank laid across two joists and start laying one ring of bricks. In the first ring, the bricks have to be laid of 20 cm. and 10 cm. lengths alternately. This enables a series of gaps and projections being formed wherein the next layer of bricks can fit in. All the bricks are laid on end.



TIE ROD USED AS IN THE CASE OF MASONRY JACK ARCHES



Figs. 756-758. R.C.C. Jack arch details.

Laying is started from the ends. If lime mortar is used for the construction of the arch, the bricks adjacent to the joists should be laid in cement mortar to protect the joist from getting corroded due to contact with lime. The end bricks have also to be suitably cut for their proper contact with the joists. The bricks are laid in mortar and all precautions necessary for the proper laying of brick-work are followed. Finally as is the case with all arch work, the key brick is introduced. This sets in the arch. The key should be laid in stiff mortar and fitted as tight as possible. For laying the next ring, the centring is pushed ahead by the mason. This operation is carried out by catching hold of the bricks laid with one hand and giving light strokes of hammer with the other to the centre board till it gets into the next position which is at a distance of about 20 cm. from the previous one. Second and succeeding rings of bricks are laid with all bricks 20 cm. long and built as described above. Care is taken to see that all the rings interlock with each other. The last ring is again of alternate full and half bricks. The arch is kept wet for about ten days and then the top portion, *i.e.*, spandrils and a small height above the crown is filled with cement or lime concrete on which the desired type of wearing coat can be laid. These arches should be built only after the masonry in the end walls has sufficiently hardened.

Concrete jack arches are built on a centring which is made of 3mm. thick steel plates bent to the required shape of the soffit of the arch. Two holes are cut at the ends of the plate at distances of about 3/4 metre apart longitudinally with the other pair. Two iron rods about 12mm. diameter and of lengths which can fit in the distance between joists are used to support a wooden block driven tightly between the rods and the curved plate. These rods have suitable eyes at one of their ends and each rod is passed through the eyes of the other so that by sliding the eyes towards or away from each other, the total length of the two rods can either be increased or decreased. The plate gets supported on the rods at 75 cm. interval longitudinally and also cannot spread laterally. Concreting is done on the top of the arch in the usual manner. After the concrete has cured, say for a period of ten days, the centring can be removed by knocking off the blocks and opening out the rods. The underside of the arches is plastered to improve the surface. If lime concrete is used, the joists should be prevented from deterioration by encasing them, in cement concrete. For very dry climate, this precaution may not be necessary.

(4) **R.C.C. slab floor :**

Reinforced concrete slabs are becoming very common in the construction of modern buildings. A simple slab is suitable for small spans which do not carry heavy loads. When the ratio of the length of a room to its width is greater than 1·5, slabs are designed to span along the shorter width. The reinforcement in such a case is run parallel to the shorter walls. The thickness of the slab depends on the type of concrete used, the span, floor loads etc. These slabs rest on the walls and are considered as simply supported if the walls are made of bricks. To allow the slab a freedom of movement, the top of the wall is covered with a layer of plaster rendered smooth and a thick coat of bitumen is applied to this plaster. The slab rests at its end on the wall. If the building is of reinforced concrete framed construction, it is necessary to build the slab monolithically with the supporting beams. Mixing, laying, finishing and curing of the concrete is described in chapter XVI.

When rooms are nearly square i.e., the ratio of the adjacent sides of the room is less than 1·5, the slabs are designed spanning in both directions and are called two-way slabs. The main reinforcement of the slabs runs parallel to both the sides of the room. At corners suitable mesh reinforcement is provided at top and bottom to allow for stresses which are created on account of the partial fixity of the corners.

Reinforced concrete slabs are easy to cast and provide a very smooth surface at the bottom which provides a good appearance and does not create difficulties in lighting arrangements. However, they are restricted to spans not greater than about 4 metres for ordinary loads of residential buildings.

Steel girder and R.C.C. Slab Floor : When the spans are larger R.C.C. slabs become uneconomical unless additional supports are introduced below the slabs. As a simple type of construction, steel girders can be introduced below the slabs to reduce the spans. These slabs may be built as individual units on the steel girder or can be laid as continuous slabs on the girders. The reinforcement is provided in the first type, on the underside of the slab whereas in the second case, the reinforcement has to be provided at the top of the slab over the beams, some reinforcement being taken continuously at the bottom. The amount of steel provided at the top of the slab is usually equal to that used at the bottom in the mid span of the slab. In some buildings it may be necessary to protect the steel beam from fire by encasing them in concrete or they may be encased in a covering of metal lath and cement plaster.

(5) **R.C.C. beam and slab floor :**

For larger spans and for heavier loads, R.C.C. beam and slab construction is becoming very important type of floor construction which is commonly used for most of the buildings. The slab is designed as a continuous slab monolithic over the beams, the reinforcement being provided as in the case of R.C.C. continuous slabs laid on steel girders. The slab acts as a flange of the beam and as such is cast monolithically with the beams. Hence the size of the beam is reduced. The main reinforcement of the slab runs parallel to the short span but small amount of reinforcement is also provided parallel to the longer span for proper distribution of loads, etc. Two-way slabs can also be used for openings which are nearly square. The slab and beam type of construction is very economical. Sometimes the bottom projecting beams are covered by laying a false ceiling underneath it.

(6) **Flat slab floor** :

Whenever the use of beam is objectionable, flat slab construction is preferred. Flat slab floor is a slab directly supported on columns without any intermediate beams. The advantages of flat slab construction are :

(*a*) No projection of beam is visible and hence no additional ceiling is needed ;

(*b*) More clear head room is available ;

(*c*) Better lighting facilities are available ;

(*d*) For heavier loads, thinner section of the slab is needed ; and

(*e*) The construction is easy.

The disadvantages are :

(*a*) The panels have to be nearly square ;

(*b*) At least three continuous panels are needed for economical construction ; and

(*c*) It is not economical for lighter loads.

There are various types of flat slab construction. The two types generally used are :

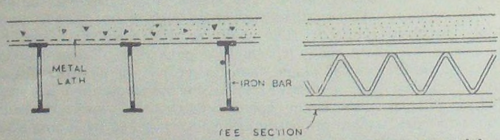
(*i*) *Two-way reinforced flat slab* : In this type the reinforcement is parallel to the panel's length and breadth. The steel is at the bottom in the middle portion of the panels while it is at the top near the column edges and top of the column.

(*ii*) *Four-way reinforced flat slab* : In this system, the reinforcement bands run from column to column diagonally in addition to the reinforcement provided parallel to the panel's sides.

Flat slabs are used in factories, ware-houses, commercial buildings etc. Sometimes the slab is thickened at the column head (which is always flared). This type of treatment is needed when very heavy loads are to be catered for. Such construction is called flat slabs with drops.

(7) **Beams and patent reinforcement slab floor :**

Generally round or square mild steel bars are used in the construction of R.C.C. slabs. But for small slabs and light loads, it may be of great advantage to use patent reinforcements. The usual type of reinforcements are wire meshes, expanded metal lath or



Figs. 759-760. Light metal girders to support Patent reinforced slab.

ribbed metal lath. Wire mesh is used for ordinary construction whereas the ribbed metal lath is used on light slabs poured without any formwork. The ribs span the distance between the supports and are rigid enough to take the loads. The mesh is so fine that the concrete will not run down but will form a substantial grip with the lath. The supporting girders may be of rolled steel joists of solid section or steel open web joist built up of two steel channels or T-section and inclined bars acting as a web. The rough lower side of the slab may be concealed and protected by plastered ceiling. These joists are spaced at about 60 cm. centre to centre. The slab is generally 5 to 7·5 cm. thick.

(8) **Hollow tiled ribbed floor :**

Ribbed slab floors consist of a number of small beams spaced closely and cast monolithically with the slab In the ordinary slab, the area of concrete below the neutral axis of the section does not contribute to the increase in strength of the section. Its object is only to hold the reinforcement in position. Hence if concrete below the neutral axis could be eliminated and only left in position at places where the steel reinforcing bars are placed, an economical construction would be feasible. This would make a slab with small ribs at the bottom. The steel is carried within the ribs and is about the same as needed for a solid slab except for small reduction due to the decreased weight of the slab which is to be carried now Larger diameter bars are used as the space within the ribs is limited for accommodating the steel. Generally ribs are not less than 10 cm. width. The slab between the ribs is 5 to 10 cm. in thickness and is reinforced with wire mesh or with bars of small diameter running perpendicular to the ribs. The reinforcement is not bent over the ribs. For nearly square spans, the slab may be ribbed in both directions.

The cost of such type of ribbed slabs is very high due to intricate formwork needed for their construction. Hence the sides of the joists and the bottom of the slab are cast by placing hollow clay tiles, hollow gypsum tiles or sheet steel cores. Wooden formwork is built for

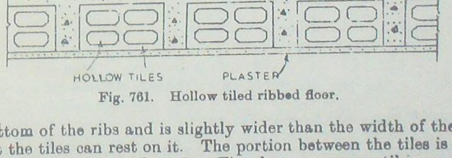
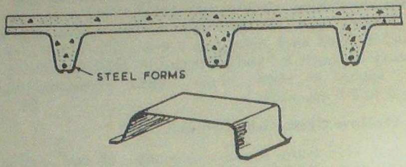


Fig. 761. Hollow tiled ribbed floor.

the bottom of the ribs and is slightly wider than the width of the ribs so that the tiles can rest on it. The portion between the tiles is concreted and a slab is laid on it. The clay or gypsum tiles provide a smooth surface at the bottom which can be easily plastered.

The sheet steel cores can be made of thicker metal so that they can be removed later on. Non-removable types are made of very thin sheet steel and these are left in place. In this case, the metal lath for the plaster is fixed before the cores are set and is wired to the bars in the ribs. As an alternative, it may be fixed in the steel cores. Formwork for such type of construction is similar to the one needed for clay tiles.



Figs. 762-763. Ribbed floor with Steel forms.

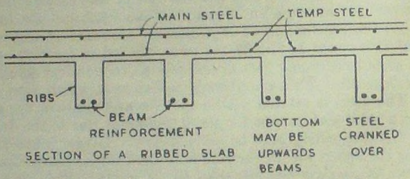


Fig. 764. Section through a R. C. C. ribbed floor.

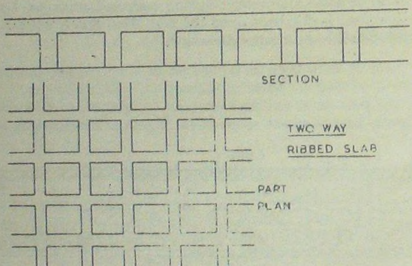


Fig. 765. Section through a two-way ribbed floor.

(9) **Hollow tile jack arch floor** :

Instead of using bricks as the individual units for building up a jack arch, hollow tiles of structural clay can be substituted for the construction of floors. These floors afford a light type of construction and have also good appearance. Further they reduce the passage of damp, if used in a roof.

QUESTIONS

1. What are the various types of floorings used for ground floor construction ? What factors will you take into account in selecting a type of floor finish for ground floors ?

2. Describe briefly the construction of brick flooring and stone flooring.

3. What is meant by conglomerate cement flooring ? What are the advantages and disadvantages of monolithic type of floor construction ?

4. Describe briefly how a non-monolithic concrete floor is laid over a cement concrete base.

5. What are the types of wooden floorings used for ground floor construction ?

Describe briefly the construction of a planked flooring supported on dwarf walls for a ground floor of a building.

6. What is meant by a terrazzo floor ? Describe in detail the laying of such a floor.

7. Write short notes on :

(*i*) Mosaic floor ;

(*ii*) Asphalt flooring ;

(*iii*) Glass flooring ; and

(*iv*) Magnesite composition.

8. Name the various types of floor construction suitable for the upper floors of a building.

What are the various factors based on which a particular type of construction can be adopted ?

9. What are the advantages and disadvantages of a single wooden flooring ? Explain with the aid of sketches the construction of a single type of wooden floor over a room 3 m. X 6 m. in size.

10. A room 5·5m. X 7.5m. is to be covered by a wooden flooring. Describe with sectional details and plan the construction of a double wooden floor. What are the various methods of fixing ceilings to wooden floors ?

11. What is meant by a jack arch floor ? Describe briefly the construction of a jack arch floor using bricks. What precautions are necessary for this type of construction ?

12. Write short notes on :

(*i*) Flat-slab floor construction ;

(*ii*) Ribbed slab floor construction.

Briefly describe the advantages of each of the above types of construction.

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2. **Lea F. M.** : *Floor Finishes.*
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4. **Crockhill** : *Carpentry and Joinery.*
5. **Voss W. C.** : *Fire-proof Construction.*
6. **British Standard 1187** : *Wood-blocks for Floors.*
7. **British Standard 1286** : *Clay Tiles for Flooring.*
8. **British Standard 1344** : *Asphalt Tiles for Paving and Flooring.*
9. **British Standard 1076, 1410 and 1451** : *Mastic Asphalt Flooring.*
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12

STAIRS

Stairs are provided in a building to afford a means of communication between the various floors. These are steps arranged in series and placed in an enclosure called staircase. Since they have to perform a very important function, they should be designed properly to provide maximum comfort, ease and safety. They are generally placed in the centre or to one side of a building. The location will depend upon the position of rooms and the type of approach needed to them. They are made into different units to facilitate construction and to economise space. Stairs should be properly ventilated and lighted. A building may have a number of staircases between the various floors depending on the number of people using the building. In public buildings, the staircases should be near the main entrance whereas in private buildings some privacy is essential.

Materials

The selection of materials for the construction of stairs depends upon the availability of materials, funds available, desired life of the building, aesthetical importance and fire resisting quality expected. Stairs may be made either of timber, bricks, stones, mild steel, wrought iron or plain and reinforced concrete. Combination of two or more of these materials may be used in the same stair. Sometimes, a finishing of márble, mosaic or checkered, plaster on metal lath is also provided.

Definitions

(*i*) *Tread* : Flat or horizontal upper portion of a step on which the foot is placed for ascending and descending.

(*ii*) *Riser* : Vertical member between treads.

(*iii*) *Rise* : Vertical distance between the upper faces of any two consecutive steps.

(*iv*) *Going*	:	Horizontal distance between the faces of any two consecutive risers.
(*v*) *Flight*	:	A series of steps without an intermediate platform.
(*vi*) *Landing*	:	Flat platform at the head of a series of steps. Whenever this platform extends right across a staircase, it is called half spaced landing. In case this extends only for half of the staircase width, it is called quarter-spaced landing.
(*vii*) *Nosing*	:	The outer projecting edge of a tread.
(*viii*) *Line of Nosing*	:	An imaginary line connecting the nosing points parallel to the slope of the stair.
(*ix*) *Hand Rail*	:	Rail of wood or metal on the side of stair fixed at about waist height at an incline or at level on a landing.
(*x*) *Newels*	:	Posts set at the top and bottom of a stair supporting the handrail.
(*xi*) *Baluster*	:	Vertical members supporting the handrail.
(*xii*) *Winders*	:	Radiating or angular steps which give a change of direction to the stairs.
(*xiii*) *Strings or stringers*	:	Sloping members which support the steps in a stair.
(*xiv*) *Walking line*	:	This is an approximate line on which people walk on a stair and is about 45 cm. from the centre of the hand-rail in plan.

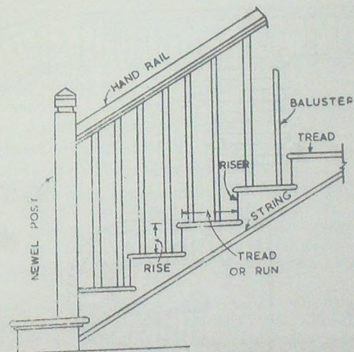
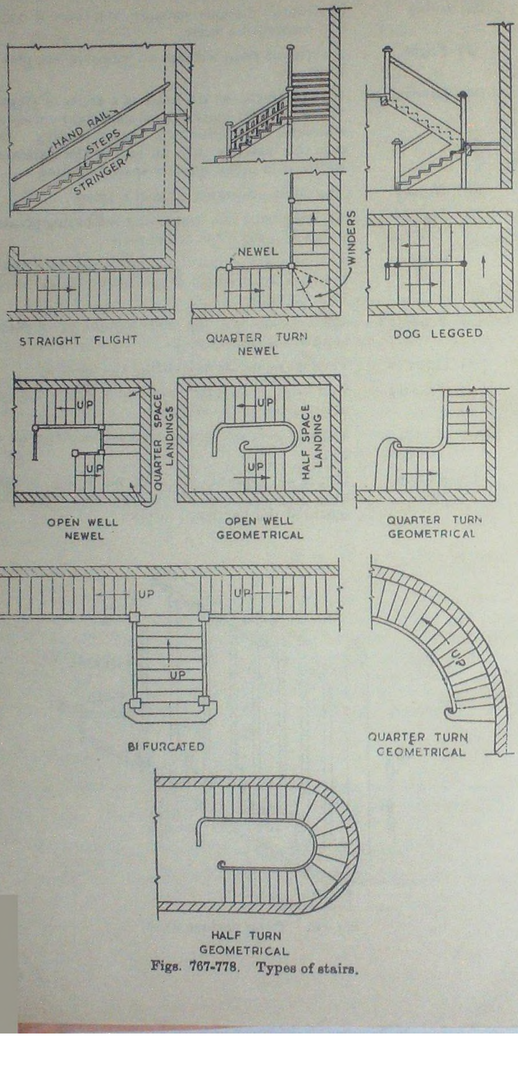


Fig. 766. Terms used for stairs.



Figs. 767-778. Types of stairs.

Types of Stairs

The types of stairs are :

(*i*) *Straight flight stair* : The stairs continue throughout their entire length in one direction only. This may consist of a single flight or a flight with one or two landings in-between.

(*ii*) *Quarter turn stair* : When the direction of the flight is changed at right angles either to the left or to the right, quarter turn stairs are used. These are of two types. In the first type the change in direction is effected by introducing a quarter space landing. In the other type winders are used.

(*iii*) *Half-turn stair* : In this, the direction of flight is reversed, *i.e.*, turned by 180° by the introduction of landings and or winders. A half space landing may be used.

A quarter space landing and winders may be used as shown in figure 770.

(*iv*) *Three-quarter turn stair* : This has its direction changed three times with its upper flat crossing the bottom one.

(*v*) *Bifurcating stair* : In this, the wide bottom flight is divided into narrow flights at the landings.

(*vi*) *Geometrical or continuous stairs* : The strings and hand-rails are continuous and are set out in accordance with geometrical principles.

They may be of the following types :

(*a*) *Winding stairs* : See figure 777.

(*b*) *Half turn stair* with landings or newels.

(*c*) *Spiral stair* : In this the steps project from a central post.

Essential Requirements

(*a*) *Step Proportions* : It is very essential that the design of the steps should be carefully worked out so as not to make the steps either too wide or too short. Further the rise should not be excessive which otherwise would cause inconvenience to the user. The following rules may be followed :

(*i*) Rise + tread not <40 and not >45.

(*ii*) $2\times$Rise + tread not <58 and not >63.

(*iii*) Rise $\times$ tread not <400 and not >500.

All dimensions are considered in centimetres.

For important buildings, a rise of not greater than 18 cm. and tread not less than 27 cm. should be satisfactory. For ordinary buildings, slightly greater rise and a slightly lesser tread may be permitted. However rise greater than 20 cm. should not be allowed. On similar considerations, a tread of less than 22 cm. should not be used.

(*b*) Width of stair should be adequate for the number of people who are expected to use them. About 1 metre wide stair for residential buildings and $1\frac{1}{2}$ metres for public buildings is considered essential.

(*c*) The slope of the stair should never be greater than 40° and not less than 20° to prevent undue exertion or wastage of space.

(*d*) All the risers and treads shoul l be of uniform dimensions.

(*e*) The stair should be well lighted especially at turns.

(*f*) Generally the number of steps in a flight should not be greater than twelve.

(*g*) Sufficient headroom should be provided. This should be at least 2 m. However a headroom of 2·10 m. is recommended.

(*h*) Winders should be avoided. If they are to be used, they should be of sufficient width.

(*i*) Construction of stair should be such that it ensures the use of sound materials and preferably possessing fire-proof qualities.

Wooden Stairs

The wooden stairs are of the following types :

(1) **Straight Flight Stair :** This is used in places where

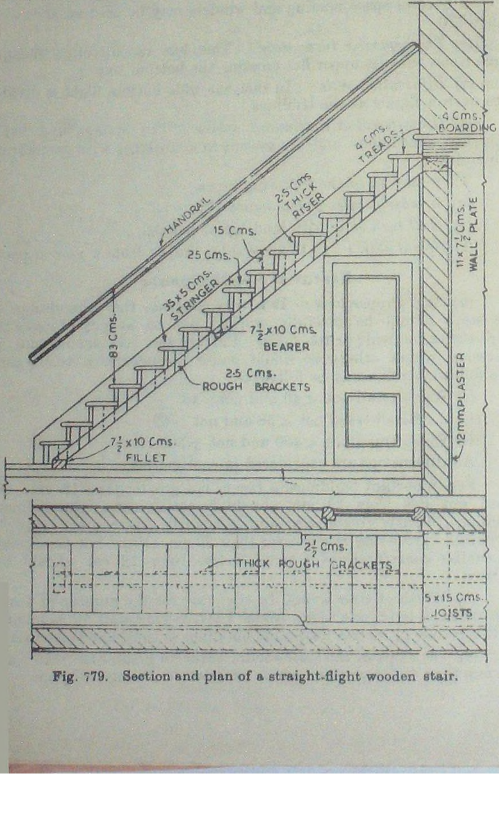


Fig. 779. Section and plan of a straight-flight wooden stair.

restricted width is available for the location of the stair and the height between the floor is less.

(*a*) *Steps* : The thickness of the treads should not be less than 4 cm. and that of risers $2\frac{1}{2}$ cm. The treads and the risers are connected by tongue and groove joint and screwed or nailed. The nosing should not project more than the thickness of the tread. It may be suitably finished at the ends by giving a scotia or cavetto moulding. A half round moulding may also be used.

(*b*) *Stringers* : The treads and risers are supported by two 35×5 cm. stringers which are fixed to the walls. A 5 to 7.5 cm. wide margin is provided and the upper edge of the stringer is suitably finished. For wider stairs, an intermediate support in the form of 10×7.5 cm. wooden joist (bearer) is used. This is secured at the foot and the top of the stair. Small, shaped wooden pieces are fixed to the bearer. If more than one bearer are used, the stringers may be of lesser width. The ends of the steps are housed into the wall stringers to a depth of about 1.25 cm. The grooves are tapered and should permit hard wood wedges being put into them. These wedges enable the steps to be fitted tightly. Small triangular blocks may also be used. These are glued to the underside of the treads and risers.

(*c*) *Hand Rails* : This is fixed to the wall with the aid of plugs. Special moulding may be used for giving a better appearance to the handrail. This is laid parallel to the slope of the stair.

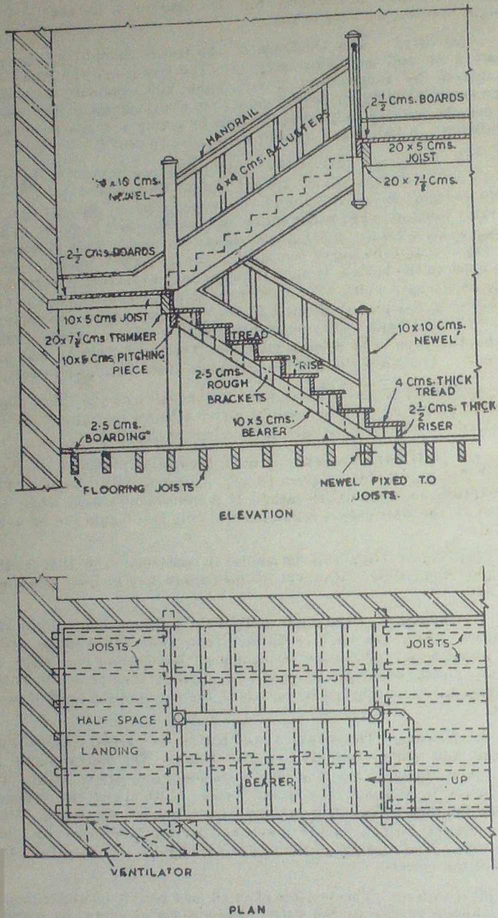
(2) **Half-turn Stairs** : A brief description of one of the types called Dog-legged stair is given below. This is so called because of its appearance in sectional elevation. It is conveniently used when the length of the stair-case is restricted and only two flights can be accomodated.

(*a*) *Steps* : They can be similar in construction to that of the straight flight-stair. However inclined risers may be used (*see* Figs. 780-81).

(*b*) *Stringers* : The outer ends of the steps are housed into the stringers which are slightly thicker than those fixed to the wall, *i.e.*, about 5 cm. The outer stringer may be of either one piece or of two pieces which are tongued and grooved together. The outer stringers are strengthened by newels at the foot and the head of each flight.

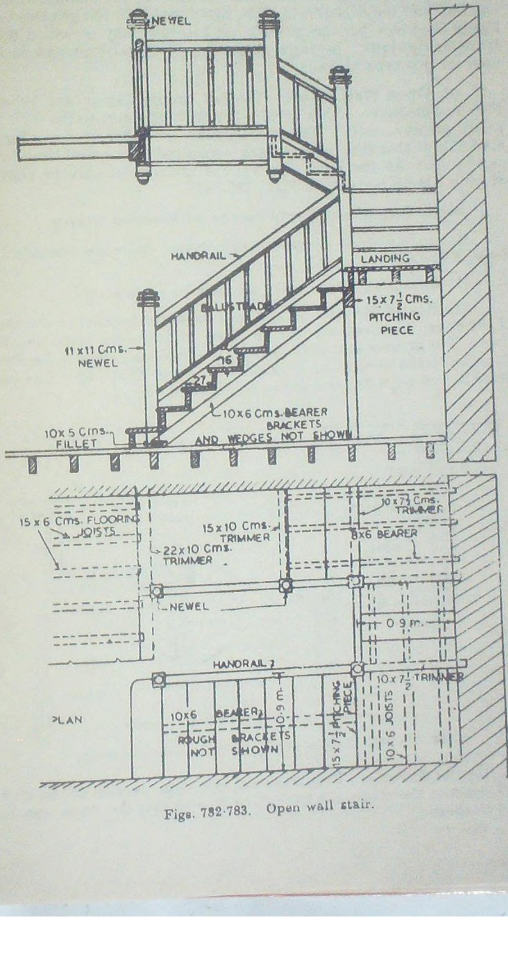
(*c*) *Newels* : The newel at the bottom is carried through the flooring and nailed suitably to a joist below. The central newel is also taken down to the floor level or below it and firmly fixed. To this newel is attached the trimmer joist which spans the opening at the landing. The stringers may have tenons which are fitted into mortices formed in the newels and are finally secured by pins or dowels. The nosings of the treads are slightly set back from the edges of the newels.

(*d*) *Landings* : This is made of small joist resting on the trimmer joist which is carried by the walls. The joists are covered by tongue and groove planking.



Figs. 780.781 Section and plan of a dog-legged wooden stair.

(e) *Handrail* : The handrail for the upper flight is housed, tenoned and dowelled to the two newels. The upper end of the lower handrail gets intersected by the upper outer stringer. As an additional measure, a handrail may be fixed to the wall for the portion of lower flight and is fixed similarly as described in straight flight stair. The handrail provided at the top landing is fixed to



Figs. 782-783. Open wall stair.

the newel at one end and to a half newel at the other and which in turn is plugged to the wall.

(*f*) *Balusters* : If square balusters are used, they should not be less than 5 cm. wide and are spaced $7\frac{1}{2}$ to 10 cm. apart. They are either housed or tenoned into the handrails and the stringers. A continuous groove is sometimes formed on the underside of the handrail and the balusters may be fitted into this, the grooves being finally filled in. For cheap work, the balusters may be nailed to the stringers and rails. Bronze or other type of metal balusters may be used for this type of stairs.

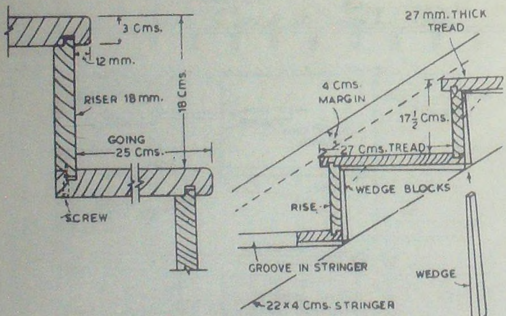
(3) **Open Well Stairs**. This has an opening or well between the outer stringers. This gives a better appearance to the stair but needs greater width. The construction is similar to a dog legged stair except that the stringers are connected to the newels and rest on the joist at the end. The various components and the method of joining them is shown in Figs. 782-783.

Some Important Components of Wooden Stairs

Some important components of wooden stairs are described in detail below :—

(1) *Stringers* : These are of the following types :—

(*a*) *Housed Stringers* : They have the slopes parallel to the slope of the stair. Grooves are cut in them to house the tread and the riser. The grooves are wide enough to enable the steps to be fitted in and also the wedges to be fixed. This type of stringer has been described on page 283 and shown in Figs. 784-785.

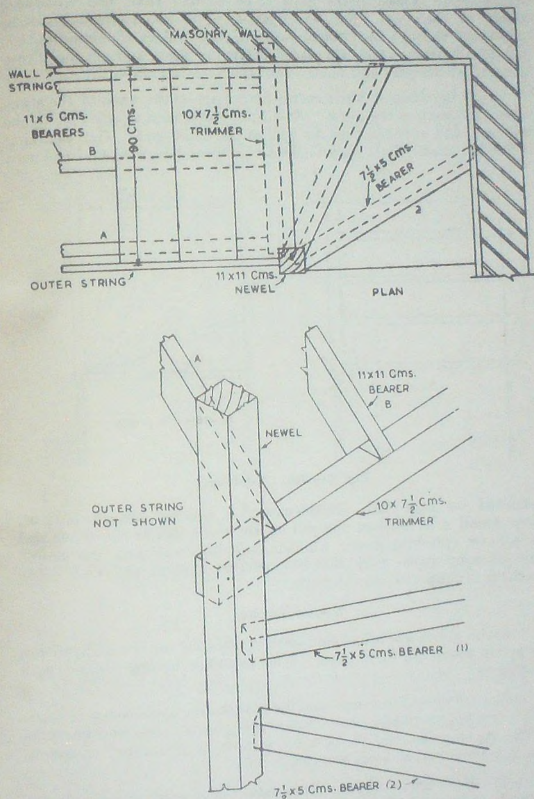


Figs. 784-785. Typical details for fixing of wooden steps.

(*b*) *Cut Stringers* : They have one side-slope parallel to the stair slope whereas the other side has cut notches so that the steps can be fixed to them.

(c) *Wreathed Stringers* : They are needed in geometrical stairs. They are in plan similar to the shape of the stair.

(d) *Rough Stringers* : When the stringers need intermediate supports, rough stringers are used. They are also called bearers or

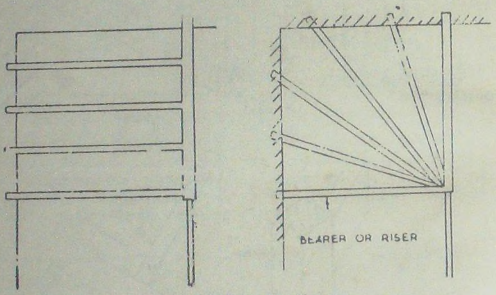


Figs. 786.787. Plan and detail of winding stair.

carriers. (see Figs. 786-787). They also support the boarding or plaster which may have to be laid on the underside of the stair.

(2) *Winders* : It is desirable to have the treads of winders at the walking line equal and must be at least 22 cm. For narrow stairs, the treads of winders are supported on the risers which are cantilevered from the walls, the outer end being housed into the newel post. These risers have to be thicker than the remaining risers of the stairs. For wider stairs, since the bearers cannot be continued through the circular portion, the winders are supported on separate bearers which are placed below the risers and are built into the wall at one end and housed into the newel at the other end.

(3) *Landings* : A trimmer is placed across the walls of the stair-case and bearers rest on it. Small joists are fixed at one end to the trimmer and supported on the wall at the other end. The planking is fixed to these joists. This forms a half spaced landing and has been



Figs. 788-789. Landings.

described on page 281. In the case of a quarter spaced landing, these small joists rest at one end on the walls and at the other end on a beam (pitching piece) which is built into wall and the newel. This pitching piece may also be cantilevered from the wall. The planking is supported on the joists.

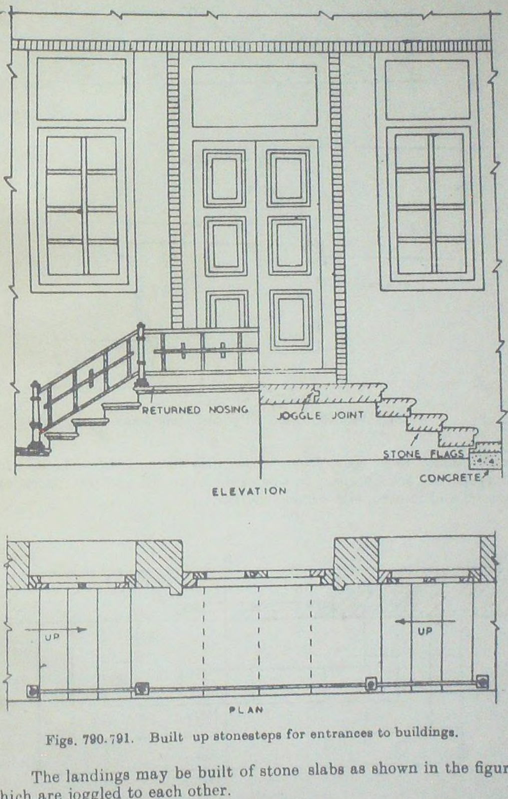
Stone Stairs

Stone stairs are heavy and need substantial supports. They are are not in much use these days. With use, they become slippery and dangerous.

Stone Steps : These are used for threshold, approaches to basements, heating chambers, etc. Stone provides a very good material for use as steps because it is hard, durable and weather resistant. The following type of steps are used :

(1) *Rectangular steps* : They are cut of solid stone and the lower edge of one step is supported on the top back edge of the other.

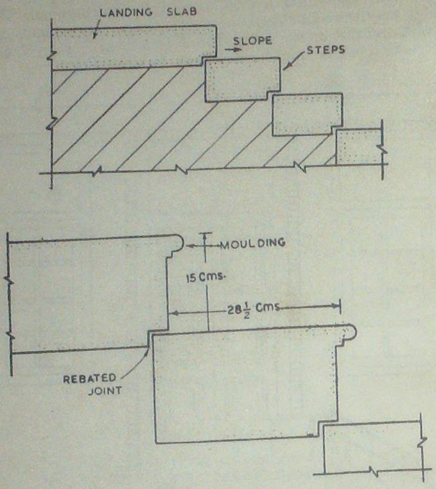
Rebated or checked joints, if used, strengthen the stepping. The top front edge may have moulded noses. The steps may be built solidly into a wall and rest on the other side on to a dwarf wall. This type of construction can be used for entrances to a building.



Figs. 790-791. Built up stonesteps for entrances to buildings.

The landings may be built of stone slabs as shown in the figure which are joggled to each other.

(2) *Built-up step* : The tread and riser of each step are made of thin sawn slabs. The thickness of the treads, if supported on ends



Figs. 792-793. Rebated square stone steps.

only, should be at least 5 cm. They may be used as a facing for concrete or brick steps. In this case, the treads and the risers are bedded and jointed with cement mortar.

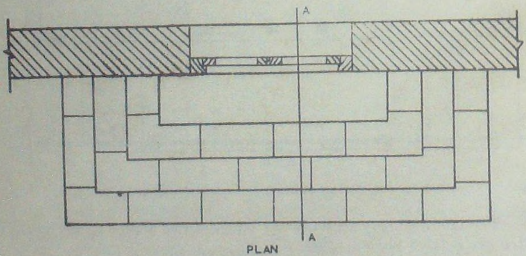


Fig. 794. Stone step entrance.

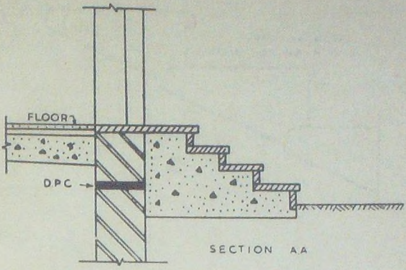


Fig. 795. Stone step entrance.

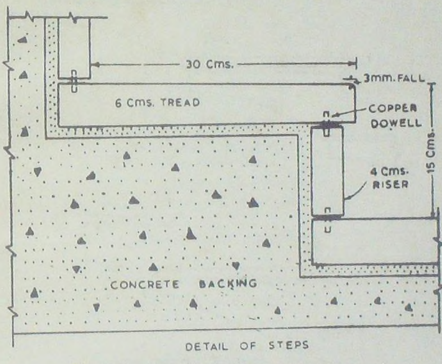
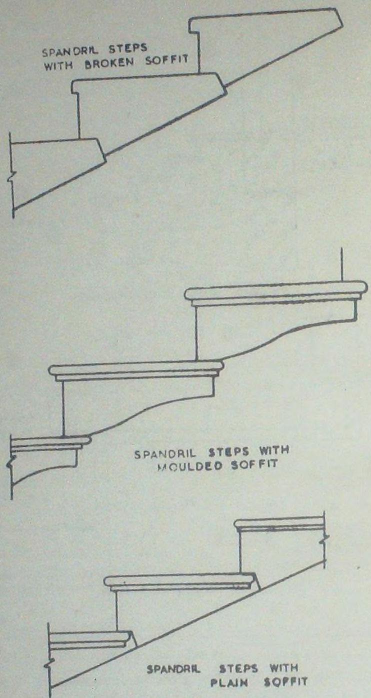


Fig. 796. Stone facing for concrete steps.

(3) *Spandril steps* : These steps are approximately triangular in shape except at the ends where they are built in the walls. They add to the beauty of the stair. A splayed rebated joint is given between each step and the splay should not be less than 5 cm.

Stone Stairs : They were formally used in the case of commercial or public buildings. The steps generally used are of spandril type. They are either :

(*a*) *Cantilevered from the wall* : In this case, the steps are properly supported in the wall and are fixed with mortar. As already stated the section at the support is rectangular. The projection of the step should be limited to 1·5 m. The minimum bearing of the step should be 20 cm.



Figs. 797-799. Spandril steps.

(*b*) Built into the wall at both ends.

(*c*) Built into the wall at one end and the outer end beam supported on a steel I Section. Special angle iron cleats are used at the connection of the stone steps with the I-Section.

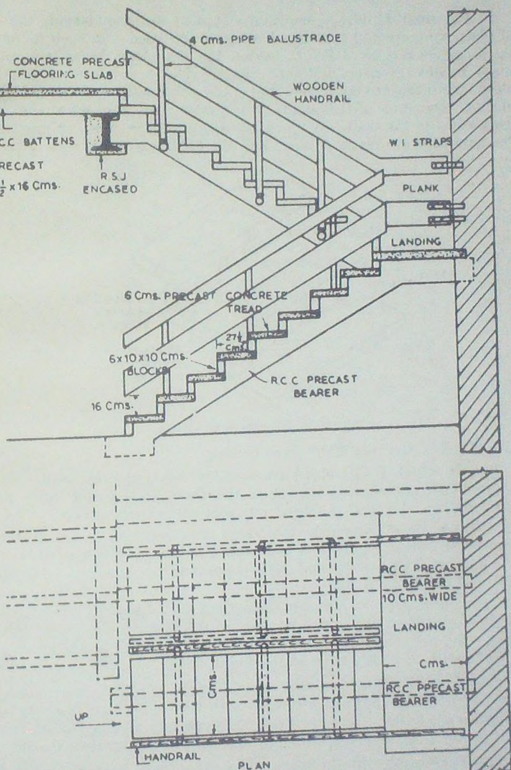
or (*d*) Built into the steel joist at both ends.

Concrete Stairs

Concrete stairs are becoming very popular these days because of their advantages such as strength, durability and fire resistance. Moreover, they can be constructed in many forms.

Plain concrete stairs are used in place of stone stairs these days. They are mainly suited for entrance to the buildings. The steps are mostly of spandril type and are supported as in the case of stone stairs. They may be cast in situ or precast steps may be used. Reinforced concrete stairs are mostly used at present. The advantages of the reinforced concrete stair construction are :

(*i*) It can be easily moulded into any desired geometrical shape.



Figs. 800-801. Precast R.C.C. stairs.

(*ii*) It is more fire resistant.

(*iii*) It needs less bulky section so that more of headroom is available.

(*iv*) It is less noisy.

(*v*) It has more attracting appearance if suitable finishes are used.

(*vi*) It can be kept clean.

For small buildings, composite type of stairs envisaging the use of plain concrete and reinforced concrete are used. In such a type, the stringers can be of R.C.C. beams, the top slope being cut in a shape to suit the risers and the treads. The treads are of precast plain concrete slabs and the risers, are of small, precast concrete blocks. One end of the stringer is resting on the base and the other rests on the wall. A precast concrete slab is used as landing. The handrails are made of wood and the balusters are of steel pipes.

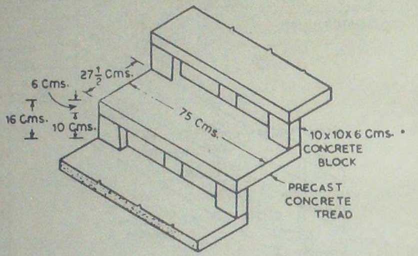


Fig. 802. Precast step details.

R.C.C. stairs can be of three types :

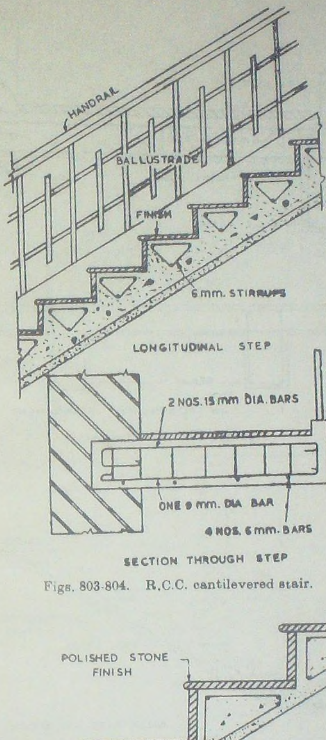
(*i*) In which R.C.C. steps are cantilevered from the wall. The reinforcement is placed at the top of the tread and a few bars are placed at the bottom of the riser, suitable cover being given.

(*ii*) A stair in which the steps are designed to act as slabs between the two stringers or a wall and a stringer. The stringers act as inclined R.C.C. beams and are supported at the top and the bottom of the landing.

(*iii*) *Slab type* : In which each flight is designed as an inclined slab and reinforcement is laid parallel to the slope of the flight. The flights may be supported on the beams at the ends or the landings may be included in the span of the flight slab.

Unfinished R.C.C. surface would give a highly unattractive stair. Hence the steps are provided with tiles, terrazzo, marble or other suitable finish The inclined stringers may also be given suitable covering in accordance with the desired architectural treatment.

It is essential that the steps are covered with a material which will not render the tread slippery, hence checkered grooves may be made on the surface or other suitable roughening devices may be used.



Figs. 803-804. R.C.C. cantilevered stair.

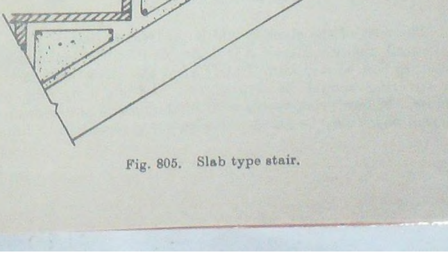
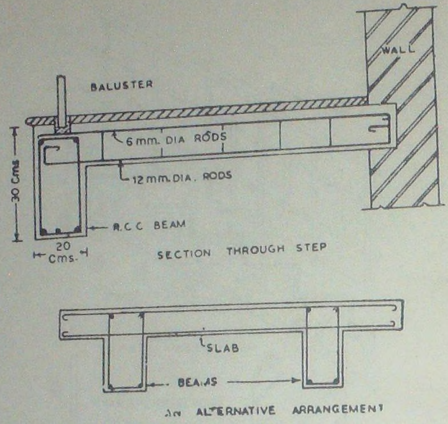


Fig. 805. Slab type stair.



Figs. 806–807. Slab type stair.

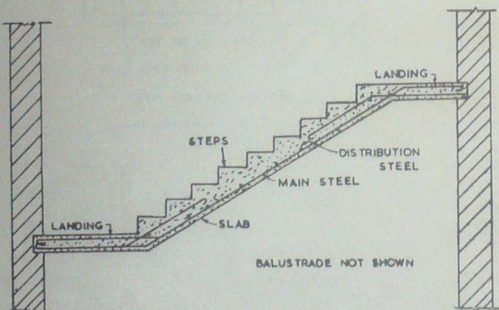
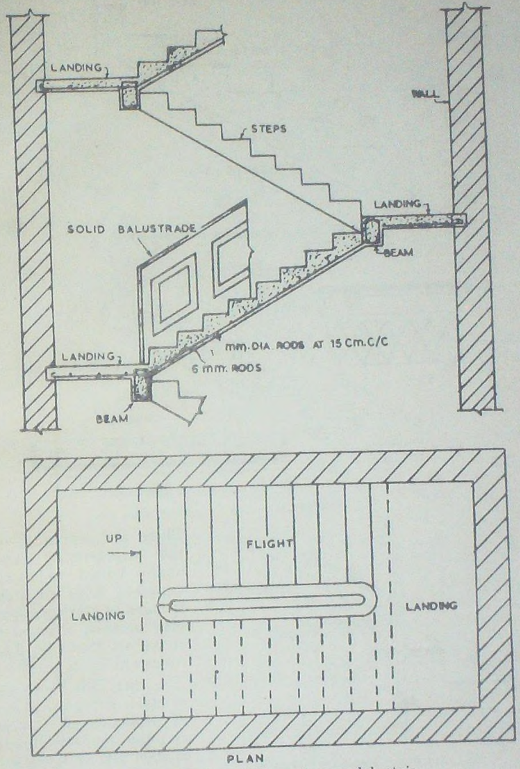


Fig. 808. R.C.C. slab stair.

The nose of the steps should be so treated that it does not get cracked off easily. Hence it is desirable that the concrete covering, if used, should be laid immediately after the steps are cast or else this covering should be keyed with the steps by roughening the surfaces. Wherever excessive wear of the nose is anticipated, steel or cast iron noses may be fitted to the concrete steps.



Figs. 809-810. R.C.C. continuous slab stair.

Metal Stairs

Steel and cast iron stairs are used in exceptional cases where fire proof construction is desired, *e.g.*, in factories, go-downs etc. They are of four general types :

(*i*) The simplest type consists of steel channels acting as stringers. The treads are of steel checkered plate or of concrete slabs.

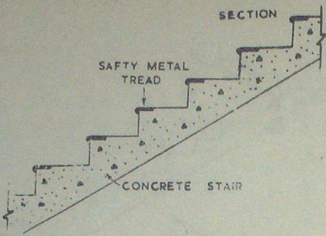
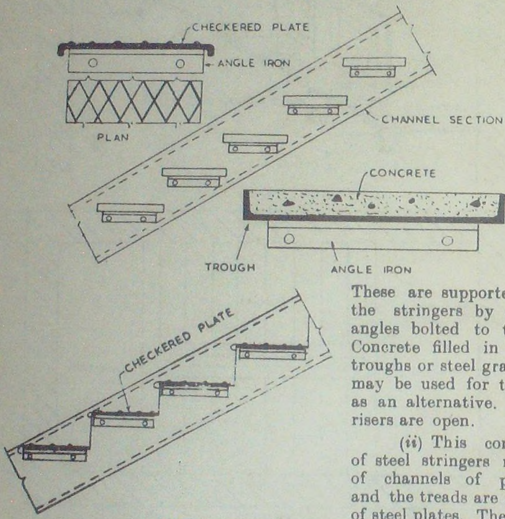


Fig. 811. Metal nosing for concrete stair.



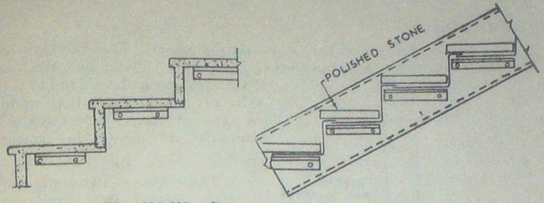
Figs. 812-815. Metal stair details.

These are supported on the stringers by small angles bolted to them. Concrete filled in steel troughs or steel gratings may be used for treads as an alternative. The risers are open.

(*ii*) This consists of steel stringers made of channels of plates and the treads are made of steel plates. They are finished in a suitable manner, *i.e.*, they may be covered with stone, marble, etc. They are used in important buildings.

(*iii*) In this, the stringers are of steel and risers of concrete. The concrete is suitably finished.

(*iv*) *Spiral Stairs* : They are used where the space available is too small and the traffic is less. They are made of C.I. pipe newel fixed in the centre and around this C.I. steps are fixed. The steps have suitable checkered treads for safety.



Figs. 816-817. Concrete or metal and stone stairs.

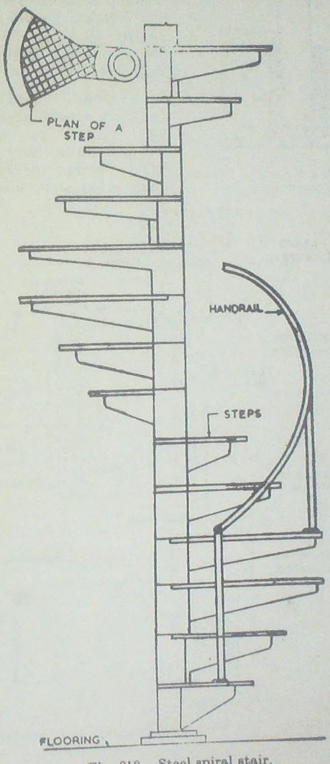


Fig. 818. Steel spiral stair.

Balustrade

This consists of a handrail and balusters. The handrail is generally of wood and has special mouldings. They follow the line of the stringers and are fixed to the walls or newels depending upon the type of stairs. Some typical handrails are shown in figures 820-825.

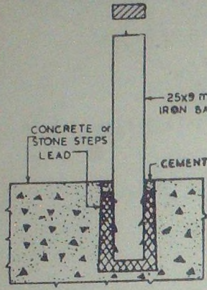
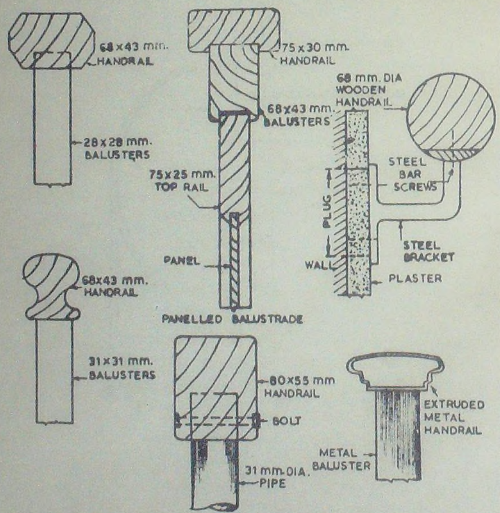


Fig. 819. Fixing of a metal baluster in concrete.

These days handrails of chromium plated steel fixed on the top of polished wood are used. The handrail should be fixed at a height of 45 to 50 cm. above the line of nosing. Handrail on landings should be at least 90 cm. high.

Balusters : They are generally not spaced greater than 15 cm. centre to centre. For wooden stairs, they are made of wood whereas for other types of stairs, balusters made of metal



s. 820-825. Various types of handrails and balusters.

are used. They may have special shapes and mouldings carved on them or else they may be made of plain rectangular or pipe sections. Some of the types commonly used are shown in figures 820-825.

Ramps

A ramp is an inclined plane joining two floors. It is mainly used for carrying machinery, equipment, trolleys, cars, etc., to upper floors in multi-storeyed and public buildings. It can, however, also be used by pedestrians. In addition to the great utility of carrying goods and pedestrians, ramps have an aesthetic value. It consists of a continuous rising surface with transitions at the floor level.

Ramps may either be located externally, *i.e.*, extending from the general building line or internally, *i e.*, inside the building. The location depends upon the use to which ramp is put. For carrying heavy loads, external position is preferred, whereas for pedestrians, it can be situated inside the building.

The dimensions of the ramp also depend upon its use. For pedestrian traffic, a minimum slope of 1 in 10 and a maximum of 1 in 6 can be adopted. Its width is limited to about 2 m., and can be of dog legged type in plan. Landings at every change in direction are provided with widths equal to that of the ramp.

For carrying cars and other machinery, much greater dimensions are required The width is kept at a minimum of 4 m. and maximum of 8 m. A gentle slope of 1 in 10 is given. A straight flight type or curved type of ramp is preferred and no landing is necessary.

For external locations, ramps are constructed with two retaining walls with rising tops on either side and the central portion being suitably filled with rising surface. If the ramp is provided inside a building, it may be designed as an inclined R. C. C. slab or as slab supported on columns or strings. A non-slippery wearing surface is a must to avoid slipping. Rough cement or granolithic surfaces give satisfactory performance in this respect. Surface patterns or transverse grooves may be formed for improving slip resistance. Metal surfaces, being smooth, are not adopted for ramps.

Lifts

For multi-storeyed buildings, the installation of lifts is a must to avoid fatigue in climbing up the stairs and for quick vertical circulation between different floors. The provision of lifts in the structure is a highly specialised job. However, certain provisions are required to be made in the building layout and structures for accommodating lifts and other accessories like operating devices. A vertical shaft with openings at the floor level is provided. The shaft is located at a suitable place such as by the side of the stair or within the open well of a stair. It may have sides built in masonry or concrete or metallic cage with suitable doors. The shaft extends below the ground floor or the basement floor, as the case may be, to accommodate the spring buffers for slow speed lifts and hydraulic buffers for high speed lifts. Usually, a machine room is located at the top of the lift shaft for housing equipment and accessories. However, it can also be at the bottom, by the side or at the back of the shaft. The size of the room is normally $4 \times 3 \times 2.5$ to 3.0 m. Its floor should be suitably designed to support the heavy loads coming over it. It has to support the weight of the lift car, equipment, passengers, the balancing weight and the weight of motor with the winch arrangement.

The shaft for the lift should be able to accommodate the lift car, balancing weight, and vertical guides for them. Previously, collapsible doors were provided both for the lift car or cage and the opening in the shaft at the floor level. Now, flush doors of sliding type are provided. The doors at the floor level are fitted with electro-mechanical safety locking devices with special emergency lock release.

QUESTIONS

1. What are the various types of stairs used in buildings ? Illustrate your answer with sketches.

2. Two floors of a building are to be connected by wooden straight flight stair with a difference in height of 2.75 m. between the floors. The stair should be 45 cm. wide. Draw a dimensioned sketch showing the constructional details and briefly describe the various components.

3. Draw a sectional elevation and plan of a dog-legged stair connecting two floors of a building. Describe in detail the various constructional features of this type of a stair.

4. Write short notes on :

   (*i*) Stringers ; (*ii*) Winders ; (*iii*) Landings ; (*iv*) Open well stairs.

5. What are the types of stone stairs and steps ? Illustrate with sketch how stone stair can be constructed for an external door of a building.

6. What are the various types of concrete stairs ? Describe with sketches the construction of a precast concrete stair.

7. Write short notes on :

   (*i*) R.C.C. slab stairs ; (*ii*) Metal stairs ; (*iii*) Spiral stairs ; (*iv*) Balustrade ; (*v*) Handrail ; (*vi*) Ramps ; and (*vii*) Lifts

References

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13

ROOFS

The function of a roof is to give a protective covering to the building so that rain, snow or wind may not damage the building. It is erected at the highest part of the building and is made up of a framework over which a covering is laid Roofs are constructed keeping in view the climate of the place and the materials available. Sometimes architectural considerations may also have an important bearing on the selection of roof type. The general types of roofs are listed below :

(*a*) Sloping roofs.

(*b*) Flat roofs.

(*c*) Shelled roofs.

(*d*) Domes.

Sloping Roofs

The various shapes which can be given to roofs of this type depend on the area covered, materials available, type of lighting and ventilation needed inside, available appliances etc., etc.

Some important types of sloping roofs are given as under :

(*i*) *Shed roof* : This is the simplest type and slopes only in one direction. It is used for smaller spans.

(*ii*) *Gable roof* : This roof slopes in two directions and is used commonly.

(*iii*) *Hip roof* : This slopes in four directions.

(*iv*) *Gambrel roof* : This roof also slopes in two directions but there is a break in slope.

(*v*) *Mansard roof* : This slopes in four directions but there is break in slopes.

(*vi*) *Saw-tooth or North-light roof* : This is used in factories etc. where light is admitted from the glazing fixed on the steep sloping sides of the roof.

Wooden Sloping Roofs

Terms Used :

(*i*) *Ridge* : Apex line of a sloping roof.

(*ii*) *Ridge piece* : A member which runs horizontally at the highest level of the roof.

(*iii*) *Hip* : External angle of a sloping roof at which the roof slopes are turned down

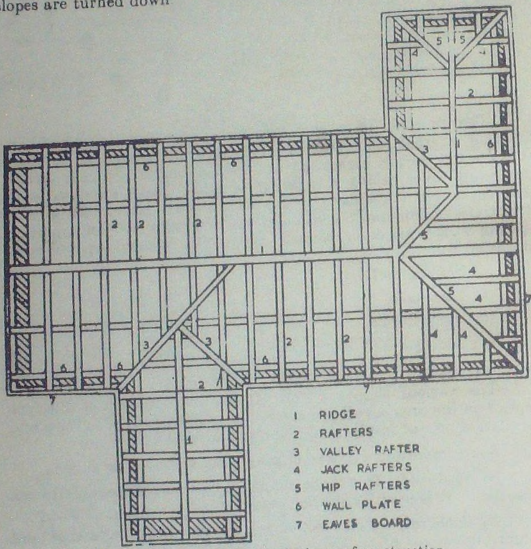


Fig. 826. Terms used in sloping roof construction.

(*iv*) *Common Rafter* : Members supporting the battens or boardings under the roof covering.

(*v*) *Hip Rafters* : These are wooden members which form the hip of the roof and to which the common rafters are attached.

(*vi*) *Eaves* : These are the lower edges of the sloping surface of a roof.

(*vii*) *Eave-board* : Wooden board fixed along the eaves connecting the common rafters.

(*viii*) *Gable* : Wall which follows the slope of the roof from eave to ridge and covers the end of a roof.

(*ix*) *Barge Board* : Wooden planks used to fix the ends of common rafters projecting beyond the sloping top of a gabled wall.

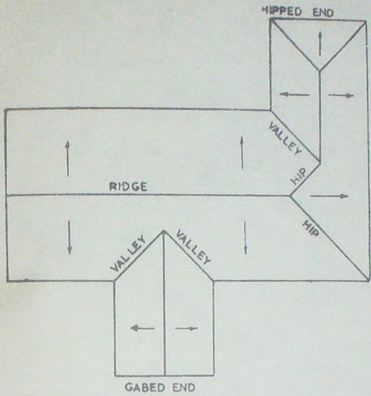


Fig. 827. Sloping roof junctions.

(*x*) *Valley* : A depression formed at the intersection of two sloping roofs at their junction.

(*xi*) *Jack Rafter* : Short lengths of rafters fixed to the hip rafters and eave's board.

(*xii*) *Valley Rafter* : Member at the intersection of two inverted slopes to which rafters are fixed.

(*xiii*) *Dragon Beam* : Short member of wood which carries the foot of a hip rafter which is attached to the tie fixed across the angle formed by the intersection of two wall plates at the corner of a building.

(*xiv*) *Purlins* : These are members laid horizontally to support the common rafters. They transmit the loads to the trusses or walls.

(*xv*) *Purlin Cleat* : Short piece of timber bolted to the rafters of a roof truss for fixing the purlins.

(*xvi*) *Truss* : A framework of triangles.

Types of Wooden Sloping Roofs

(*i*) **Lean to Roof** : This is a roof which covers the verandah of a building and projects from the main wall of the building. This is suitable for spans upto 2.5 m. If, however, slightly greater spans are used, purlins may be added. On one side, the common rafters are supported on a wall plate which in turn rest on a projecting corbel from the wall. The lower side may also rest on the wall plate or may be fixed to a vertical post with bolts and nuts

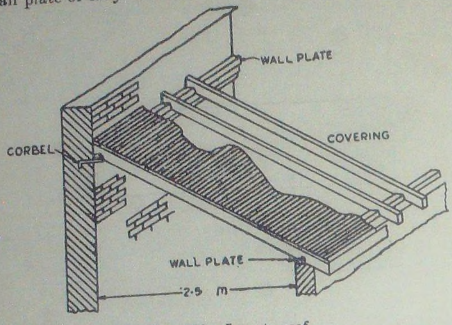


Fig. 828. Lean-to-roof.

in case the verandah is exposed. The covering may be fixed to battons running across the rafters or a wooden boarding directly fixed to the rafters. It is essential that the leakage at the junction of the roof with the wall be prevented.

(*ii*) **Couple roof :** Couple roofs are used for spans upto 3½ metres. They consist of two rafters with a central ridge piece at the top. At the bottom, they are fixed to the wall plates. They are unsuitable for large spans because of the danger of walls being spreading due to the thrust of the rafters. Brickwork between

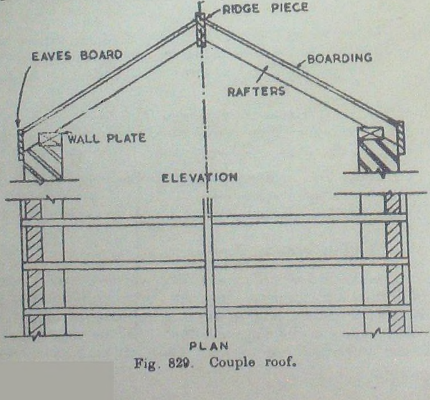


Fig. 829. Couple roof.

the common rafters is carried to the bottom of the planking which is fixed to the rafters. This leaves no gap between the roofing and the wall which otherwise would provide an inlet for birds etc.

(*iii*) **Couple Close Roof** : This consists of two rafters arranged as above and connected by a wooden member which acts as a tie. This horizontal tie prevents the outward spreading of the walls and also can act as a support for any ceiling which might be fixed beneath it. These roofs can be used for spans upto 4½ metres.

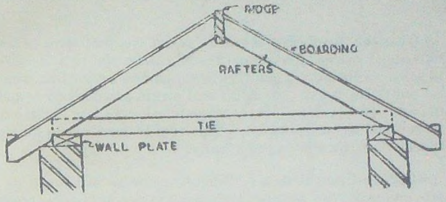
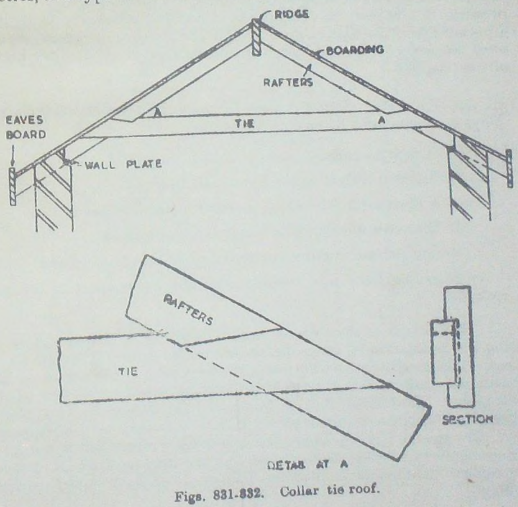


Fig. 830. Couple close roof.

(*iv*) **Collar Tie Roof :** For spans between 4 metres and 5½ metres, this type of roof is commonly used. Each pair of rafters has a



Figs. 831-832. Collar tie roof.

collar, *i.e.*, a wooden section of the same width as the rafter. This is fixed at a height of half to one-third of vertical height between the wall and the ridge. It is better to place it as low as possible for giving maximum strength to the roof. This collar subjects the rafters to excessive bending stresses and it is essential that the joint between the collar and the rafter be perfect. Any deflection of the rafter will try to spread the walls away. The collar is dove tailed with the rafter. Bolts may be used as an additional safety.

(*v*) **Collar and Tie Roof :** When the roof span exceeds the previous given values, a combination of collar tie and couple close roof is used. In this, the rafters are supported by purlins which rest at the ends on walls. A collar and struts are used to support the purlins and the rafters. Advantage is taken of any partition walls, etc., to support the ceiling joist. This roof is used where purlins can be supported at the ends economically.

(*vi*) **King-Post Truss :** When the spans are large or intermediate supports for purlins and ties are not available, trusses are used. The total weight of the roof is carried on to the walls vertically. The framework of a truss is built in such a way that it does not alter its shape when loaded. Triangular shape of the frame offers greater rigidity. Members of trusses are subjected to direct stresses of compression or tension, the magnitude of bending stresses is negligible. To ensure this, the central lines of the connecting members should meet at one point and the loads should be applied at the apex points of the triangles.

A King-Post Truss is used for spans of 6 metres to 9 metres. The components of a King-Post Truss are :

(*a*) A central upright member called King-Post.

(*b*) Inclined rafters called Principal Rafters.

(*c*) A horizontal connecting member called Tie-Beam.

(*d*) Two struts which give support to the rafters.

(*e*) Purlins running over the principal rafters from truss to truss.

(*f*) Ridge piece and common rafters for supporting the roof coverings.

The weight of the ridge is carried down the principal rafters to the tie beam which prevents the feet of the rafters from spreading out. The weight carried by the purlin is placed in the centre of the principal rafter and is carried through the struts to the foot of the king-post. The load that is taken to the foot of the king-post is transmitted to the tie beam which in turn transmits to the supports. In this manner, the principal rafters and the struts act as compression members whereas the tie beam and the king-post act as tension members. Hence the connecting joints have to be designed accordingly.

Joints and Fastenings of King-Post Truss :

The joint between the principal rafter and the tie is a bridle joint. A central tenon is formed in the tie and the foot of the rafter is shaped accordingly. The width of the tenon should not be greater than one-third of the beam width. The cuts of the notches on the tie beam are quite long and extend to the central line of the rafter. The bearing face of the notch is made at right angles to the central line of the rafter. The joint is further strengthened

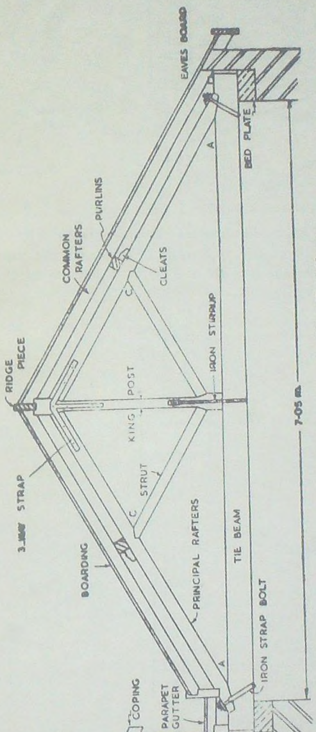
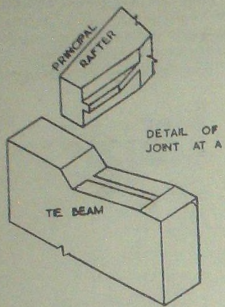


Fig. 833. Elevation of a King-Post Truss

by passing a bolt between the tie and the rafter as shown. Alternatively a strap may be used to connect these (Fig. 835). It should



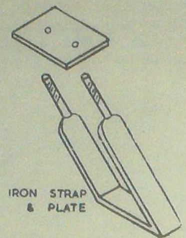


Fig. 835.

Fig. 834. Joint between principal rafter and tie beam.

be ensured that the principal rafter's central line and the central line of the tie beam meet at a point which lies on the vertical line passing through the centre of the supporting wall.

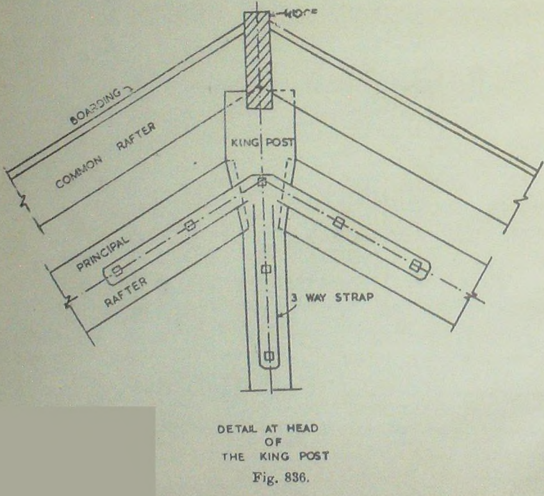


Fig. 836.

The joint between the principal rafter and the king-post is made by cutting a tenon in the principal rafter and the corresponding mortice into the head of the king-post. The top edge of the tenon and the corresponding edge in the mortice are made horizontal whereas the lower edge is parallel to the slope of the rafter. The tenon is not greater than 3 cm. in depth. The rafters and the king-post are connected by iron straps bolted together.

The joint between the king-post and the tie beam may be an

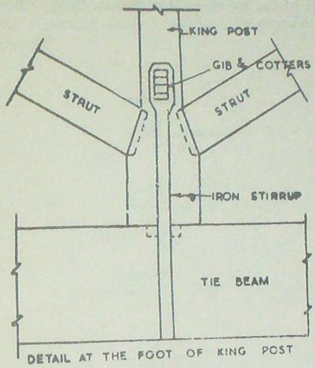
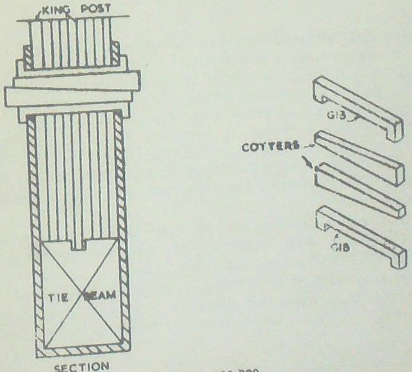


Fig. 837.



Figs. 838-839.

ordinary mortice and tenon joint or a stub-tenon joint. The king-post and the tie-beam are connected by iron stirrup to strengthen the joint further as shown in figs. 838 and 839.

Joints between the strut and the king-post or the rafter are also mortice and tenon type. The joint at the head of the strut (*See* Fig. 840) has an oblique tenon which is housed into the rafter. The joint at the foot of the strut is of a single abutment tenon type. The king-post is shaped to form a good support for the struts and the lower edge of the tenon is cut horizontally. Double abutment tenon joint is also used.

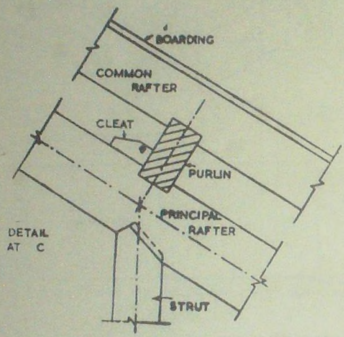


Fig. 840

(*vii*) **Queen-Post Truss** : Queen-post trusses are used upto spans of 13½ metres. It consists of two queen-posts, two principal rafters, struts, tie beam, straining beam, straining sill, purlins, etc., (*See* Fig. 841). The struts, as usual, will cause thrust on the foot of the queen-post and to resist this force a straining sill is fitted in-between the two posts. A straining beam is fixed in-between the heads of the queen posts to resist the thrust which the rafters give to the posts. The principal rafters, straining beams and struts are in compression whereas the queen-post and the tie beam are in tension.

The joints at the head and the foot of the queen-post are of the mortice and tenon type and the edges of the tenons cut in a manner as described under King-Post Truss.

The usual sizes of the timber for various members of the King and Queen Post Trusses are given in different handbooks. However the following rules may be used in determining the approximate sizes.

(*i*) Thickness of King-Post truss in centimetres $= \frac{\text{Span in mts.}}{2}$

(*ii*) Thickness of Queen-post truss in centimetres $= \dfrac{\text{Span in mts.}}{2{\cdot}5}$

(*iii*) Area of cross-section of principal rafter in sq. centimetres $= 15 \times$ Span in metres

(*iv*) The section of King-post, Queen post and struts should be square.

(*v*) The depth of the tie beam in centimetres should be from 5 to $6\frac{1}{2}$ times the thickness of the truss.

(*vi*) Depth of straining beam should be about $\frac{3}{4}$th of the depth of tie beam.

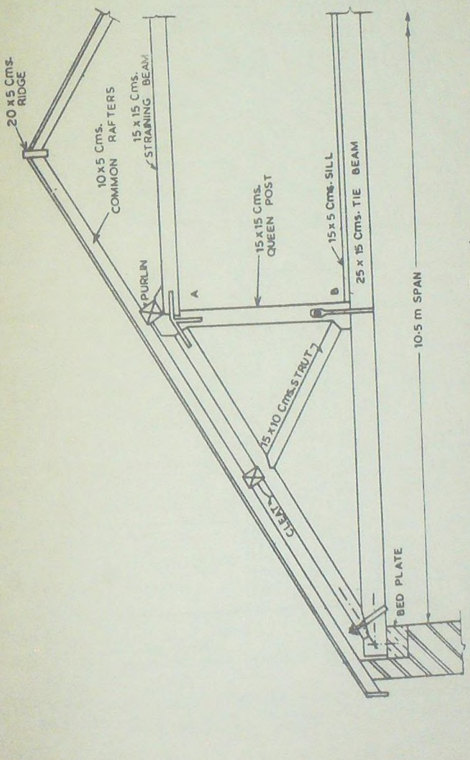


Fig. 841. Queen-Post Truss Elevation.

(viii) **Mansard Roof Truss** : The advantage of this type of truss is that a room can be made inside the roof. This is a two-sloped truss and an approximate shape can be visualised by placing a king-post truss over a queen-post truss. The lower slope should not be steeper than 75° and the upper slope should not be greater than 30°. The construction of various joints is similar to the king and queen-post trusses.

(ix) **Laminated Roof Trusses** : Thin wooden sections are very economical and easily available. Moreover they transmit lesser load to the truss. Laminated trusses are built up of thin wooden members. The design and size of members depends upon the span,

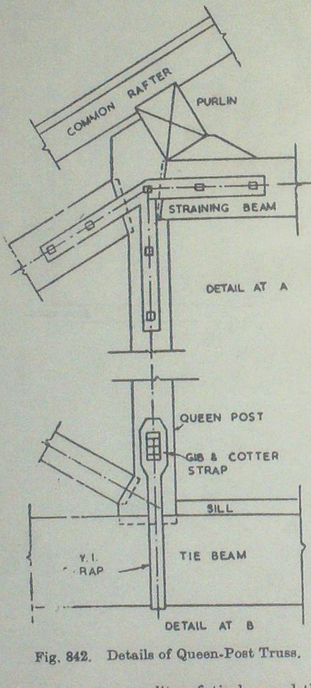


Fig. 842. Details of Queen-Post Truss.

distance apart of the trusses, quality of timber and the weight of the covering material. The connection between the various members is very simple. Either bolts or nails are used ; the former being employed for higher spans and the latter for small spans. Special

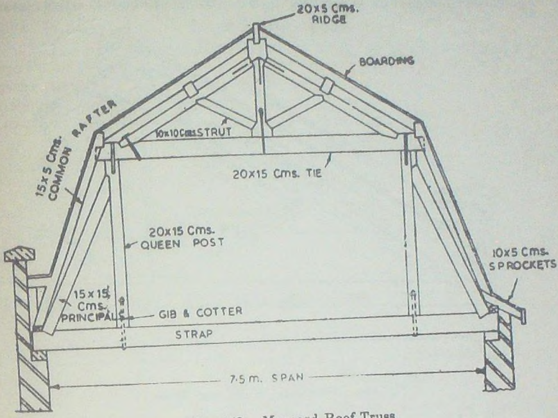


Fig. 843. Mansard Roof Truss.

connectors may be used if more strength is desirable. This type of roof is specially suitable for light weight coverings.

(x) **Bel-fast Roof Truss :** This is also called a Bowstring or latticed roof truss. It is made of thin sections of timber and can be used for big spans upto 30 metres but lighter roof coverings are to be used. The central rise is about one-eighth of the span.

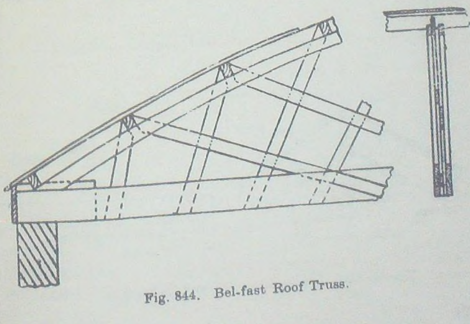


Fig. 844. Bel-fast Roof Truss.

Composite Sloping Roofs

Roof trusses built of timber and steel are termed as composite roof trusses. The tension members if made of wood are very bulky because their section is reduced at the joints. Hence if steel bars

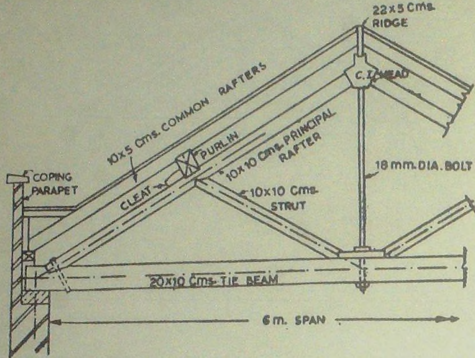
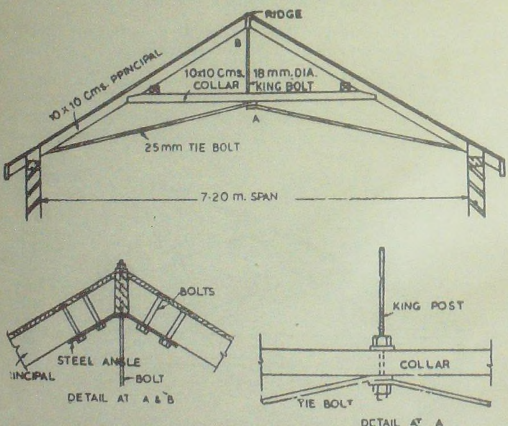


Fig. 845. Composite King-Post Truss.



Figs. 846-48. Composite collar and tie truss with details.

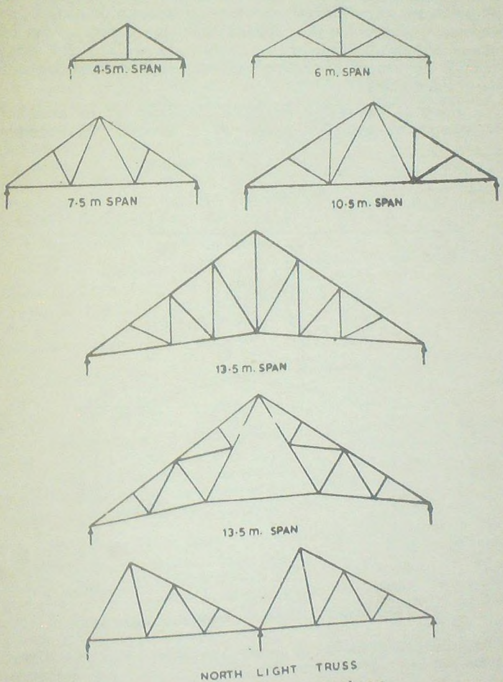
are used for tension members, an economical construction is feasible. However special fittings have to be used where the wooden members join the steel members. The joint should be so designed as to enable the use of cast or forged fittings. The types of trusses of composite nature are shown in Figs. 845-848.

Steel Sloping Roofs

The various types of steel sloping roofs can be as given below :

(*i*) Open trusses.
(*ii*) North light trusses.
(*iii*) Bow-string trusses.
(*iv*) Arched rib trusses and solid arched ribs.

The various shapes of these are shown in line diagrams in figures 849-857.

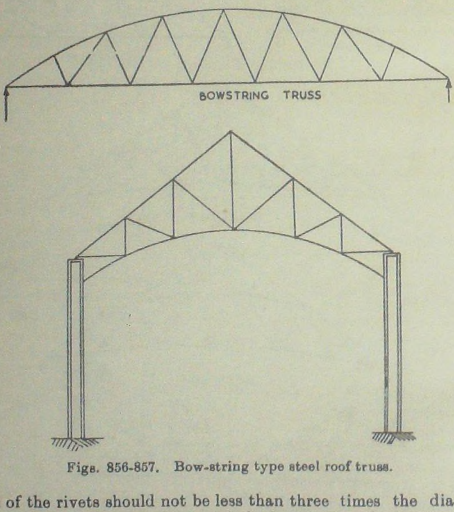


Figs. 849-855. Steel roof truss shapes.

Steel roof trusses are designed in such a way that the members are either in compression or in tension and do not have any bending stress in them. The number, size and relative position of the various members which make up a roof is dependent on the span, roof slope, covering material and the centre to centre distance of the trusses. The compression members should be quite short to avoid buckling. The tie rods should be of one piece or if made of different lengths, these should be suitably joined

The most suitable section for principal rafters is a T-section. For struts either angle iron or a channel section should be used. The tension members should preferably be of a round or a flat section. The various members may also be built of two or more sections, *e.g.*, a principal rafter may be made of two angles placed side by side. In an ideal design all members of the structure should fail simultaneously. However due to practical considerations, small sections, *e.g.*, angles less than 50 mm. × 50 mm. × 6 mm. are not used. Allowance should be made in the selection of sections for stresses imposed on account of the load not being applied along the central line of the member.

Joints: The various members are connected to each other by bolts, rivets and thin plates called gussets. The minimum



Figs. 856-857. Bow-string type steel roof truss.

pitch of the rivets should not be less than three times the diameter of the rivets. The maximum pitch is 15 cm. for compression members and 20 cm. for tension members Further a minimum distance from the centre of the rivet to the edge of the member shall not be less than 25 mm. for 15 mm. diameter rivets. Generally 15 mm. diameter rivets are used for smaller spans and 20 mm. rivets for bigger spans. At least two rivets should be used for all connections. Gusset plates should be designed according to the forces coming on the members but should not be less than 6 mm. in thickness.

Some of the roof trusses are detailed below.

(1) **Trusses for small spans** (upto 7m.)

The ends of these small trusses rest on bed plates which may be of stone or concrete. The ends are further bolted down with rag bolts which hold the truss down.

For small spans, all members may consist of angles connected with gusset plates. The diagonal tension members are connected on one side of the gusset plate whereas the main tension member is connected on the other side. At the foot of the truss a short angle is fitted on both sides of the gusset which rests on a bearing plate. The holes in the bearing plate are made in such a fashion that they correspond to the holes in the angle cleats and the holes in the bed plates so that the rag bolts can pass through. The cleat holes are made slightly bigger than the diameter of the rag bolt to allow for the small variation in dimensions.

At the apex, the wooden ridge piece is secured by two bent plates and are bolted or rivetted to the main rafters The purlins, if made of wood, are fixed to the rafters by angle iron cleats which are bolted or rivetted to both of them. Whenever joints occur at the purlins, longer cleats are used.

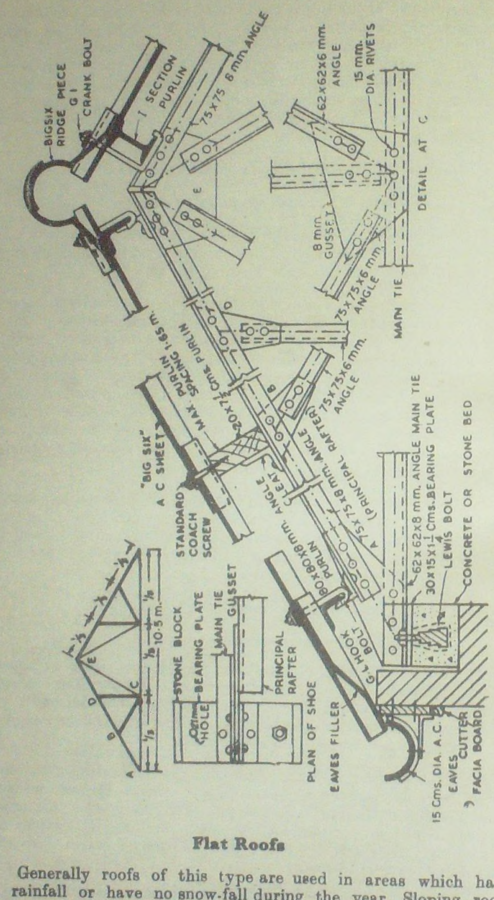
For this span, 15 mm. diameter rivets are used.

(2) **Trusses for large spans :**

The arrangement of members for bigger spans is shown in Figs. 858-859. The members may consist of more than one section. They may be two angles or channels or flats connected by a gusset with the other members at the joints. The section of the member can be reduced as the force in it gets decreased.

The method of joining and construction is similar to the one described above except that bigger trusses cannot be rivetted completely in the fabricating shops. For this reason, the truss is rivetted in two portions at the shop and gusset plates at the connecting ends are rivetted to them. The two halves are erected and finally rivetted at site.

Bigger bearing plates are used for these trusses and the cleats are connected to them by counter sunk rivets. Slotted holes are left in the bearing plates for fitting the rag bolts.



Figs. 858-859. Steel roof truss details.

Flat Roofs

Generally roofs of this type are used in areas which have less rainfall or have no snow-fall during the year. Sloping roofs have a very good advantage that they can be drained easily but the drainage of flat roofs. is a big problem. Whenever materials which are not impervious or members frequently joined are used in the construction of roofs, drainage is difficult. Hence wooden roofs, as a rule, are made a little sloping and reinforced concrete roofs are flat. Moreover wooden roofs are constructed of small members which if arranged in a trussed form could be used for a bigger span. Wooden flat roofs are used only for small spans.

(*i*) **Wooden flat roofs :** These roofs are generally having a slope of less than 10°. They are in fact similar to wooden floors but have a steep slope on the top to drain off the water. They consist of joists which are covered with cross girders or planking. The method of fixing the joists, the cross-girders and the boarding or planking is described under the chapter on wooden floors. However some important points concerning wooden flat roofs are noted below.

(*a*) The slope to be given to the roof should not be less than 1 in 50. However steeper slopes than this are desirable.

(*b*) The direction of the slopes is dependent on the position of outlet for water.

(*c*) The boarding should be laid parallel to the slope of the roof.

(*d*) The slope on the boarding is formed by fixing small tapering sections of wood (furrings) either parallel to or at right angles to the joists. The latter method is to be preferred.

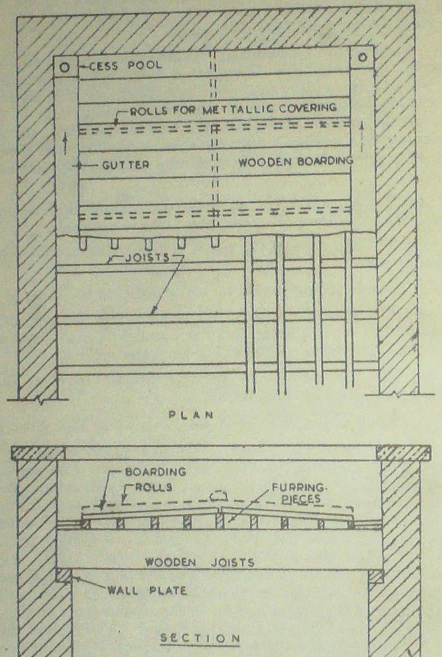
(*e*) The roof should be given a suitable covering for water proofing and for prolonging its life.

A section of simple type of roof is shown in Figs. 860-861.

(*ii*) **Battened Flat Roof**. This type is made up of wooden or R. C. C. joist (battens) (*See* figs. 862-863) spaced close together and are supported on walls or in addition on an intermediate steel joist and are covered with brick tiles in one or two layers. These tiles are cement pointed and further are plastered at top. For water proofing this type of a roof, two coats of bitumen are applied on the plastered top. The tiles are 30×15×3 cm. if laid in two layers or 30×15×5 cm. if laid in one layer and are laid in such a way that the joints come over the centre of the battens. It is to be ensured that the joints are straight and fine. The second layer of tiles is laid on a 1·25 cm. bed mortar which is spread on the first layer of tiles. The joints in the top layer with respect to the bottom layer are broken. Tiles resting on walls should have a bearing of at least 11 cm. and shall be tightly fitted into the brickwork of the parapet so as to leave no gap. After plastering the tiles, 10 cm. of earth may be put and the same mud plastered wherever water is led away, special platform shall be built on the top of the earth to prevent scour.

(*iii*) **Jack Arch Flat Roof.** Small brick or concrete arches are built within steel joists supported on the walls of the room. The construction of this type is described in Chapter XI on flooring. In the case of roofs, a covering of 10 cm. thick earth filling plastered at top is given. As an alternative or in addition special water proofing compounds may be used.

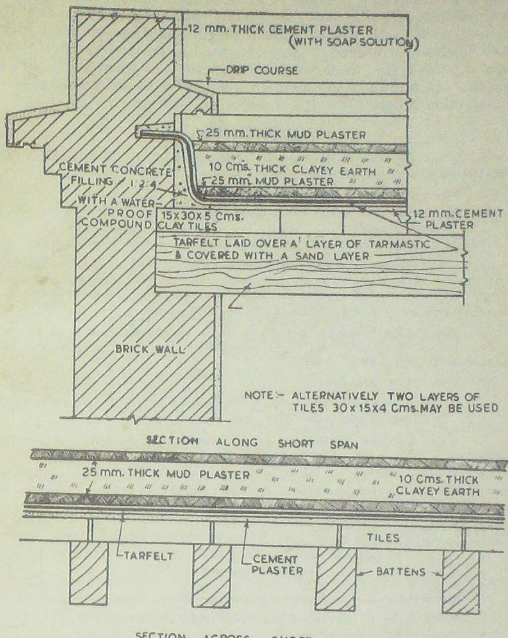
(*iv*) **Reinforced Concrete or Reinforced Brick Flat Roofs.** They are similar to the types described under floorings. However drainage and heat insulation have to be accounted for.



Figs. 860-861. Wooden Flat Roofs.

Shell Roofs

Such type of roofs are used frequently these days for covering big structures. The shell type of construction has an advantage that a lot of material is saved as the section needed is very thin. Moreover, enough space inside the roof is available for use as there are no projections within it. For big buildings, reinforced concrete shells are used whereas for small buildings shells of catenary type made either of bricks or plain concrete are used. However a shell type roof construction is being developed at Central Building



Figs. 862-863. Battened Flat Roofs.

Research Institute. Roorkee (India), for use in small buildings. This envisages the use of about 5 cm. thick lime concrete shell sloping in two directions and supported on small battens which can be precast. These can be fitted on the rooms in individual units and supported on walls or joists as the case may be.

Shell type construction can be used for factories. Wherein north lighting is desired, saw-toothed shells are used. Details of this type of construction are given in chapter on reinforced concrete construction.

Domes

A dome is a roof of semi-spherical or semi-elliptical shape. They are constructed of stone or brick or concrete and are supported on circular or regular polygon shaped walls. The structure of the dome is such that within certain height and diameter ratios, very small thickness is needed. They are used where architectural treatment is needed, *e.g.*, in monumental structures or where roofs have to be built on buildings circular in plan. They need special type of construction procedure which is described later on.

QUESTIONS

1. What are the various types of sloping roofs ? Describe briefly the construction of a lean-to-roof using wood as the main material.

2. Write short notes on :
   (*i*) Couple roof (*ii*) Couple-close roof (*iii*) Collar tie roof (*iv*) Collar and tie roof.

Illustrate your answer with sketches showing constructional details.

3. What is meant by the term "King-Post-Truss" ? A room 7·5 m. × 15 m. in plan is to be covered by a wooden sloping roof. Show in detail the type of roof suitable with typical elevation, sections and joint connections.

Approximately give the sizes of the various members.

4. When does it become necessary to use a "Queen-Post Truss" for the construction of a sloping roof ? Give detailed elevation, sections etc. of a Queen Post Truss for 12 m. span.

5. Write short notes on :
   (*i*) Mansard roof truss (*ii*) Laminated roof truss (*iii*) Composite king post roof truss (*iv*) Bel-fast roof truss.

6. What are the advantages of steel roof construction ? Draw neat line diagrams to illustrate the use of various roof trusses for different spans.

7. A room 10·5 m. × 21 m. in plan is to be covered by a steel roof. Draw detailed elevation and sections of a typical roof truss suitable for this span. Complete details of joints and supports should be given.

8. Write short notes on :
   (*i*) Wooden flat roofs (*ii*) Shell roofs.

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14

ROOF COVERINGS

Roof covering is a material which gives a protective surface to the roofing structure. The function of the covering is only to prevent ingress or egress of heat and moisture into the building. It does not withstand structural loads which are directly taken by the roofing elements. It is only to take loads to the extent over which it is supported on the roof members. There are various types of coverings depending on the character of the building, the type of roofing structure, local conditions, cost, etc. Mainly in India, thatch, wood, shingles, tiles, slates, asphalt, asbestos cement sheets and corrugated iron sheets are used as covering materials. In other countries bituminous felt, glass and copper or other sheet metal roof coverings are also used. A brief description of each covering is given in the following paragraphs :—

Thatch

This is one of the most ancient types of roof coverings and is used mainly in village areas. It is suitable for rural buildings, mainly because the cost is very low and thatch is abundantly available in those regions. Thatch either from straw or reed is used.

The supporting structure in the case of thatch may consist of ordinary truss work which is overlain with a network of battens so as to form a grid over which the thatch can be tied. Ordinarily the thatch is available in a sort of bundles which can be laid on this network and tied to it with the aid of wire or hemp rope. Each bundle is lapped sideways and also course after course so that the penetration of rain into the structure is resisted as much as possible. Thatch unit can be made on ground itself by tying it to network of 25 mm. diameter bamboo spaced at 15 to 22 cm. centres and making the unit in size of 1·5 to 2 m. by 1·2 to 1·5 m. These units can thus be taken as a whole and laid over the wooden trusses or other types of supporting structures.

For adequate resistance against rain penetration the thatch covering should be at least 15 cm. thick. It should have a good slope of 40° to 45° as a minimum. Thatch is liable to catch fire and as such it is desirable that it be made fire proof so as to resist fire hazards. Thatch can be dipped in a fire-resisting solution or the latter can be sprayed on to the roof after the thatch is laid. Various types of fire proofing materials are available and a lot of research work at the Forest Institute of India and by other countries has been carried out. One of the formulae generally used for fire proofing is :—

	Kg.
Sulphate of Ammonia	13
Carbonate of Ammonia (Lump)	6
Borax (Lump)	3
Boric Acid	3
Alum (Lump)	7
Water	225

It is also desirable to make thatch worm-proof so that it is not easily attacked by insects and birds do not gather inside it. For this reason it is treated with solutions of sodium bicarbonate and copper sulphate or other chemicals which are poisonous to the breeding of insects.

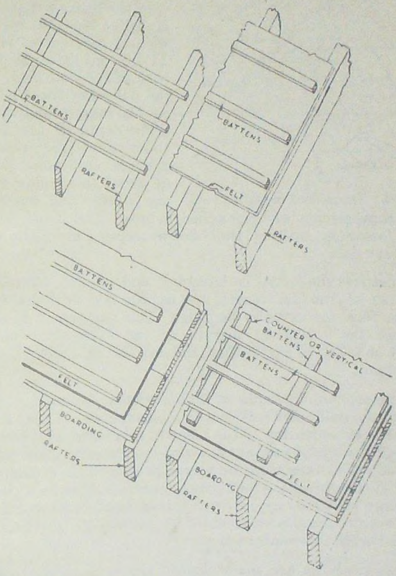
Slating

Slate is a sedimentary rock which owing to intense pressure, volcanic upheavals and other internal structural changes has lost its original bedding and has acquired its essential characteristic tendency to split into thin sheets. Chemically, slate is built of silica and alumina compounds which are inert and incorrodible and contribute largely to its permanent stability. The various colours of slates are due to the staining by absorbed products of metallic origin. The natural and most common colour is some shade of grey and the other colours are bluish-grey, purple, red, blue and black.

A good slate should be free from white patches which are generally of small dimensions and nearly round in shape. These patches are caused by the presence of iron pyrites and they decompose when exposed to weather. Slate should be even in colour and texture throughout. It must be hard and brittle but not tough, *i.e.*, should not break easily when thrown on ground. When struck it should give a ringing sound. It must be impervious to moisture.

The common sizes of slates vary from 60×35 to $25 \times 12\frac{1}{2}$ cm. sizes of random widths and of constant lengths or of random sizes are also available. Various names are given to slate sizes by tradesmen. The larger sizes are suitable for bigger roofs as they make fewer joints, require lesser nails, fewer battens and need lesser number of small pieces at hips and valleys. Regular sized slates vary in thickness from 1.5 mm. to 4.5 mm. for smaller sizes and from 9 mm. to 12 mm. or more for bigger sizes.

There are various methods of fixing slates. When the roof consists of timber rafters the only cheapest method of preparing it is to fix battens across the rafters. The battens are generally of 50×18 mm. size. A roof of this type will be water-tight but is not very efficient. The second method is to fix wooden boards directly to the rafters and nailing the slates to the boards. To make the roof further waterproof and preserve equal temperature in the interior of buildings, an asphalted felt layer may be introduced between the boarding and the tiles. Felt is liable to decay at times for want of ventilation and to prevent this, battens are fixed thereby giving a free circulation of air. Should any water find its way between the slates, the water will lodge upon the horizontal battens thereby



Figs. 864-867. Different types of supporting structures for slate roof covering.

tend to rot. The best method which is usually adopted for good class work is to have close boarding and layer of felt. As described above, over this felt, vertical battens or counter battens of 50×37 to 18 mm. in size are nailed through the felt and the boarding over the centre of these rafters. Ordinary battens are fixed across at required distances. This type of construction gives a considerable amount of space between the slate and the batten which further prevents rapid changes of temperature. Any rain water which tries to come down the felt and below the slate batten to the eaves gets removed so as to leave the roof sound and dry but the cost of this work is excessive. For fixing the slates to steel roof trusses, small wooden purlins may be fixed to support the boarding and battens.

The pitch of the roof mainly determines the size of the slates which can be employed. Smaller slates are suitable for steep pitches and large for flat pitches. The cover of one slate over the other which is below it is called lap and varies from $4\frac{1}{2}$ cm. for vertical slating to 11 cm. for flatter slopes. The area of the slate exposed, after the slates have been laid, is called the margin and the 'gauge' is the depth of the margin or the distance from nail hole to another nail hole. The layer of slates in one line is termed the course and has a proper bonding arrangement with the other course. The bond is an important factor in making the roof waterproof especially when the pitch is very flat.

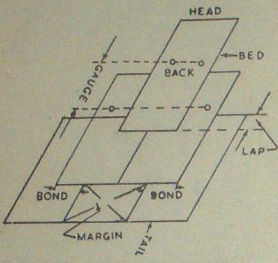


Fig. 868. Terms used in slating.

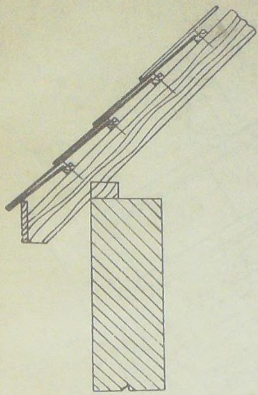
Sometimes the gauge is irregular and is not related to the lap. Slates of random length are usually laid so that their length diminishes from the eaves to the ridge. The gauge may be regulated to produce the breaks on margin of the successive courses, but care must be taken to check that the lap is not reduced below a specified limit.

There are two methods of fixing slates depending upon the position of the nail holes. When the holes are placed near the centre it is termed centre nailing. The holes in this case are punched or drilled sufficiently above the centre of the slates to allow the nail to clear the top of the slates in the course below. This system gives a better hold to the slate and employs fewer slates in a given area. The nails are protected by only one thickness of slates so that if this breaks at any time the water will find its way in. Centre nailing is the method which is usually adopted.

When the holes are made below the top of the slate, the method is termed head nailing. The nail hole gets covered by two thicknesses of slates so that if one gets broken, it is still protected from weather by the other slate. The actual lap is 25 mm. greater than the nominal one. More slates are needed in a given area of the roof and the lifting tendency on account of wind is more in this case.

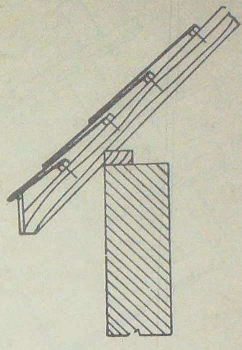
Each slate should be secured with two nails drawn through the holes perforated for them into the batten or boarding below.

Copper, zinc or malleable iron nails are used. Composite nails made of an alloy of copper, zinc and tin are stiff and being cheaper are sometimes preferred. Cast yellow metal nails are very durable. They should be used where the atmospheric conditions are



CENTRE NAILING

Fig. 869. Centre nailing method for fixing slates.



HEAD NAILING

Fig. 870. Head nailing method for fixing slates.

harmful to the other types of nails. The durability of copper nails is considered to be adequate for normal exposure and for slating; general nails less durable than copper nails are also in use. Zinc nails should be used only in areas where the atmospheric pollution is very low and at a place away from the sea coast. The length of the nails should vary according to the size and thickness of the slate. Where slates are centre-nailed longer nails are usually needed. If the nails are too long they will damage the battens. Slates may be holed either by hand or by machine and sometimes drilling by machine is preferred. The holes should be made from the front towards the back of the slates, a small counter sunk is thus left in one face of the slate which serves to take the head of the nail when the slate is thick. Care should be taken while making a hole by hand to ensure that there is no undue spalling. The distance from the slate edge to the centre of the hole should not be less than 3 cm. Usually for head nailing, the centres of the holes are 25 mm. from the head of the slate. For centre nailing the holes are so placed that the nails will just clear the head of the slate underneath. In slates which are not of uniform thickness, the holes should be so located that the thicker end of the slate supports it. Thicker slates should be used in the lower course and the thinner ones on the ridges.

The first row of slates is called the doubling eaves course. This row is fixed all along the eaves before the main part of the roof is

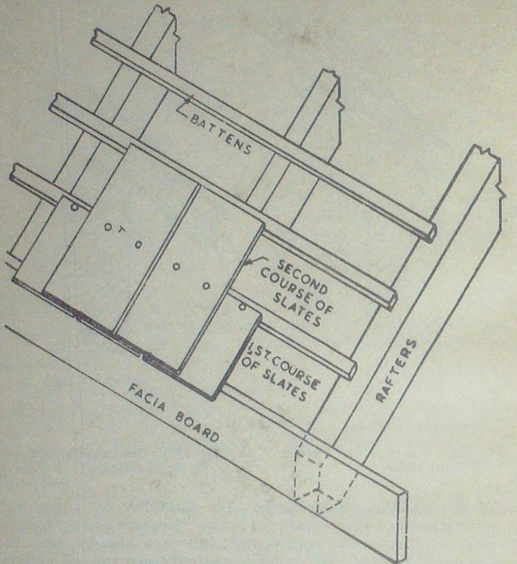


Fig. 871. A typical method of fixing slates at eaves.

enclosed. But bottom edge of the slate projects about 7·5 cm. over the facia board so that the rain water is thrown clear into the eaves gutter. This course is head-nailed and a 5 cm. batten is fixed at such a distance from the outside of the facia board that the head of the slate rests on the centre of the battens. The second row is so laid that slates can be laid flush with eaves course at the bottom, each slate being nailed through the centre.

Sometimes the double batten or the tilting fillet is placed behind the facia board. This method is better as otherwise the slates sometimes break, if the holes are too near the top of the slates.

At the gable end of the wall or at the verge, the side of the slate is allowed to overhang a distance of about 5 cm. The gap between the slate and the brick-work is pointed with mortar or suitable wooden moulding fixed.

The ridge course may also be of double slates so as to preserve the proper lap. The tilting fillet or thicker battens must be

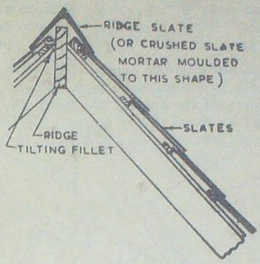


Fig. 872. Covering of ridge with slates.

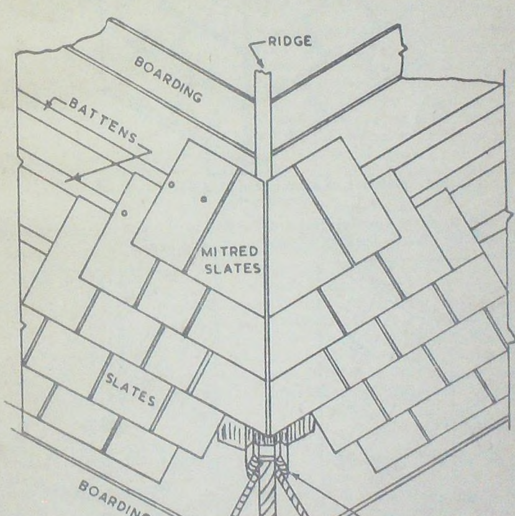


Fig. 873. Finishing of a hip with mitred slates and a secret gutter.

placed along the ridge piece. The last course is finished about 4 cm. from the ridge. The gauge and the lap should be carefully worked out from the top of the ridge. The joint at the top should be perfect so that the water may not drip in. Sometimes tiles are used for protecting the ridge. Slate ridges with wings on each side are also used. The wings are fixed with brass or copper screws.

A similar treatment can be given for finishing the hips at the lower end. Usually a hip hook made of wrought iron is fixed so as to makea stop to prevent the lowest tile from slipping down. The hip may be formed by slates closely cut and mitred down the line of

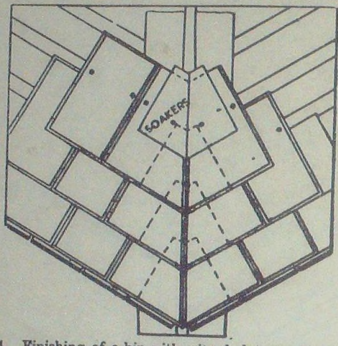


Fig. 874. Finishing of a hip with mitred slates and lead soakers underneath.

the hip to form a secret gutter along the hip. The hip may also be finished by placing soakers of lead across the angle.

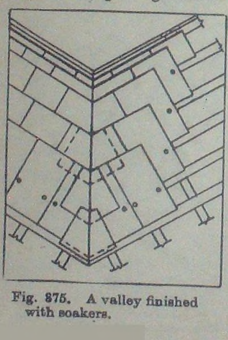


Fig. 875. A valley finished with soakers.

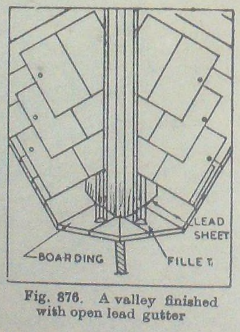


Fig. 876. A valley finished with open lead gutter

A roll may also be used as a method of covering the ridge and sloping timbers are set up above the top of the battens to receive the wooden roll. The roof is then covered with strips of lead 50 to 54 cm. wide. The strips should be lapped $7\frac{1}{2}$ cm. at the joint and should be bent along the side. The lead should be secured to the wooden fillets by nails. A valley may be formed without slates and soakers bent across the angle where the intersection of roofs occurs. Open valleys are formed by placing tilting fillets along the roof. A valley board should be used on each side of the valley to form the surface for lead covering of the gutter.

Glass slates may be used in the roof to give proper light to the rooms below.

Tiling

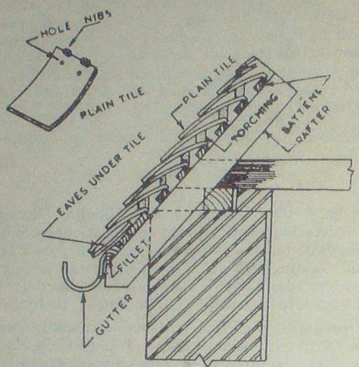
Tiles have been used from olden times as a means of covering the roof. Various shapes of different specifications have been improved from time to time for use. Clay tiles are mostly used after they have been burnt thoroughly in a fashion similar to bricks. Sometimes cement concrete tiles have also been used but their use is limited on account of excessive cost and the difficulties in their manufacture.

The preparation of roof for tiling is precisely the same as that for slating. The battens are usually of 4×2 to $2\frac{1}{2}$ cm. in size and are set out to the required gauge depending upon the tile size. The tiles are hung to the battens with same projections which are made in the tile itself. Some courses of the tiles are also nailed to give added strength. Tiles are mainly kept in position by a sort of interlocking action on account of their self-weight. Tiles are a better non-conductor of heat and cold and as such the use of battens only is not very objectionable. If boarding is used, the tiles have to be fixed on battens nailed to the boards or otherwise counter battens may also be used and should be less than $4 \times 1\frac{1}{2}$ cm. in section.

In normal cases, the pitch of the common rafters or the surfaces on which the tiles are laid should not be less than 40° for plain tiles and 35° for single lap tiles. Where abnormal conditions may be expected, for example, near coasts or in areas where heavy snowfall occurs, these pitches may not ensure full protection from the weather. In such cases the pitch may be increased or the roof may be felted. Alternatively counter battens may be used with or without boarded background. The pitch of the outer surface of the tile gets further decreased due to the fact that each tile is tilted up at its lower edge by the tiles below and thus this slope becomes lesser than the pitch of the common rafters.

Plain Tiles

Plain tiles measuring about 25×15 cm. to 28×18 cm. in size are used in thicknesses from 9 mm. to 15 mm. They have continuous projections on one end or may have two small projecting nibs. These nibs for hand-made tiles should not be less than 9 mm. wide and should have a depth of not less than 9 mm. Camber should not be less than 5 mm. and not more than 10 mm. These values can be slightly decreased in machine made tiles. Two nails are provided, the centre of each nail hole being not less than 25 mm. from the side of the tile and 15 mm. from the under side of the nib.



Figs. 877-878. Details of the fixing of plain tiles.

The lap and gauge in tiling are quite important. The maximum gauge should be about 10 cm. giving about 6 cm. lap for a 26 cm. tile. For a lesser gauge, *i.e.*, about 8½ cm. the number of tiles needed per unit surface of the roof area gets increased. Special tiles are made for the under course at eaves and top course at the ridges to avoid cutting. Special tiles are also made for the hips and valleys. Hip tiles may be in a bonnet shape or may have the shape of a half round, one or angular. The valley tiles may be in angular or rounded form. The bonnet hip tiles give a satisfactory finished appearance. There is no hard line at the intersecting plane and slight amount of latitude in use is allowed.

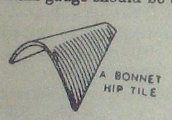


Fig. 879. A bonnet hip tile.

The half round tile is suitable for ridges but is somewhat difficult to be used on the hips of small roofs. Half round tiles are bedded along their lower edges only and their unders are pointed. The angular hip tile is mainly used with handmade tiles to allow for any distortion or warping of the tile during burning.

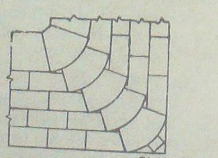


Fig. 880. Plan of hip corner using bonnet tiles.

Valley tiles made in angular or rounded form must be preferred to open or secret gutters as they preserve the homogeneous appearances of the roof, which is better from aesthetic considerations. Alternatively the valley may be laid with mixed tiles and the joints made waterproof by the use of soakers in a manner similar to slating. Whenever open or secret gutters are used, the lead sheet is suitably bent over the fillets and carried up over each side slope about 20 cm. higher than the meeting place. Secret gutters are not suitable as they get filled with dirt.

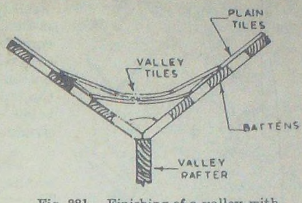


Fig. 881. Finishing of a valley with special plain tiles.

Where verges occur, the tiles are bedded and pointed in cement. A tilt along the edge is given so as to throw water inwards. One or two courses of tiles are bedded in cement along the wall. A projection of about 5 cm. is given on the outside.

Whenever the gable has a parapet wall, the roof is kept satisfactorily finished with lead soakers and stepped flashing of a cement fillet.

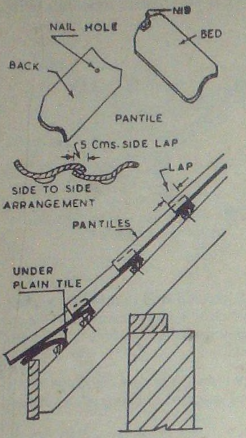
Single Lap Tiling

This differs from the plain tiling in a manner that it overlaps only the tile immediately in the course below and not in the course which is next to one below it. They are not suitable to resist the weather owing to their being only one thickness of tiles in most parts of the roof except at laps. The breaking of one tile or some crack may cause leakage. To prevent leakage, some tiles are bedded with mortar and pointed. A better method would be to use boarding, felt and battens or counter battens.

Pan Tiles

This is one of the oldest type of clay tiles. The roof is covered by the use of bent tiles. There is saving in the quantity of materials and consequently in the weight of the covering. This is on account of the fact that the lap of these tiles is only with the tile just below it. Precaution against leakage from the vertical joints is provided by the edge of the tile which turns over and completely covers the edge of the next tile in the same course. As the tile is practically segmental in section, water is diverted to the central channel immediately it falls and hence there is little chance of it leaking from the joints.

The tiles are about 30 to 35 cm. long and are about 20 to 25 cm. wide. The head or longitudinal lap varies from 7·5 to 10 cm. according to the pitch of the roof and the degree of exposure. The two opposite corners at a joint may be cut to the depth of the lap so that reasonable cover is maintained between the tiles ; otherwise four thicknesses of tiles would occur at the corners resulting in open joints due to tilting, etc. The joint of the bottom left hand corner of a tile with the top right hand corner of the tile below and to the left is called shouldering.



Figs. 882-885. Details of pan tiling.

Pan tiles are nailed in a manner similar to that of plain tiling. They are fixed to tiling battens of about 4×1 cm. size. At eaves, the pan tiles are bedded with mortar on plain tiles. Occasionally three or four courses of plain tiles are provided at 10 cm. gauge at the eaves. The idea of this treatment is to distribute the flow of water from the channels of the pan tiles above and to prevent if from overshooting the gutter. Fillings at the ridge course are cut out of waste tiles. The ridge tiles are then bedded in a level line along the top of the pan tiles. Where an extra course of plain tile is bedded along the top of the rolls, an improved effect is achieved. Verges in pan tile roofs can be given easily. Two courses of plain tiles are bedded on brickwork to form an under clock and on this is placed a roll to cover the upturn of the pan tile. At exposed positions, the pan tiles can be made resistant to storms by fixing clips at each splayed joint so as to get additional strength. The valleys in this type of tiling work are finished with a lead gutter, the lead sheeting may be bent over the fillet.

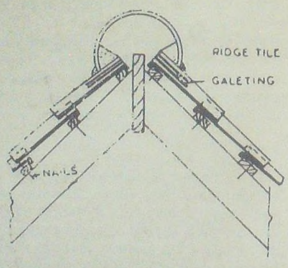


Fig. 886. Fixing of pan tiles at ridges.

Curved Tiles—Spanish Type

This tile is about the same length as the ordinary pan tile but has a lesser width. It is segmental in section which has a simple curve similar to an open channel pipe and tapers in width by about 20 mm. from bottom to top. The tiles are laid in alternate positions in a course, the first one having the round side upwards and the second with hollow side on the top. This procedure is followed all along the course, so that the curve of the first and the third and each alternate tile is downward and laps over the upstanding edges of the other tiles, thus interlocking together in a series of alternate ridges and hollows which extend in a line from eaves to ridges. The convex tiles are laid with narrow sides up at the top so that when the next course is laid, the tiles being wider at the bottom fit over the heads of the previous course with a lap of about 7.5 cm. The concave tiles are placed with the wide end at the top so that the narrow ends of the next course can lap over in a similar manner. This makes an effective roof. The same kind of tile can be used for hips and ridges, the ends lapping over each other as before. A specially wide tile is used for the valleys, the course of each side resting on the edge of the valley tile. No pointing is needed with this type of covering as joints fit in completely together. Bedding with mortar is only needed on the hips and ridges at the sides of valleys. The minimum pitch with t' 's type of roofing is about 35°.

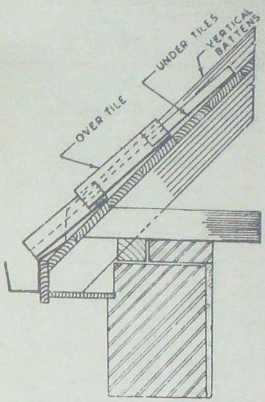
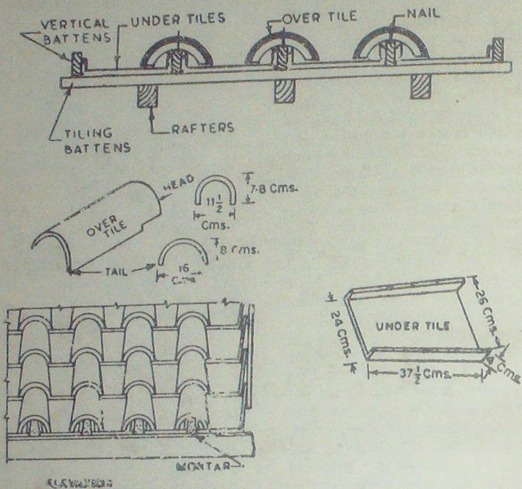


Fig. 887. Fixing of Spanish tiles at eaves.

Italian or Allahabad Tiles

These tiles with flat broad bot om have a beautiful shape. The under tile is a flat one and has a level depression with upturned flanges along the two edges. It measures about 23 cm. at the interior end and about 26 cm. at the wide end, the length being about 37 cm. The over tile is half round in section and has tapering from 12 to 16 cm. This allows the tile in the next course to fit in. Vertical battens are placed between the sides of the under tiles and to this the over tiles are secured with one nail. The horizontal battene of about $5 \times 2\frac{1}{2}$ cm. size are fixed with rafters to support the vertical battens. Alternatively boarding nailed to rafters may be used for support. Half round ridges and hips are used in these tiles. They are bedded along their sides only and may be jointed in cement mortar. The pitch of the roof is about 35°. The over tiles may have interlocking devices for added strength.

Clay tiles make a good roof for residential houses. They are non-conductors of heat and help to prevent extreme changes of temperature within the building. When they are made of good materials and are burnt well, they form quite a durable covering. These have a good appearance and suit the surrounding architecture of urban and rural houses. These days they can be got in different colours ranging from bright red to different shades of purple or even black.



Figs. 388-391. Details of Italian tiles or Allahabad tiles.

The disadvantage of a tiled roof is that the tiles are heavy and being smaller in sizes need more laps which increase the total weight of the roof covering to an appreciable extent. The weight is further increased because of the necessity of placing the rafters closer in order to reduce the span of timbers and to throw off rain water effectively. The average weight of a tile roof is about 75 kg. per square metre and thereby heavy timbers are needed to support them. Most tiles are porous and therefore absorb moisture to a great extent depending on their quality. The tiles are not so porous as to allow the water to drip freely to the other side but care should be taken while casting tiles that imperviousness is ensured as much as possible.

Wood Shingles

Shingles are not used as a roofing material abundantly these days, but are only adopted in places where timber is cheaply available. Such type of construction is possible in the hilly areas. This type of covering is very light and consists of small units which give an artistic appearance when assembled on the roof slope. They do not get affected in their strength by rough use and can be replaced easily. However, they have got great disadvantage in being liable to catch fire. They are also liable to get split under the influence of heat.

Shingles should be cut of good seasoned timber which is not liable to get warped or shrunk. Shingles are cleft out of the log or may be sawn. Sawn shingles are generally used but they are slightly inferior as the timber fibres get cut and thereby the strength of the shingle gets reduced.

Shingles vary in length from about 33 to 40 cm. and in width from about 6 cm. to as much as 25 cm. They are about 9 mm. thick at the tail and may taper at the head to lesser thickness. Shingles cut of quartered logs should be rift sawn for better work. Flat or plain sawn shingles got by cheaper methods of conversion should not be used except for cheap work.

The method of laying shingles on a roof is similar to that used for slates and tiles except that the lap is increased slightly and

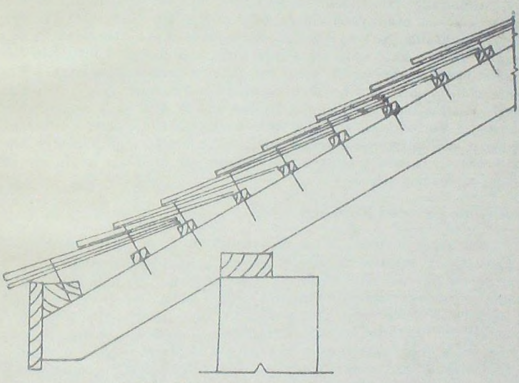


Fig. 892. Fixing of wooden shingles at eaves.

the gauge gets decreased. The gauge varies with pitch. The shingles may be laid in random widths. Those wider than 20 cm. should not be used as they get split when dried. A gap of about 3 mm. or so is generally left between the adjacent shingles to allow for any swelling which may occur. These are fixed with copper nails or alternatively with galvanised iron nails. In olden days wooden pegs were used to fix the shingles but that method is not satisfactory and is not used now. Two nails are required to fix each shingle and this must be driven carefully so as not to split the wood. Generally centre nailing of the shingle is preferred to the head nailing.

Whenever there are abrupt changes in weather, it is possible that shingles may get split near the centre and this crack in the centre will lead to a vertical joint in the course below and thereby would give a free passage for the rain water to pass. As a protection against this, it is advisable to lay the shingles with the joist across at a point about ⅓rd of the distance across the shingle in the next course.

Shingles may be fixed to battens which are supported on rafters directly. Since shingles are unable to provide a substantial protection against heat or cold, they can be fixed to wooden boards and battens or directly to the boarding. Fixing along with the boarding will provide a sort of air gap in between the shingle and the board thereby reducing the ingress of heat or cold. When felt is not used along with the wooden boarding these boards can be fixed with a small gap in between the two so as to permit free access of air to the underside of the shingles so that drying of the roofing can take place easily after it is wet with rain.

Generally two thicknesses of the shingles are used. At the eaves and at other places on account of the lap, three thicknesses occur. Suitable eave course may be provided for better work. The ridges may be fixed with the aid of wider shingles each butt jointed. A split board covered with wood roll may be used alternatively. The ends of this board may be dovetailed. Lead covered ridges are also used. At the hips, the shingles are cut mitred and lead soaker can be used. For valleys, shingles with lead soakers are used. Alternatively a lead gutter with boards provided at each side to receive the lead sheets is used. Ornamental shingles are used for roofs so as to get a pleasing effect.

Asbestos Cement Roofing

Asbestos cement is a material consisting of cement and asbestos. It is quite durable and is being adopted commonly as a roofing material. This type of roof covering is not heavy and hence a great reduction in the size of roof timbers is possible which gives a lot of economy. The roof covering is quite impervious and no moisture can pass through the sheets. Asbestos cement is perfectly fire and vermin proof. It does not rust and needs no protective coating of any other material. The cost of fixing is considerably lesser than the other types.

One of the disadvantages of this type of roof covering is that in colder climate, condensation is introduced on the underside of the roof where the buildings are occupied by human beings or by animals. Since most of the types of this covering material have got the single lap instead of having an additional lap over the unit which is one course below, there is always a possibility of some leakage to occur. But this is prevented by fitting tightly one sheet over the other. This material has also got a very low thermal conductivity and heats the room when it is used in summer or keeps the room very cool in winter. Another short-coming of this material is that, it does not give a good attractive finish to the exterior of the roof. The roof covering of this material is not considered to be of a great aesthetic value.

Asbestos cement products for covering roofs are available in the form of slates, tiles and sheets.

A. C. Tiles

The tile may be of a diamond or of a rectangular size. These tiles can be laid on boards on the roof or directly on the battens

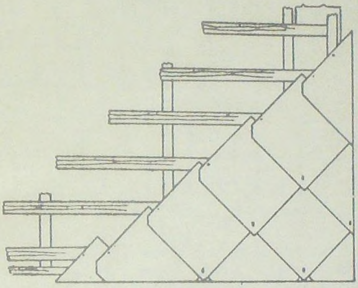


Fig. 893. Fixing details of A. C. tiles.

which are nailed to the rafters. Usually the latter method is followed. The tiles which are laid in the diamond pattern have got sizes of about 38 cm. square before the corners are cut off. They are supplied at the site with holes ready for nailing so that no cutting, etc. is to be done later on. These tiles have got a lap of 7 cm. to $8\frac{1}{2}$ cm. At the eaves similar pieces of specially cut units are used. These are nailed to the tiling battens with two nails, the bottom edge projecting about 5 cm. into the gutter or so. The larger pieces are then placed in flush at the bottom edge for the first course and nailed at each side. Two copper rivets with large flat ends are used with these tiles. The head of one rivet is slipped under the chamfered corner of the tile with the shank pointing upwards before the nails are driven. When the next tile is laid, the rivet gets gripped between the two and cannot move out. This method is followed throughout the roof until the opposite end is rigid. The subsequent courses are laid by slipping the hole in the tile over the projecting shank of the rivet and nailing the tiles at the sides as before. The ends of the rivets are then bent over to hold the tiles securely. This when completed, the whole surface of the roof is not only nailed tightly to the battens but each separate unit is also fastened to the course below so that no movement is possible. Special ridge tiles are used for finishing the ridge. These ridge tiles are lapped over the ordinary tiles which are carried to the top of the ridge line. A pitch of 30° is usually adopted for such type of roof.

A. C. Slates

An alternative to the diamond pattern is the use of slates with square corners. Each slate is centrally nailed with two nails and

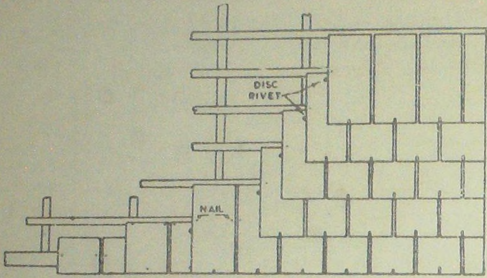
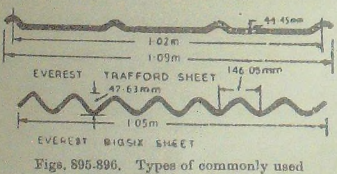


Fig. 894. Fixing of A. C. slate roof covering.

in addition to this, one rivet is placed at the centre of the tail, the head of the rivet being pushed under the edge of the slates below when the last course is fixed. These rectangular slates vary in sizes from 60 × 30 cm. to about 37 × 17 cm. They are fixed in the eave courses and other odd places.

Corrugated Sheets

Straight and corrugated sheets of various sizes are available for being fixed on industrial roofing or on large spaces. At greater intervals, the corrugation may be small with a pitch of 7 cm. and the thickness of the sheet being 3 mm. The width of such a sheet is about 0.75 m. and the length varies from 1.25 to 3 m. in increments of 15 cm. Wider corrugated sheets with deeper corrugations as a pitch of about 12.5 cm. are also used. The corrugated sheets may also have flat portions in between the corrugations (Trafford Sheets). The thickness of this type of sheet may be as much as 6 mm. These sheets have got an end lap of 15 cm. and a side lap varying from 5 cm. to about 12 cm. The purlin spacing varies from 1 m. to 1.5 m. (normally the maximum spacing is 1.25 m.).



Figs. 895-896. Types of commonly used corrugated A. C. sheets.

Table giving details of commonly available Corrugated Sheets

	Big Six Corrugated Sheets	*Trafford Sheets*
Standard lengths in metres	1.52, 1.83, 2.13 2.44, 2.74, 3.05	1.52, 1.83, 2.13, 2.44, 2.74, 3.05
Overall width in metres	1.05	1.09
Laid width in metres	1.01	1.02
Cover efficiency (allowing for side and end laps of 3.05 in sheet)	91%(approx.)	89% (approx.)
Purlin spacing in metres	1.68 (Max.)	1.68 (Max.)
Spacing of rails for Side cladding in metres	1.98 (Max.)	1.98 (Max.)
Horizontal lap in metres	0.15	0.15
Actual cover of 3·05 m. sheet as laid in Sq. m.	2.92	2.94
9.29 Sq.m. laid area requires of sheeting (allowing for loss by side and end laps with 1.83 m sheet) in Sq. m.	10·59 (approx.)	10.96 (approx.)
9.29 Sq. m. laid area requires of sheeting (allowing for loss by side and end lap with 3·05 m. sheets), in Sq. m.	10.22	10.59
Weight of 9.29 Sq,m. as laid in Kg.	161.93	150.95

These sheets are fixed with the smoother surface uppermost to steel purlins. Wooden purlins of normal sections can also be used. The sheets are always fixed from top of the corrugation through the holes (2 mm. greater in diameter than the screw) drilled to receive 7 mm. diameter screws which are about 11 cm. long. They are driven into the wooden purlins and water tightness is assured by the use of asbestos cup washer and a lead coated washer above it. The sheet is secured at six positions, two at the head, two at the bottom and two at the intermediate purlin. With steel purlins, hook bolts are used along with the washers to keep the sheets in position. At the eaves suitable eave fillers which fit in the respective corrugation of the asbestos cement sheets are used. These are used to prevent undue draft into the roof and infiltration of birds, etc. The asbestos cement ridge tile is provided for covering the joint at the apex of the roof. These ridge pieces are made of two parts each overlapping the other.

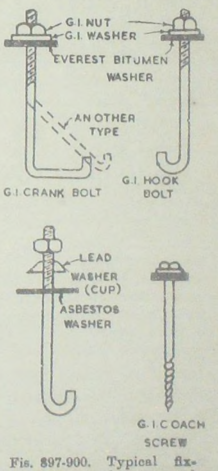


Fig. 897-900. Typical fixing of bolts and screws used with corrugated A.C. sheet.

While fixing the sheets, the purlin spacing and the length of the sheets are first checked to see that the arrangement will provide the specified overhang at the eaves and proper laps are obtained. An eaves course is laid first and the work started at the left hand end of the building so that the side laps have a better protection from the rain driven by wind. The first sheet is laid uncut but the remaining sheets in the bottom row should have the top left hand corners cut or 'mitred'. The sheets in the second or other intermediate rows should have both the left hand corner and the bottom right hand corner cut, with the exception of the first sheet in each row which should only have the left hand corner cut. The last or top row should have the bottom right hand corner cut, with the exception of last sheet which is laid uncut. Whenever sheets are laid from right to left, the whole process of cutting described above is reversed. 15 cm. end laps are suitable for roof slopes greater than 21½ degrees. For lesser slopes the laps should be

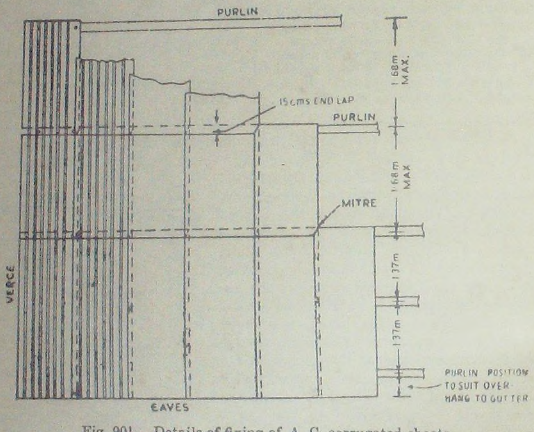


Fig. 901. Details of fixing of A. C. corrugated sheets.

increased accordingly. Sheeting should be laid at the end opposite to the direction of prevailing wind and rain. The overhang at the eaves must not be greater than 37 cm. Mitring of sheets is essential to get a proper fit wherever four corners meet. The top edges to eaves must extend 7·5 cm. beyond the centre line of timber purlins or 4 cm. beyond the back of steel purlin.

Galvanized Corrugated Iron Roofing

Corrugated iron roofing is widely used, although it does not have a very good appearance. The main reason for its use is that it is very durable, light and fire proof. It is also easy to alter such a type of roof covering. Galvanised iron is usually manufactured in sheets which are corrugated or bent in a series of parallel depressions from end to end. The purpose of corrugation is mainly to give to thin iron sheets additional strength as they are only supported on purlins at fixed intervals. Moreover this corrugation helps in proper discharging of water away from the sheet. The idea of galvanising the iron sheet with zinc is to protect it from rusting in wet weather. This coating of zinc may get damaged only in atmospheres which are contaminated with fumes of factories containing acidic materials. One of the difficulties with this type of material is that it transmits heat and cold easily. It is liable to create condensation problems on the inner side in colder climates.

The laying of corrugated iron sheets is very simple. The sheets are fixed to purlins which are supported on 2 to $2\frac{1}{2}$ m centres. The sheets are nailed to these timbers with galvanised nails or screws. The washers have to be used to prevent water from passing through this hole. Each sheet is fixed with one screw in the central corrugation and one at each end. The screws are always placed on the top of the ridge to prevent infiltration of water. These screws are not driven until the adjacent sheet has been lapped over the first. About 7·5 to 15 cm. lap should be allowed at the ends of the sheet. This would give a sort of air gap between the sheet and the plank and prevent condensation.

For preventing lot of heat getting transmitted from the galvanised iron sheet, tiles can be laid over this type of covering. Battens of 4×4 cm. size are laid over the ridges of the corrugations at about 45 to 50 cm. centres and are securely screwed from the sheets into the purlins below. Between these battens, the corrugated sheet is also fastened to the purlins by 7·5 cm. long screws. The horizontal battens of about $5 \times 1{\cdot}5$ cm. size are fixed to the sloping battens to which tiles are laid in the usual manner. The ridge and hips are finished in a similar manner to that of the tiles.

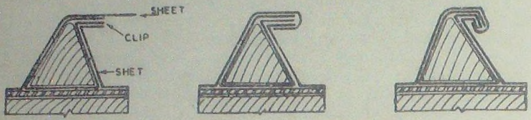
Sheet Metal Roof Coverings

Copper Roofing :

Copper sheet is used for roofing purposes and forms a durable covering. When exposed to atmospheric action a protective coating is formed which develops in course of time to give a greenish colour. This coating when subjected to further atmospheric action permanently protects the copper sheet. It is resistant to corrosive action of gases, etc., which are usually present in areas where factories are prevalent. Copper is a ductile and elastic material. These properties enable the metal to withstand considerable physical damage and its elasticity enables it to be bent to suitable shapes.

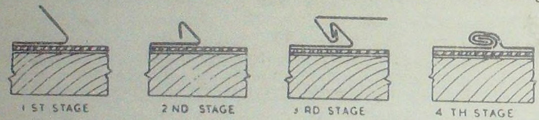
The copper roofing is light in weight which permits the reduction in roof sizes. The copper roof covering consists of a number of sheets jointed along the edges and is held down to the roof by means of clips inserted in the fillets. For protection, the joints are raised and across the fall they are bent to allow water to flow free over the sheets. The width of the sheet selected is governed by the mechanical and physical property of copper and the durability required for the roof. The rigidity of the sheet varies with the thickness. Copper sheeting of 26 gauge usually in width not greater than 5 cm. and that of 21 gauge of a width not greater than 6·5 cm. are used. Generally sheets of 22 to 24 gauges are used. Similarly the length of the sheet varies from 3·5 m. for a 22 gauge sheet to 3·0 m. for a 24 gauge sheet. As the sheets are finished by welting at the edges, the distance between the finished seams will be less than the width of the sheets.

The joints for the protection along the slope are made by turning up the edges of the sheet and are formed by bending over



Figs. 902-904.

the wooden rolls or by welting into the standing seam. The wooden roll is used where the traffic is expected on a roof and the standing



Figs. 905-908.

seam is adopted where it is not liable to get damaged. The joints across the fall are made by welted seams. Where the pitch is greater than 60 degrees a single welted seam is used and whenever the pitch is less than 60 degrees a double welted seam is essential. For slopes between 60 degrees and 10 degrees, no drips are essential. Where the slope of the copper covering is less than 10 degrees, drip should be used to accelerate the flow of water.

In any case the slope of the copper sheet when laid should not be less than 5 cm. in a length of 3 metres. The copper covering surface should be laid to even slope and provided with the smooth finish. Care should be taken to prevent the copper sheet from getting into direct contact with concrete by interposing a felt layer. Dovetailed wooden battens of $5 \times 2\frac{1}{2}$ cm. size are set flush with the surface and run across for standing seam joints. Whenever wood rolls are adopted the spacing can be increased. Underlayers of felt should be provided to concrete roofs to reduce condensation and on timber roofs to reduce noise. This felt is laid with butt joints. This felt may be fixed by copper nailing or other means to guard against wind, etc., during work. Concrete roofs should be coated with two layers of bitumen before the felt is laid. The heads of the nails securing the boarding should be flushed below the surface and boarding plained to a smooth finish. Copper nails are used for fixing as iron nails would result in the decomposing of sheets due to electrolytic action.

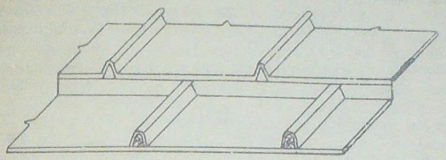


Fig. 909. Copper roofing plan using staggered rolls.

Although the expansion and contraction of copper due to changes in temperature are small, yet provision is to be made of

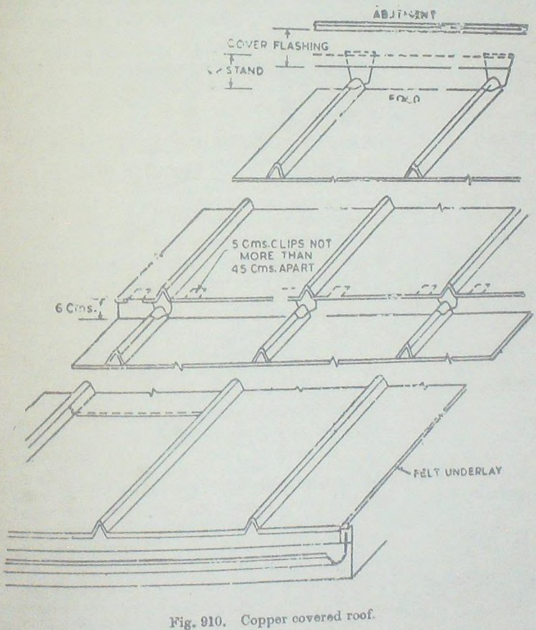
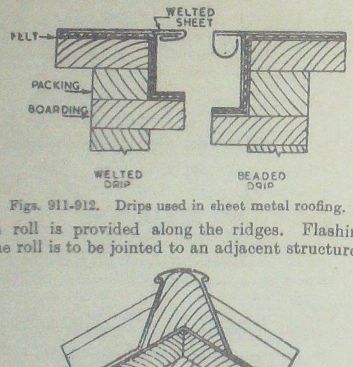


Fig. 910. Copper covered roof.

these movements. Joints should be formed as stated earlier with the aid of the wooden rolls of standing seams. Wood rolls may consist of rectangular or square wooden sections. Copper clips of about 5 cm. width are placed under the rolls at about 90 cm. centres. The rolls are secured by copper or brass screws and are spaced at a distance equal to about 7½ cm. less than the width of copper sheet. The development of the roll is to be done carefully and different methods are adopted, some of which are shown in Figs. 902-904. Welted standing seams are used whenever the roofs are not subjected to traffic. The sheets are first welted end to end and then the stirrups are placed on the roof and the standing seams formed by means of pliers. The height of the finished joint is about 20 mm. Welts are used for end to end joints. In the first stage the edges are turned up by about 25 mm. and are turned down subsequently. The edge of the adjacent sheet is turned in a similar manner and engaged in the bend of the other sheet so as to form a welt after being turned over. Single lock turns are sometimes used for sheets fixed on steep slopes. Where the copper sheet passes over the apex or ridges, a ridge roll 4 cm. higher than



Figs. 911-912. Drips used in sheet metal roofing.

the wooden roll is provided along the ridges. Flashings are used whenever the roll is to be jointed to an adjacent structure.

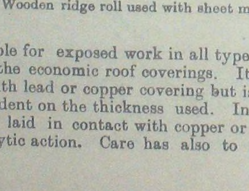


Fig. 913. Wooden ridge roll used with sheet metal roofing.

Zinc Roofing

Zinc is suitable for exposed work in all type of buildings and provides one of the economic roof coverings. It does not last long as is the case with lead or copper covering but is cheaper. Its life is primarily dependent on the thickness used. In industrial places it should not be laid in contact with copper or iron on account of the risk of electrolytic action. Care has also to be exercised that water does not discharge from iron or copper rain water pipe on to a zinc roof.

The standard sizes of the roof sheets are about 90 cm. in width and are about 2·4 metres in length. The thickness of the sheets varies from 14 to 16 gauge. The minimum fall for zinc roofs is about 4 cm. in a length of 2·4 m. The boarding on which the zinc roof is laid should not be less than 20 mm. in thickness and laid diagonally in the direction of fall. Boarding may be tongued and grooved. Building paper felt is used to cover the boarding. Wood rolls are used for jointing and the detail is shown in Fig. 914. Drips may be used for transverse joints and the distance is 15 cm. less than the length of the sheet metal. Either welted or headed drips may be used. Drips are not used when the pitch of the roof exceeds 1 in 8. The transverse joints are then made in the form of single lock welt as in the case of copper.

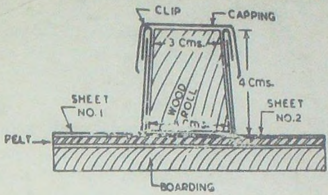


Fig. 914. Wood roll details.

Bituminous Felts

Tar and bituminous felts are used as covering materials. Bituminous felts are more durable and are free from salts and also do not melt or soften unduly under heat. These felts are non-porous and impervious to moisture penetration. They are flexible and can be adapted to any type of substructure which may be curved or have a dome shape, etc. They can be laid quickly and they are light in weight. They are also not liable to crack owing to the settlement of the building or otherwise. Heat or cold does not disintegrate them. The felts cannot, however, withstand wear and tear of the traffic. Its appearance is unattractive and it does not provide a self-supporting structure with the result that it needs a substructure which should be very durable.

The surface to which the roof is to be laid should be arranged to ensure a rapid flow of storm water in the required direction. For flat roofs, the finished surfaces should have a fall of not less than 1 in 60 and the gutters should have considerable slope and provision for that should be met while designing the substructure. The substructure may consist of wooden boardings which are duly supported on joists. The concrete substructure should be treated and prepared so as to avoid loss of adhesion and cracking. A primer coat may be given to reduce porosity and to ensure proper adhesion.

On timber substructure, the first layer of the felt should be secured by nails spaced at about 5 cm. centres along laps and about 20 mm. from the exposed edges. Whenever additional security is needed, extra nails are added midway between the laps. The subsequent layers of felts are bonded as described below.

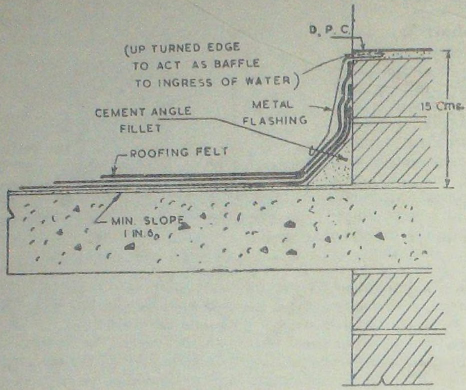


Fig. 915. A typical detail of bitumen roofing felt covering.

All concrete or similar substructure should get a bituminous coat primer after the surfaces have been brushed thoroughly and dried up. The first layer of roofing felt is bonded hot and each substructure layer is bonded similarly. The bonding compound is heated to a temperature not in excess of that required to ensure an effective bond. The first length of the first layer of the felt is laid in position and firmly rolled back half way. The bonding compound is spread on to the roof as the felt is rolled out, pressure being applied to the felt so as to engage the compound while it is still hot. Any surplus compound is squeezed out and the edge of the felt is smoothened as work proceeds. The other half of the length is then rolled up and the process repeated. Subsequent lengths are laid in a similar manner and the same method is employed for the subsequent layers. The bonding compound may be spread in the form of roll or applied by means of brushes.

Layers should be made to follow each other in such a way that minimum of incomplete work is exposed to weather. Whenever a finish of cement concrete or tiles, etc., is applied to the surface, the top layer should be given a dressing of hot compound applied with the aid of brush.

The felts are laid with lap joints at least 5 cm. wide at the sides and 7·5 cm. at the ends. When a single layer of bituminous felt is laid on the sloping timber substructure the joints should be raked with bituminous lap cement (a bitumen cut back applied cold) ide applied along the joints to cover the exposed nails. At junction with walls of parapets, the felt should be taken up the angle fillet upto a height of at least 15 cm. above the finished surface of the roof.

Asphalt Mastics

Two kinds of asphalt are used in building operations, *i.e.*, the natural and the artificial. The artificial product consists of bituminous material which is mixed with a filling of sand, chalk and other ingredients. It is not a true asphalt mastic which is made by the process of nature.

Asphalt mastics are quite impervious. They can be easily repaired and are not highly inflammable. They can withstand stress that arises from unequal settlement or other defects. Since this material when laid in a heated state is very plastic, it can be laid over an irregular shaped surface.

As a general rule, mastic asphalt is primarily used on flat roofs but can also be employed on sloping or vertical surfaces if desired. The materials that have to be reduced to plastic state by the application of heat are liable to soften or sag when they are subjected to the hot rays of the sun.

Before the asphalt mastic is laid, all dust and rubbish must be carefully removed from the surface of the roof so as to increase the adhesion. Asphalt is generally laid on concrete but this material can be applied to a boarded covering if necessary. The boards must be fixed close together so that no open joint is left through which the asphalt can sink. The roof may be covered with sheets of felt to minimize the danger of the asphalt falling through the joints into the space below.

It is perferable to finish the whole surface in one operation but whenever it is not possible, the joint must be finished well. Asphalt mastic is heated in large drums or boilers and made into a plastic molten state. It should be stirred at regular intervals with iron rods so that the whole mass is heated uniformly and no portion gets over-heated. After converting it into a plastic state, it is carried in buckets to the site. It is spread over the surface by the workmen with the aid of wooden float carefully and worked into corners and angles. It is pressed slightly so as to make it as dense as possible and also to get as level surfaces as possible. Dry sand is spread over the surface before finishing it with a float so as to prevent the asphalt from sticking the latter. Special care must be taken to finish the joints between the two adjacent layers. A skirting may be run alongthe side walls and parapets to get a good joint and also to prevent thewall from getting wet with splashes of rain. While laying on sloping surfaces, special precautions must be taken to prevent the dragging of the mastic coverings.

Glass Covering

Glass, as a roof covering material is used primarily on roofs of industrial buildings, factories, etc., so that light can be admitted through the roof to the working surface. Prismatic glass is also used in some cases for roofing purposes to increase the volume of natural illumination that is admitted into a room. This type of covering is very expensive. Further if it gets broken, the people working below suffer from the risk of injuries. It is difficult to keep this type of roof water-tight. The roof gets dirty in course of time and it is essential to wash it at regular intervals.

Roofing glass is cast in plates from 5 mm. to about 25 mm. in thickness. It generally has got ribs which serve the purpose of providing better illumination than plain glass. The fixing of glass was previously done by the aid of the plastic putty and wooden or other types of heads. This arrangement is not satisfactory. Putty gets disturbed after sometime and results in a leaky roof. Moreover, use of putty needs constant maintenance. Various type of fixtures with glass plates have been devised. One of them using glazing bars is shown in Fig. 916. In this type, glass sheets are bedded on soft asbestos cords throughout the length of the bar and held in position by extruded lead capping which is secured to the stem with small brass bolts. A special stop at the foot of the bar is used to prevent the glass from slipping down the roof. Each pattern has a condensation channel underneath so that the moisture on account of the condensation on the inside of the glass can run off to the bar and escape by the channel to the gutter. A part of the bar projects above the surface of the roof thereby permitting planks to be laid across the sheet when maintenance is needed.

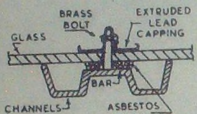


Fig. 916. A typical glazing bar of improved type used for glass roofs.

Selection of a suitable roof covering

The various factors which have to be kept in view while selecting a particular type of roof covering for a given building are briefly described below :—

1. *Initial Cost*

The initial cost of roofing material varies from time to time and also with a given place. Slate roofing is cheaper in hilly areas and similar is the case with wood shingles. Clay tiles are cheaper and can be manufactured only at places where the bricks are made. While considering the initial cost of a covering material, the additional cost on account of the weight of the supporting members must be considered. Materials which are heavier need stronger superstructure which adds to the cost.

2. *Maintenance*

The cost of maintenance forms one of the main items while deciding the type of particular roofing material. Wood shingles and tiles need less frequent repairs than that of thatch roofing. Asbestos roofing sheets, slates, etc need occasional repairs and very little maintenance, while still lesser care is needed for built-up copper or zinc sheet metal roofing.

3. *Slope of the Roof*

Thatch, slates and tiles need steeper slopes to prevent water penetration, whereas corrugated sheet and sheet metal roofing need small slopes.

4. *Durability*

The life of the roofing material is important to determine its economical value. It depends on many factors and varies from place to place, but under normal conditions clay tiles, slate, copper, zinc, etc. have got a longer life. Asbestos cement roofs and wood shingles are classified as having medium life whereas thatch has got the least life.

5. *Resistance to Fire*

Fire resistance is equally important in any type of structure. Thatch roof covering has got the least resistance and clay tile, slate or sheet metal roof offers greater resistance to fire.

6. *Weight of the Roof Covering*

The heavier the weight of a particular roof covering the stronger supporting structure is needed which adds to the cost. Clay tiles and slates are the heavier types of the roof coverings. Asbestos cement roof covering and wood shingles have got a lighter weight whereas sheet metal coverings are much less in weight.

7. *Type of Construction*

Special type of construction is needed for certain types of roof coverings, *e.g.*, for sheet metal roofing extra care has to be taken at joints, etc. Clay tiles do not need much attention.

8. *Appearance*

Appearance is the important factor from the architectural point of view. Clay tiles or shingles give a good appearance in certain cases. Cement tiles are satisfactory for industrial buildings. Asbestos cement coverings are not so attractive unless specially treated.

9. *Heat Insulation*

In tropical countries insulation of heat is very important, as transmission of heat through the roof makes the rooms very hot and undesirable for living.

Asbestos cement sheets, unless used in double layers, have got a very low resistance to the transmission of heat and similar is the case with corrugated metal roofing. Clay tile or thatch gives adequate protection against thermal effects.

QUESTIONS

1. Describe in detail the various points to be considered in the selection of a suitable type of roof covering.

2. What are the essential qualities of a good slate to be used as roof covering ? Give the sizes of slates used. Describe the various methods employed for the fixing of slates.

3. What are the various types of tiles which can be used for roof covering ? Discuss the merits and demerits of each one of them.

4. What is asbestos cement ? What are the disadvantages of asbestos cement covering ? Write short notes on :

(*i*) A. C. Tiles.

(*ii*) A. C. Slates.

5. Write short notes on

(*i*) Thatched roof.

(*ii*) Corrugated sheets.

(*iii*) Sheet metal roof coverings.

(*iv*) Bituminous felts.

(*v*) Asphalt mastic.

(*vi*) Glass covering.

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3. **Blauie, E. G.** : *Roof Coverings.*
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6. **British Standards Institution** : *Asbestos Cement Sheet Roof Covering.*
7. **Mackey W. B.** : *Building Construction.*
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15

STEEL WORK

Steel is used to a large extent in modern multi-storeyed buildings. Construction in steel work is more economical for buildings which are more than ten storeys in height. Generally a framework of heavy steel sections is erected to take all loads and partitions or walls are built of other constructional materials. Structural steel and concrete combination may be used in building work. A typical example would be to have columns of structural steel and flooring systems of reinforced concrete. Due to ease in erection and heavy loads which structural steel work can take, it is commonly adopted for factory buildings.

Various types of sections and shapes are used for building work. Most of them are made by rolling. The white hot ingot of steel is reduced under the action of a steam hammer or in a cogging mill from where these are taken to the finishing rolls. Plate sections are formed by passing and repassing the metal through the rolls till the desired thickness is obtained. Other sections are made with the aid of cylindrical rolls having circumferential grooves which give the required shape to the metal.

The common types of sections used in structural steel work are shown in Figs. 917-938 and are described below.

Plates : Plates may be of any size or thickness but generally they are not rolled to thicknesses less than 5 mm. and greater than 28 mm. The maximum area of a rolled plate is limited to 30 sq. m. Larger plates have a tendency to be thicker at the centre than around the edges. Plates lesser than 4 mm. in thickness are denoted as sheets. Sometimes plates are marked with different patterns which may be pressed into them, *e.g.*, checkered plates. Common uses of plates in building construction are as webs and flanges of deep beams, column flanges, column bases, etc.

Flats : These are rolled as in the case of plate but are much longer in lengths and have shorter widths. The widths vary from

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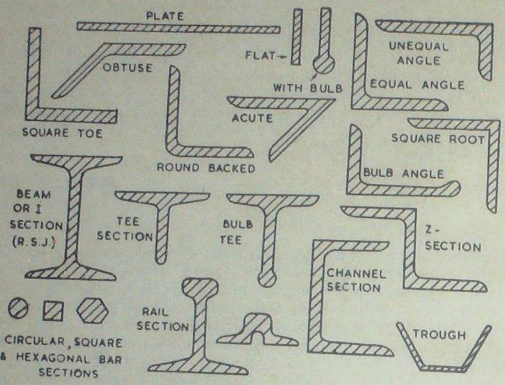
Flats : These are rolled as in the case of plate but are much longer in lengths and have shorter widths. The widths vary from

18 mm. to 50 cm. the minimum and maximum thicknesses vary from 3mm. to 8 cm. Flats are costlier than plates but are put to a



Figs. 917-938. Sections in Steel work.

considerable use in building construction. Flat section may have one rounded side with greater thickness than the remaining section and this is called bulb ball. These are used only in specific instances.

Angles : Angle section are the most commonly used in different components of a steel framed building. Indian Standard Specifications lay down the sizes of angle sections. Most common types are angles with equal legs and with unequal legs. The equal angles vary from 2 cms. $\times$ 2 cms. to 20 cms. $\times$ 20 cms. in size and 3 mm. to 5 mm. in thickness. The term 2 $\times$ 2 cms. denotes that the widths of legs are 20 mm. overall. Unequal angles vary in size from 2 $\times$ 3 cms. to 22 $\times$ 10 cms. and thickness from 4 mm. to 20 mm. Special angles with a square toe, round backed, acute, square root and bulb types are also available. These are used to a limited extent in special constructional features.

T-Sections : These are used for roof trusses and for certain built up columns. They are designated by the width of the stem, width of the table and by the thickness. The standard sizes vary from 4 cms. $\times$ 4 cms. to 15 cms. $\times$ 15 cms. with thicknesses from 6 mm. to 8 mm. Special T-Sections with bulbs etc. are also used to some extent.

Channels : Channels are used for beams, columns and other small jobs. They are designated by the depth flange width and weight per unit length. The size varies from 5 $\times$ $7\frac{1}{2}$ cms. $\times$ 3 kg. to 42 $\times$ 10 cms. $\times$ 30 kg. Whenever stronger channels of lesser depth are required, these are specially cast with greater thicknesses than given by the Standards.

Joists : Rolled Steel Joists or I-Sections are most commonly used for beams and columns. They are denoted by the flange width, overall depth and weight per metre run. The British Standard Joists Section vary in size from 7×4 cms. to 60×17 cms. In U.S.A. I-Sections having very wide flanges are used.

Miscellaneous Sections : Z-Sections, rail-sections, troughs, bars etc. are used to a limited extent in steel work for a building.

The British Standard Specification No. 15 lays down the basic properties of structural steel. Two qualities of steel are specified.

No. 1 quality : Steel made by the Open-Hearth Process or Acid-Bessemer process. Sulphur and Phosphorus—contents not exceeding 0.06 per cent.

No. 2 quality : This is similar to No. 1 with the addition of copper from 0·2 to 0·5 per cent.

The tolerances in the dimension are as under :

Lengths : (*a*) When cut lengths are specified : ±25 mm.

(*b*) When minimum lengths are specified +5 cms. −0.

(*c*) When exact lengths are specified : ±3 mm.

Rolling margins, over and under the specified weight of 2½ to 5 per cent are permissible.

Specifications for high tensile steel having a tensile-strength of 5000 kg./cm.² are also given.

Connections

Steel members are fastened together by means of rivets, bolts or by welding. Modern tendency is to go in for welding. Rivets are fitted at site or in the fabrication shop, the latter being called as shop rivets and the former as field rivets.

Rivetting : Common practice is to connect the members by rivets which are permanent fastenings and cannot be removed unless the rivet is destroyed. Rivets used in building construction are made of soft steel with a tensile strength (breaking) of 3500 to 4000 kg./cm.² with an elongation of not less than 26 per cent on a gauge of 8 diameters. Wrought iron rivets are sometimes favoured for site work as wrought iron has the property of retaining malleability even longer than that of steel, after being forged. Rivets generally have a hemispherical button-shaped head and a cylindrical shank. In driving a rivet, it is heated red hot and placed in a hole through the members which have to assist it in connecting. The projecting end is then upset to form a head with the aid of a pneumatic or hydraulic riveter. A corresponding projection left in the riveter gives the desired shape to the rivet head. While driving, the other side of the rivet is held in place by a dolly. As the rivet cools, it contracts thereby tightening the grip. Hand rivetting is used only in small structural jobs or in the field when only a few rivets are to be driven. Red-hot rivets are hammered down to the final shape.

Holes for rivetting may be punched, drilled or bored. For small works, rivet holes are generally punched. Drilled holes are always preferred as the holes are truly circular and cause less damage to the surrounding metal. The diameter of the hole is kept $1\frac{1}{2}$ mm. larger than the rivet shank so that it could be inserted easily.

Rivet heads of various shapes, semi-circular button heads are commonly used. Whenever more clearances are desired, a flattened head is made. Counter-sunk heads are used when least projections are desired. They may have a flush face which is got by chipping. The conventional method of denoting various types of field and shop rivets is shown in Figure 939.

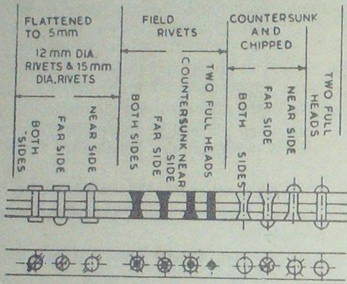


Fig. 939. Types of rivets.

Cutting of rivets may become necessary at times. This is accomplished by chipping off the head with a pneumatic chipper and then the rivet is driven out with a pin-maul. Sometimes the heads are burnt with an acetylene torch but care is to be taken to prevent damage to the surrounding metal.

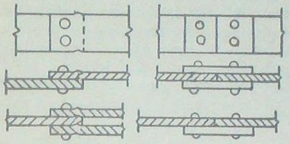
The centre to centre distance between the adjacent rivets on the same rivet line is called pitch. Generally minimum pitch in structural steel work is specified to be three times the diameter of the finished rivet. However, the absolute minimum pitch is twice the diameter of the rivet plus one cm. Specifications lay down the minimum pitch as under.

1 cm.	dia	rivets—	4 cm.	pitch.
1.25	,, ,,	,,	— 5 ,,	,,
1.75	,, ,,	,,	— 6 ,,	,,
2.00	,, ,,	,,	— 7 ,,	,,
2.50	,, ,,	,,	— 8 ,,	,,
2.75	,, ,,	,,	— 9.5 ,,	,,
3.00	,, ,,	,,	— 11.0 ,,	,,

The maximum pitch should not be greater than 16 times the thickness of the thinnest plate with a maximum of 30 cm. Special rules for maximum pitch are also given for angle connections, tension members etc.

A suitable edge distance, *i.e.*, the margin between the edge of the hole and the edge of the plate has to be provided for the prevention of failures. A minimum edge distance of $1\frac{1}{2}$ times the diameter of a rivet hole is specified. However where the edge has been formed by shearing instead of rolling, this distance is increased to $1\frac{3}{4}$ times the diameter of a rivet hole.

Two most commonly employed joint connections are (1) Lap joint in which the connected plates are lapped one over the other and rivetted and (2) Butt joint in which the plates are connected with the aid of additional plates. Rivets in one or more rows may be used to connect the members.



LAP JOINTS BUTTJOINTS

Figs. 940-945. Joint connections.

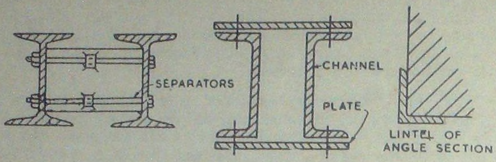
Welded Connections : This is the most common method of connecting structural members. Two methods of welding used are electrical welding and gas welding. The electrical welding is further divided into resistance arc, shielded arc and atomic hydrogen welding. Gas welding is commonly called as oxy-acetylene welding. In both the methods, the pieces to be welded are placed in contact and edges are melted so that the metal flows from both the pieces together and when cooled, they get jointed by the aid of a weld. For satisfactory jointing, additional metal is supplied with the aid of a metallic rod which can be used as an electrode.

Bolt connections : For temporary connections, bolt joints are used. The diameter of the holes is kept 1 mm. larger than the external diameter of the bolt threads. Bolt connections are also used wherever rivetting is difficult, may be due to lesser number of rivets needed or difficulty in connecting.

Structural Members

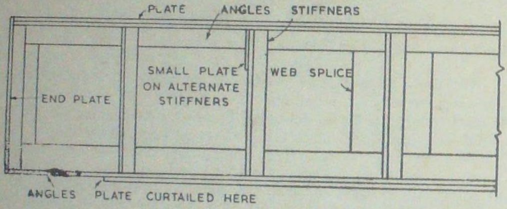
Steel Beams : Beams include girders, lintels, etc. A simplest beam would consist of a single rolled steel joist section or an angle section for carrying little loads. Whenever a beam has to take greater loads, compound sections are used. Compound beams consist of two or more single steel joists connected together through bolts and separators which hold them in position. Separators are placed at $1\frac{1}{2}$ to 2 m. apart.

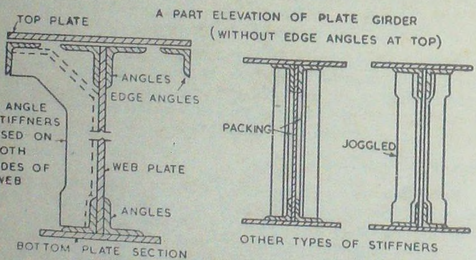
For still heavier beams or girders, two channels may be used back to back or spaced apart and their flange area increased by the addition of one or more plates at top and bottom, Plate girders are used when very large loads have to be carried. A plate girder is a built up beam consisting of top and bottom



Figs. 946-948. Steel Beams.

flanges made up of angles and plates. The web consists of one or more steel plates. All the individual pieces are rivetted or welded together. Since plate girders are deep beams, it is necessary to stiffen them laterally to prevent buckling under high compressive forces in the top flange. Angles or T-sections are used as stiffners. They are rivetted to the plate girder at suitable intervals and may be bent so as to form joggle type or packings may be used to keep them straight.





Figs. 949-952. Plate girder and its details.

Open Web Beams : Beams carrying light loads and where the shearing forces are not excessive, open web beams are used. These consist of small T-sections acting as flanges connected together by a bent iron bar to keep them at the desired distance apart.

The following points should be noted about steel beams :

(*i*) It is always economical to use as deep beams as possible since they can take higher loads.

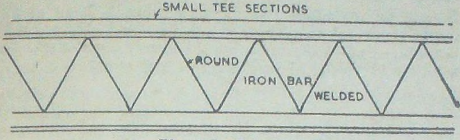


Fig. 953. Open Web Beam.

(*ii*) The cost of the beam may increase while economising in weight, *e.g.*, if lattice girder is used for a solid section plate girder, the cost of fabrication, etc., may be more in the case of the lattice type.

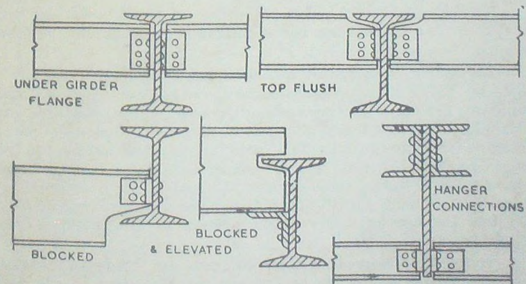
(*iii*) The deflection of steel beams under the usual loads should not exceed $\frac{1}{480}$th of the span or in exceptional cases $\frac{1}{360}$th of the span.

(*iv*) Stiffness of the web is essential wherever excessive forces on account of compression in flanges are created due to the lesser widths of the flanges.

(*v*) To distribute the concentrated loads of the beams on the bearing walls, suitable bed plates of stones or concrete should be used.

Beam to Beam Connection : It is necessary to transfer the loads from one beam to the other in a framed building or from beams to girders in the usual cases. The various types of connections, generally adopted, are :

Undergirder flange : In this case the beam is accommodated below the top flange of the girder. Small iron angle cleats are rivetted to the beams as well as to the girder so as to form a strong connection.



Figs. 954-958. Beam to Beam Connections.

Top-flush : In this type of connection, the top flange of the beam and a portion of the web is cut off so as to accommodate the top flange of the girder. Angle cleats are rivetted to the beam and girder for making the joint.

Blocked connections : This is used when a beam at a lower level is to be connected to a girder at a higher level. The lower flange of the beam is cut off to accommodate the lower flange of the girder, the webs of the two being connected with angle cleats.

Blocked and elevated : This type of connection is suitable for beams meeting at higher levels with the girders. A suitable recess to fit in the top flange of the girder is cut from the beam and the beam is rested on an angle cleat which in turn is bolted to the girder.

Hanger connections : These are used to connect beams and girders at different levels. The connection is made with the aid of a plate and angle cleats or bolts and rods may be used.

Columns : Individual small columns may consist of rolled steel joist or a rolled steel joist with two flange plates. Bigger columns can be made by rivetting together two or three rolled steel joists so as to form a compound column. Other forms of compound columns commonly used are a combination of rolled steel joists and channels, two angles, channels with flange plates or lattice bracing, four angles and a web plate and four angles joined together with lattice braces. Whenever angles or channels or joists more than one in number are used without flange plates, it is necessary to inter-connect them with the help of lacings and batten plates which make the column to act as a combined unit.

The types of lacings used are :

(*a*) *Single Lacing* : These consist of small flat iron rivetted to the column components in a zigzag manner.

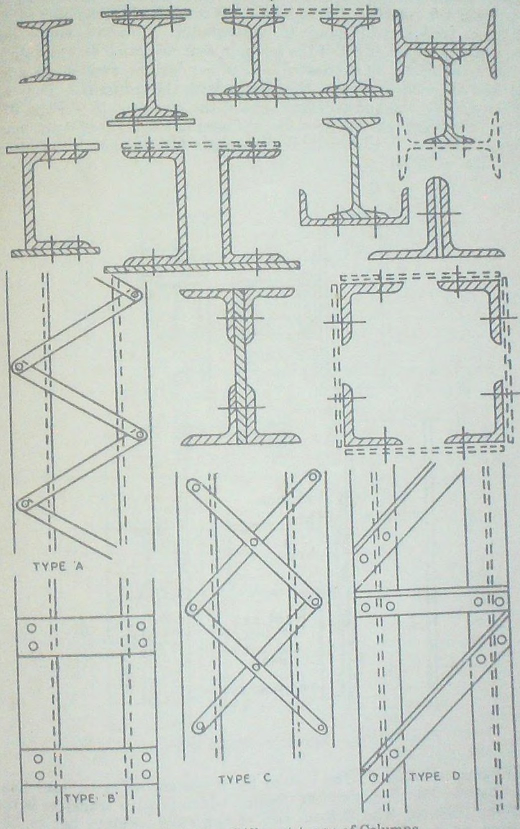
(*b*) *Batten Plates* : These are thin plates or flat sections rivetted at suitable intervals at right angles to the axis of the columns.

(*c*) *Double Lacing* : This consists of small flat irons rivetted to the column components in a cross manner.

(*d*) *Z-Type Lacing* : This comprises of small angle sections rivetted to the column, one in the horizontal position and the other inclined.

The choice of the type of column depends upon the load to be taken by the column, dimensions of the neighbouring parts, fixing conditions, fire proof treatment essential, architectural features etc. It should be ensured that all connections are of simple type and it is easy to fabricate the individual part. Columns can fail by bending along the axis having least moment of inertia. Hence it is desirable to have columns having same moment of inertia along both the axes. Generally for light loads, four small angles with proper lacings are used, but for heavier loads single I-Beam or compound I-Beam sections are used.

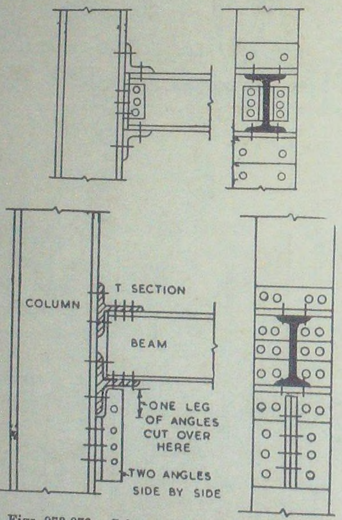
Splicing of Columns : Steel columns are made of constant sections for every two storey heights of a tall building. It is possible to change the sections of the column for different storeys on account of the reduced load which a column has to take in the upper portions of a building. This means that columns of two sections have to be joined together. Columns of different sections are connected with the aid of spliced plates and additional plates are used for proper connections. Sometimes bearing plates of steel are interposed to ensure a proper bedding for the upper column. These



Figs. 959-972. Different types of Columns.

splices are commonly made about 0·75 m. above the floor level so that they do not interfere with the beam and other connections at the floor levels.

Column and Beam Connections : Generally two types of connections are used, the framed connection type and the seated type. In the framed connection type, two angles are rivetted to the beam and the column. These angles are connected to the web of the girder or beam and the flange of the column. A small angle may be added at the bottom of the beam to seat the same on the column while erecting it. In the seated type of connection, two more angle sections are used to connect the beams with the columns. They are rivetted to the top and bottom flange of the girders. (*See* Figs. 973-974). For bigger column sections, stiffners in the form of two small angles rivetted to the column flange are fitted beneath the beams (*See* Figs. 975-976).



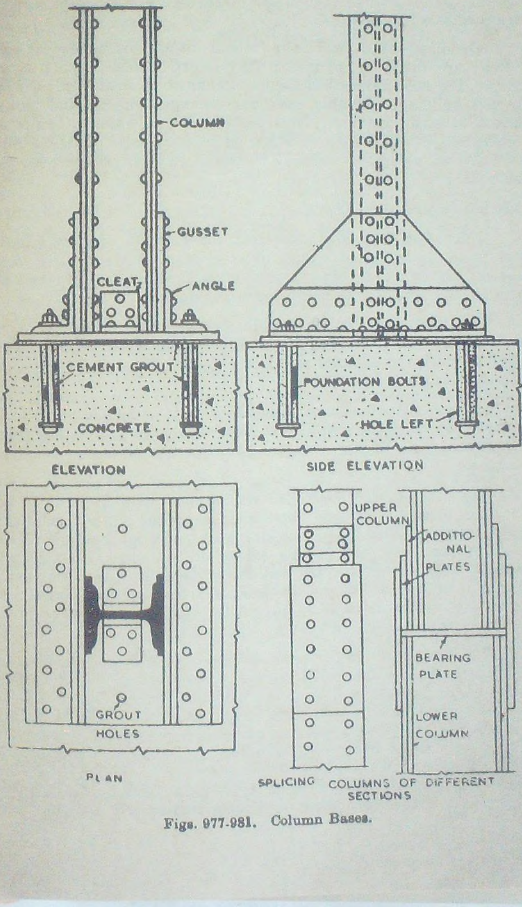
Figs. 973-976. Column and Beam Connections.

Column Bases : The load at the lower end of a column has to be transferred to a concrete footing which in turn transfers it to the ground below. The bottom end of the steel column has to be supported on a special base to distribute the load from the column to the concrete footing which otherwise would get crushed. Column bases are of the following types.

(1) *Built up bases :* Made from structural steel sections.

(2) *Cast Iron or Cast Steel bases :* These are specially cast for different types of columns.

(3) *Steel grillage :* This consists of rolled steel joists connected together and laid in tiers.



Figs. 977-981. Column Bases.

Built up column bases are mostly used and are suitable for light and moderate loads. The base is made up of steel plates which are connected to the column with the aid of angle cleats through gusset plates. A thin cement grout is spread between the top of the concrete surface and the bottom of the steel base plate. The angles and the base plate are fixed to the concrete base with the aid of foundation bolts which are placed in suitable holes left for them.

Framed Steel Buildings

Buildings which are of industrial nature or consist of many storeys are made up of a steel frame-work which support all the loads. The steel framed building is similar to a reinforced concrete framed building. In this case the columns, beams and girders consist of steel sections. The partitions and exterior walls are constructed of other light and fire proof materials. Tall buildings have to be adequately braced to resist the forces of wind and earthquakes.

Fabrication of Steel Work

This means preparing steel work for erection and includes all work necessary to layout, cut, drill, rivet or weld the steel sections. Most of the work is carried out in the fabrication shop and the work at field is to be reduced as much as possible.

The first stage is to prepare the template according to the shape of the final job. Templates may be made of wooden strips showing location of all holes and cuts. For gusset plates, card board templates may be used.

As steel is procured from the mill, it is stored in a stock-yard. All materials should be straight and if necessary they are straightened by pressure unless they have to be of curvilinear forms.

Cutting is affected by shearing, cropping or sawing. Gas cutting by mechanically controlled arcs is also used for mild steel. For high tensile steel, gas cutting is permitted under special care so as to remove all hardened material later on by machining. Plates and angles are cut cold in one stroke by shearing. Beams and channels are usually cut to the desired lengths in factories but if shearing is to be resorted to, at least 2·5 cm. of the material is wasted. A better method is to cut the beams with saws or in exceptional cases, gas cutting may be resorted to.

The next step is to lay out all the material which includes marking the steel either with the aid of templates or directly. The centres of the holes to be drilled are marked with a punch. Holes are drilled, punched or bored. All holes should generally be drilled for better work as they are true circles, are accurately centred and cause less damage to the surrounding metal. Holes are always drilled whenever thick sections are encountered. Drilled holes are generally not more than 2 mm. larger than the nominal diameter of the rivet or the bolt when punching is resorted to, the holes should be punched 6 mm. less in diameter than the final desired value and pneumatic reamers are used for making the holes to proper size.

When the components of a member are ready, they are assembled and held in position temporarily by shop bolts. These are longer than necessary and have packing washers to save time in tightening. At least two bolts should be put in one part of a member. All parts assembled should be in close contact and all bearing stiffners should bear tightly at top and bottom. No drifting should be permitted except to draw the parts together and no drift should be larger than the normal diameter of the rivet. Drifting should not distort the metal or enlarge the holes.

The assembled parts are then rivetted. All rivetting should be done by hydraulic or pneumatic pressure. Bigger rivets are heated. Heaters commonly used in the fabrication shops burn oil and give a steady flame. Electric heaters are also sometimes used. Rivets of diameter less than 10 mm may be driven cold. Each rivet should completely fill the hole and form a head of standard size. All loose, burnt or badly formed rivets should be cut out and replaced.

Column splices, butt-joints of struts and compression members depending upon contact and stress transmission should be accurately machined and close butted over the whole section. Whenever sufficient gussets and rivets are provided to transmit the entire load, the column ends need not be machined.

The whole steel work with the exception of rivets, bolts, nuts and machine faces after being thoroughly cleaned should be given one coat of red lead paint. All machined faces should be coated with a mixture of white lead and tallow. Surfaces which are to be held in contact by rivetting or bolting should be painted before assembly and the parts brought together while they are still wet. All portions of steelwork which are inaccessible after rivetting should be given two coats of red lead paint.

The steel work should be temporarily shop erected so that accuracy of fitness may be checked before despatch. All parts are inspected for defects, if any.

Erection of Steel work

Steel work is erected with the aid of derricks, slings, guys, cranes etc. All parts of the steel work should be erected according to drawings keeping in view the plumbness of columns and placing of other parts. During erection the steel work should be securely bolted and when necessary temporarily braced to provide for all loads to be carried by the structure during erection including that of the erecting equipment etc. All parts should be finely rivetted only after they are properly placed in position and final alignment is checked. The steel work is finally painted as desired.

QUESTIONS

1. What are the uses to which steel is put in Building Construction? What are the various sections used?

2. What are the various methods of connections? Give details of rivetted and welded connections.

3. Write short notes on :

(*i*) Steel beam.

(*ii*) Beam to beam connection.

(*iii*) Columns.

(*iv*) Column and beam connection.

(*v*) Column bases.

4. Write a short note on the fabrication and erection of steel work.

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16

REINFORCED CONCRETE CONSTRUCTION

Plain, reinforced and prestressed concrete are being abundantly used in the construction of buildings these days. This construction, which has withstood the test of time, is very durable and economical for most of the buildings. The construction involving either precast units or cast-in-situ building units made of concrete may be adopted. The quickness and ease of construction in the case of concrete work is a great advantage. The improved appearance and the types of various finishes which can be given to concrete surfaces are added advantages in adopting these type of construction in buildings.

Concrete is an artificial material consisting of ingredients which are coarse and fine aggregates forming inert materials and cement which acts as the binding material. It is usually made in a plastic state and gets hardened thereby achieving strength. The properties of aggregates, cement and mixing water should be suitably checked and must be of approved specifications.

Good concrete, for economical results, can be made with materials a bulk of which are generally obtainable near the site. Clean sand, strong coarse aggregates and good Portland cement are necessary for making good concrete. These materials are to be mixed in the proportions which all produce concrete having the necessary strength and other properties combined with the greatest economy. The Concrete is normally graded as M_{100}, M_{150}, M_{200}, M_{250}, M_{300}, M_{350} and M_{400}. In the designation of concrete mix letter M refers to the mix and the number to the specified 28 days works cube compressive strength of that mix in kg/cm². The principles of making concrete are well known and some of the salient points which have to be kept in view are given below :

Selection of aggregates

Aggregates are produced by the disintegration of rock and by crushing rock or gravel. These are usually graded or in exceptional cases may be used as single sizes. Coarse aggregates are usually those particles which are retained on an I.S. 480 sieve and the fine aggregates are taken as those particles which pass completely through I.S. 480 sieve. For coarse aggregates, shingle as obtained from sea-beaches is used after shells being removed. River gravels are also good for being adopted as coarse aggregates, but these may need washing. Stone which is hard and durable such as granite, basalt, flint or quartzite provides good aggregates. Limestone is also good provided it is hard and free from impurities. Brick-bats are not usually adopted for reinforced concrete work in view of the fact that they contain high proportions of lime and may have a very high porosity. They are generally used in lime concrete or cheap concrete work. Blast furnace slag is used to some extent for making concrete of light weight characteristics.

For fine aggregates, sand as obtained from sea-beaches or from rivers or lakes is used. In certain cases crushed stone dust is also used.

In the selection of the aggregates for good concrete work, it should be ensured that the aggregates are absolutely clean. They should be free from organic matter and other impurities. The aggregates used must be sound and must resist the action of weather, particularly of frost. Some aggregates contain silicious materials which may combine with the alkalies present in cement so as to produce disruption which causes disintegration of aggregates. Certain aggregates contain readily oxidizable materials which expand on oxidation and cause disruption. These type of aggregates are unsuitable for concrete work.

The grading of aggregates is very important for getting good quality concrete. If the grading of aggregates is such as will create a large proportion of voids when the concrete is compacted, a concrete of poor quality is obtained. The material as obtained from the quarry is to be suitably adjusted for concrete work, *i.e.*, grading has to be done according to definite specifications for different types of work. The aggregates should not be very fine as large amount of water is needed for their mixing and the concrete gets weakened. For best results the proportion of very fine material should not exceed 10%. The ratio of the quantity of fine aggregates to the coarse aggregates is very important and has got a great bearing on the strength of concrete in the final stage.

The maximum size of the particles which is going to be used in a particular portion of a building will depend upon the nature of work and the reinforcement used. The maximum size generally used is 5 mm. less than the minimum distance between reinforcement or is taken as the minimum cover between the face of work and the reinforcement. For thin walls, slabs, etc., the maximum size of the particles should not exceed $\frac{1}{5}$th of the thickness of walls. For mass concrete work, the maximum size of particles may be increased to such a limit that they can be used easily. The use of large aggregates will reduce the quantity of cement needed for a given strength as the surface area of the aggregate particles gets decreased, but bigger sizes are unsuitable for being worked easily.

Large sizes known as plumbs or displacers are used in mass aggregate work to save materials but they have to be suitably packed in concrete. These plumbs should be sound and clean and should not be placed very near to one another or to the exposed face.

The shape of the aggregate particles will affect the workability and hence the strength. Aggregates composed of roughly spherical particles produce the most workable concrete. The longer particles produce a harsh workable mix and hence it is a common practice to add some water or sand. This has the effect of increasing the ratio of water to a given quantity of cement and hence decrease the strength of concrete.

Cement

Three classes of cements are generally used in building construction work, namely, ordinary Portland cement, rapid hardening cement and high alumina cement. Rapid hardening cement attains its strength at an earlier age than ordinary Portland cement and hence is economical in some cases but is more costly. High alumina cement is more resistant to deteriorating effects of weathering agencies. Coloured cements or white Portland cement may be used depending on the type of finish desired. For good work, the specifications of Portland cement must be checked regularly.

Water

The water to be used in making concrete must be clean. Where ordinary drinking water is not available, the water must not be contaminated. It should not be used in excessive proportions but must be sufficient to wet the aggregates and the cement paste. It should be free from oils, acids and alkalies, sulphates or other organic matter. Sea water is not generally suitable for building work.

Percentage of solids when tested in accordance with good practice should not exceed the following :

Solids	Permissible Limit
Organic Organic Solids = (total solids— ignited residue)	200 mg/l
Inorganic (ignited residue)	3000 mg/l
Sulphates (SO_4)	500 parts per 100,000
Chlorides (as Cl)	2000 mg/l for plain cement concrete work and 1,000 mg/l for reinforced cement concrete work

Design of mixes

As far as possible, controlled concrete should be used in all concrete jobs. Controlled Concrete for use in plain and reinforced concrete structures is specified as M 100, M 150, M 200, M 250, M 300 and M 400 grades as per I.S.I. Specifications which lay down the following strength requirements.

Table : STRENGTH REQUIREMENTS OF CONCRETE
(All values in kg/cm²)

Grade of Concrete	*Compressive Strength of 15 cm. Cubes at 28 days after mixing, conducted in accordance with good practice*	
	Preliminary Test Min	*Works Test Min*
1	2	3
M 100	135	100
M 150	200	150
M 200	260	200
M 250	320	250
M 300	380	300
M 350	440	350
M 400	500	400

To obtain concrete of a required strength and workability at the lowest cost a suitable choice of materials has to be made and their proportions selected carefully, *i.e.*, every concrete mix has to be designed properly.

Concrete must behave satisfactorily in two states, namely, the plastic state and the hardened state. The choice of proportions is governed by both these conditions. If the plastic concrete is not satisfactory, it cannot be properly compacted and its structural value is greatly reduced. Satisfactory compaction can be obtained only if concrete is sufficiently workable for the particular type of compaction needed. The property of workability is of great importance from the structural point of view. In addition to the cost of placing, the basic property of concrete strength is related to the water content of a particular mix. The water/cement ratio with a particular crushing strength is constant and has to be controlled properly. As the water content increases, the strength of concrete gets decreased. This means that a minimum quantity of water would be desirable but the workability would be affected by lessening the water beyond a certain limit. The general rule of water/cement ratio is :

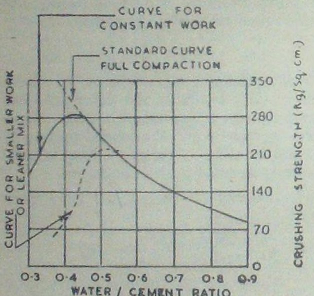


Fig. 982.

$$\frac{w}{c} = \frac{A}{S + 0{\cdot}5A}$$

where S = ultimate compressive strength (kg/sq. cm.)

w = weight of mixing water (kg.)

c = weight of cement (kg.)

A = coefficient dependent on the age of concrete, quantity and grading of aggregates, the efficiency of mixing, etc.

The value of A may range from 140 to 350 and it is therefore obvious that any average value has no practical significance. The only reliable method of assessing the quantity of A is to make trial mixes with aggregates and cement as proposed but with water/cement ratio of 0·5, 0·6 and 0·7. These mixes should be tested after 28 days' curing (see Fig. 983) in the case of ordinary Portland cement and after 7 days' curing for rapid hardening cement. For given materials and careful operation, the value of A should be very nearly equal. Curves are usually given in all the standard text books which give the value of crushing strength of concrete for a particular value of water/cement ratio at various ages.

While selecting this water/cement ratio for a particular strength, it has to include the free water present in the aggregates obtained from the quarry. The amount of water which is to be added to the mixture is found by subtracting the free water from the total quantity of water needed in a particular mix.

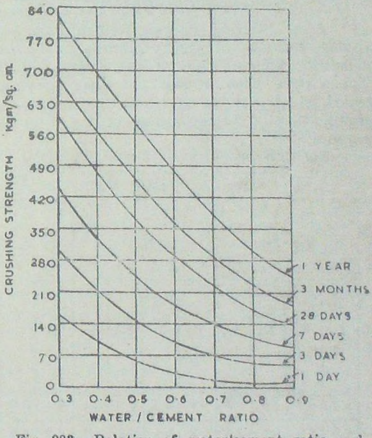


Fig. 983. Relation of water/cement ratio and crushing strength of concrete at different ages.

In choosing the strength required for any particular purpose, a definite minimum strength is usually specified to allow for the variation in the evaluation of strength from the test cubes. The amount of variation depends on many factors. However, with good control and weigh batching and constant supervision 75% of the average crushing value can be attained as the minimum strength. In the case of poor control and mixing of aggregates by volume and having very little supervision only 40% of the strength is possible.

The amount of water needed, as stated earlier, has to be sufficient to wet the aggregates in such a manner so that the mix can be laid easily at the required place.

For measuring the workability, usually a slump test or compacting factor test is carried out. Normally for slabs a slump of 5 to 10 cm. or a compacting factor of ·92 is adopted. This takes into account compaction by manually operated appliances and the presence of heavy reinforcement. These values can be decreased whenever mechanically operated compacting equipment is available.

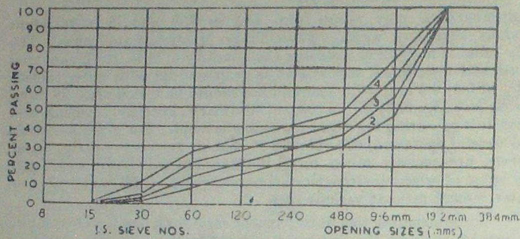


Fig. 984. Recommended gradings of the Road Research Lab. of the U.K. for 19·2 mm. max. size aggregate.

After deciding the water/cement ratio and the degree of workability, the ratio of cement quantity to the total aggregates is determined for different types of aggregates and the available grading. Tables have been worked out, after carrying out a series of experiments, which give the aggregates/cement ratio required for different grading sizes of the aggregates, shapes of the aggregates and different workabilities.

AGGREGATE/CEMENT RATIOS REQUIRED TO GIVE FOUR DEGREES OF WORKABILITY WITH DIFFERENT GRADINGS AND SHAPES OF AGGREGATE

Degree of workability	Very low				Low				Medium				High			
Grading of aggregate	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0·35	4·5	4·5	3·5	3·2	3·8	3·6	3·2	3·1	3·1	3·0	2·8	2·7	2·8	2·8	2·6	2·5
0·40	6·6	6·3	5·3	4·5	5·3	5·1	4·5	4·1	4·2	4·2	3·9	3·7	3·6	3·7	3·5	3·3
4·45	8·0	7·7	6·7	5·8	6.9	6·6	5·9	5·1	5·3	5·3	5·0	4·5	4·6	4·8	4·5	4·1
0·50			8·0	7·0	8·2	8·0	7·0	6·0	6·3	6·3	5·9	5·4	5·5	5·7	5·3	4·8
0·55				8·1			8·2	6·9	7·3	7·3	7·4	6·4	6·3	6·5	6·1	5·5
0·60								7·7			8·0	7·2		7·2	6·8	6·1
0·65								8·5				7·8		7·7	7·4	6·6
0·70															7·9	7·2
0·75																7·6
0·80																

The method of design as briefly reported above would include the procedure as under :

(1) The specified minimum strength for a particular structural element having been known, the average strength is estimated according to the degree of control which can be exercised in the field.

(2) The water/cement ratio needed to give the estimated average strength is found out from a series of standard curves depicting strength *vs.* water/cement ratio at different ages.

(3) With the aid of table, the workability required is chosen according to the conditions of the particular job.

(4) The cement/aggregate ratio that will give required workability for the corresponding aggregate grading is taken from the tables. These tables are provided for round, irregular, and crushed aggregates of different sizes.

(5) By graphically or other methods, the proportions in which the available aggregates can be mixed so as to give a grading approximately close to the design are calculated.

(6) The graded material as obtained in step 5 is mixed with the required quantity of cement and water as defined by the cement/aggregate ratio and water/cement ratio.

Trial mixes of these proportions are made which are further tested in laboratory in the form of test cubes for check purposes.

The other methods of design of mixes are briefly given as under:

1. *Arbitrary Method*

For choosing the mixes arbitrarily, the ratio of coarse to fine aggregates is varied from $1\frac{1}{2}$ to $2\frac{1}{2}$. The fine aggregates will fill up the voids between the coarse particles. The ratio of cement to aggregates depends on the strength desired. Mix of grade M_{100}, M_{150}, M_{200}, M_{250} etc. are prepared by using the ratio of cement, fine aggregate and coarse aggregate as 1 : 3 : 6, 1 : 2 : 4, 1 : $1\frac{1}{2}$: 3, 1 : 1 : 2. Mixes of 1 : 1 : 2 and 1 : 2 : 4 proportions are suitable for high strength. A mix of 1 : 2 : 4 is used for general R.C.C. construction and 1 : 4 : 8 is used for mass concrete work. Adequate quantity of water is mixed in each case to give a desired workability. The workability corresponds to a definite value of slump for a particular job.

2. *Minimum Voids Method*

This method aims at evolving a mix which has the minimum percentage of voids so as to obtain a dense concrete. This means that the fine aggregates should be in sufficient quantity to fill the voids in the coarse aggregates. The voids of each aggregate having been determined earlier, the cement is added in sufficient quantity to fill the voids in the fine aggregates. Sufficient water is added to make the mix workable.

3. *Fineness Modulus Method*

It has been found that the aggregates can be suitably defined in terms of grading by a term called "Fineness Modulus" which is a numerical index of fineness. It gives an idea of the mean size of particles in the entire body of aggregates. It is obtained by adding the percentages by weight of materials retained on each of the 10 Indian Standard sieves ranging from 76·2 mm. to I.S. No. 15 sieve and dividing the sum by 100. As a result of considerable experience, certain values of fineness modulus for fine and coarse aggregates and mixed aggregates have been found to give good workability with a minimum quantity of cement. This value varies with the size of the particle in the body of the aggregates. If the fineness modulus of a given sample does not correspond to these values, the mixture will need more cement for a given water/cement ratio and workability. Any increase in the values of fineness modulus of mixed aggregates from this value will result in a harsh mix while a decrease in the value will give an uneconomical mix for fixed water/cement ratios.

After having mixed the fine and coarse aggregates so as to obtain the desired fineness modulus of combined aggregates, the proportioning of the concrete can be done by actual field trials.

The actual quantity of cement required per unit volume of coarse aggregates and for a desired slump must be checked with the same trial mixes.

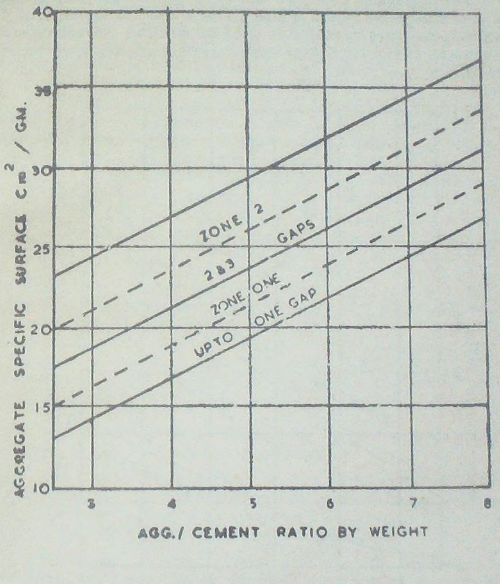
Specific surface of aggregates

It can be shown that there is a close relation between grading of aggregates and specific surface of the aggregates. It has been proved that if harshness is avoided, the strength and consistency of aggregates can be adjusted if the specific surface is consistent, which is independent of the particle size distribution.

SPECIFIC SURFACE OF VARIOUS SIZE GROUPS OF AN IRREGULAR AGGREGATE

Passing through I.S.	*Retained on I.S.*	*Sq. cm. per gm.*
No. 15 Sieve	No. 8 Sieve	260
No. 30 Sieve	No. 15 Sieve	128
No. 60 Sieve	No. 30 Sieve	65
No. 120 Sieve	No. 60 Sieve	35
No. 240 Sieve	No. 120 Sieve	16
480 Sieve	No. 240 Sieve	8
9·6 mm. Sieve	480 Sieve	4
19·2 mm Sieve	9.6 mm. Sieve	2

The specific surface of the different aggregates can be determined by the water permeability method or an assumption made on the basis of shape factor. In carrying out this test, the aggregates are separated effectively so as to avoid variation in results. After making a set of fine and coarse aggregates into various sizes the specific surface can be calculated by the use of table reproduced here. The choice of aggregates/cement ratio is mainly influenced by the strength and consistency requirements. Both strength and consistency are effected by the specific surfaces of aggregates. Strength can be considered for practical purposes as related to water/cement ratio. Similarly consistence is also considered consistent for small variation in specific surfaces. A relation has been derived between the compacting factor which is an index of consistency and the water/cement ratio. Aggregate/cement ratio is also an important

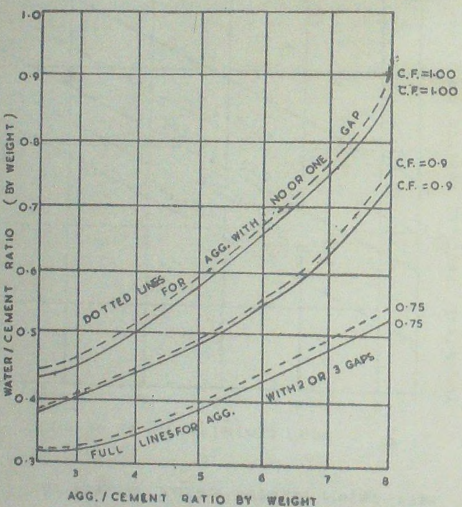


RELATIONSHIP BETWEEN SPECIFIC SURFACE OF AGGREGATES & AGGREGATE / CEMENT RATIO FOR CONTINUOUS (NO GAP) AND GAP GRADED AGGREGATES, 19·2 mm. MAX. SIZE (RIVER OR PIT RUN).

Fig. 985.

factor in the design of a mix. Curves have been drawn for denoting the aggregates/cement ratio by weight and different specific surfaces. For particular specific surface adopted, a corresponding aggregate/cement ratio can be evaluated. In a range of mixes normally used, the zone 'One' in the figure shown, indicates specific surface values for aggregates with one or no gap. The lower limit is suitable for mixes with lower sand content and the higher limit for mix requiring more sand and increased dust content. For a straight graded sand between No. 15 and 480 sieve size, it can vary by 8½% in this zone. This range is adequate for most purposes for any given mix.

For aggregates with two or three gaps, zone 2 indicates a range of acceptable values in size. This allows the variation of 6½% with a sand varying from No. 15 to 60 sieve. A corresponding water/cement ratio for a given specific surface and the zone type can be selected.



RELATIONSHIP BETWEEN WATER/CEMENT RATIO & AGG. CEMENT RATIO FOR MIXES WITH DIFFERENT CONSISTENCIES AS GIVEN BY COMPACTING FACTOR (C.F VALUE)

Fig. 986.

The procedure in brief, while adopting this method, is to select a water/cement ratio for a given strength. Depending on the consistency required an aggregates/cement ratio is selected from Fig. 986. A specific surface corresponding to this aggregate/cement ratio is selected from Fig. 985 allowing for high or low sand content. The fine and coarse aggregates are then mixed to give the required specific surface. A trial mix is made to confirm the results. The difficulty in this method is the correct assumption of specific surface of the aggregates. This can be done by the aid of various methods which, although cumbersome at present, are being simplified in the course of time.

Mixing of concrete

The simplest method used for concrete mixing is by manual means. It is done only where the quantity of concrete of insufficient to warrant the installation of machinery, the working area is less or when the distance from the mixing position to the placing area is excessive. This method has also to be adopted in places where machinery cannot be used due to excessive noise produced by it, for example, near hospitals, etc. Whenever small quantity of concrete is to be mixed, good concrete can be obtained by hand mixing. This is not possible if concrete has to be mixed in greater quantities by hand mixing. The usual procedure for mixing concrete manually is to carry out this operation on a level, clean and less absorbant platform. The top of this platform must completely be covered with sheet metal or similar covering which will not flake under the action of shovels. The aggregates and cement are stored adjacent to this platform in a proper manner. Coarse aggregate is laid evenly in a layer over the platform and the fine aggregate is spread over it, The cement layer is then spread over it uniformly at the top. In mixing the materials, care should be taken that each shovel contains some quantity of each of these materials. A suitable method of mixing is that the whole mass is mixed thoroughly 2 to 3 times while in dry state and again 2 to 3 times when water is added.

Mechanical mixing is adopted these days to a great extent. The following types of mixers are usually adopted :—

1. *Non-Tilting Types* : These are made in sizes from about $\frac{1}{8}$ cu. m. to 5 cu. m. In most cases the drum rotates in one direction and the concrete is discharged by a hopper. The direction of rotation of the drum may be reversed to discharge the concrete.

2. *Tilting Drum Mixers* : These are generally made only in smaller sizes but a few larger machines up to 3 cu. m. capacity have been made which are capable of producing about 60 cu. m. of concrete per hour.

3. *Pan Mixers* : These mixers are efficient but have small capacity.

4. *Continuous Mixers* : These mixers measure the ingredients by volume and once they have been set, their measuring is done more or less automotically. The power consumption of these mixers

is small and they are capable of producing 10 to 20 cu. m. of concrete per hour.

5. *Truck Mixers* : These are used when the mixed concrete is to bs carried to a long distance. They are used in conjunction with a central batching plant. Water is carried in a separate tank so that it can be mixed in the truck when it is near the depositing area.

The ingredients in dry state are filled into hoppers or skips attached to the mixer. The coarse aggregates are placed first at the bottom followed by fine aggregates and cement. These materials get admitted into the drums in the reverse order. No material should be put in the skip unless they have been mixed and used immediately. The materials are loaded into the skip after being correctly measured for large works and for a good quality of concrete. It is essential to have weighing machines with measuring devices for weighing the concrete ingredients correctly. Many types of weigh batching plants are available. These are swinging hopper types, horizontal hopper types and simple weigh batchers. They can be completely mobile or partially mobile and the hopper may be elevated or may have bottom discharging arrangements. The capacity of the plants is sufficient to give about 7 cu. m. of concrete per hour. For bigger works, fixed batching plants are used. They can be fed with bulk cement instead of cement available in sacks. They are economical only in large-scale construction as they need a lot of time for erection.

After all the materials have been put in the drum, mixing should continue until the mixture is uniform. The strength of concrete is effected by the duration of the mixing process. About one minute is necessary to give good strength and mixing up to 1½ minutes also improves the quality of concrete. There is no advantage in mixing beyond two minutes. The time between charging of the materials into the drums and discharging of the concrete is not less than 1½ minutes. Some machines have a device for discharging the mixed materials automatically after they have been mixed for a sufficient time. Sometimes it is specified that the materials should be mixed in a dry state before adding water. This may not be practicable with large batching and mixing plants. When the mixing plant is to be closed for more than one hour it should be cleaned.

Transporting concrete

After mixing the concrete, it has to be delivered to the final position which it has to take in a building unit. The need of transporting concrete at the earliest possible time is essential because concrete should be placed and compacted before the initial set of cement takes place. While transporting, it should be ensured that the containers are water-tight and that the loss of water and cement is avoided to a great extent. Segregation of the particles must be avoided at all costs as this would result in bad concrete. If it is unavoidable during transit, concrete should be remixed before being placed.

Good concrete may get spoiled by mishandling during transportation from the mixer to the point of incorporation. This is more true for areas where greater load of concrete is essential. The methods of transportation usually adopted are :

1. *Use of Iron Pans Which are Carried by Men*

These pans have got a small capacity and are usually of such a size that one man can lift and walk easily over the required distance. For raising concrete over some height so as to place it on the top floors of a building, ladders are erected and men stand at various levels. The same pan is being transferred from one person to the other quickly. This method of transporting concrete is only adopted for small and medium size buildings in India as it works out to be the cheapest method with such type of construction.

2. *Wheel Barrows*

Ordinary wheel barrows hold about 2 cu. m. of concrete. The wheels may be fitted with pneumatic tyres to prevent the segregation of concrete on account of series of jerks which the wheel barrow is likely to exeprience while travelling over uneven surface.

3. *Concrete Carts*

These vary in capacity from 7 to 14 cu. m. and they are designed for easy pushing, tipping and discharging. Suitable wooden platforms are laid for their easy travel.

4. *Hoists Used with Barrows*

For tall structures hoists may be used either to lift the barrow to the required height or to discharge the concrete into the hopper from which it is carried further. Some sites do not permit the use of external hoist, *e.g.*, in the case of steel buildings. In confined areas the hoist must be erected within the building and built up in sections. The topmost will rise a few feet above the working level. The guide rails are held up against each floor level by studs. A vertical hoist can frequently be arranged in multi-storeyed buildings within the space allowed for stairs or lift wells. Otherwise temporary openings have to be left in the floor panels to allow for the hoists. Cranes may be used with hoist mainly to lift skips of concrete from the site of the mixer to the building where the concrete is to be placed.

5. *Lorries*

Lorries are used whenever the distance is great. Such a case occurs when concrete is to be deposited at a place where it cannot be mixed due to the non-availability of space. General mixing plant placed at some distance from the site of work is erected. Special lorries suitably designed are used for transporting concrete. The concrete is covered to protect it from the sun, wind or rain during transport. The time to transport should not exceed more than 20 minutes when mixed concrete is to be carried.

6. *Chutes*

When concrete is to be placed below general ground level, the mixer can be placed on an upper level and concrete discharged to the lower level through a small chute of corrugated iron or timber, leading to barrows, carts or other transport facility or directly to the final position where it has to be deposited.

7. *Pumping of Concrete*

Pumping of concrete is economical and successful where the size of the aggregates does not exceed 50 mm. and the concrete is of medium workability. The control of aggregate gradings and the batching of mix have to be done effectively. The advantages of this type of work are that no traffic for transporting concrete within the working radius of about 600 metres from the pump is created. About 8 to 25 cu. m. of concrete per hour can be delivered. The system is very flexible as the pipe lines can be easily changed. Handling of concrete between the mixer and the point of incorporation is avoided which makes a better quality of concrete. The plant consists of a pipe line and a pump. The type of the pump will vary slightly with the consistency of the concrete and length of the pipe line. For a continuous discharge, it is essential for the mixing plant to be of an adequate capacity. These pumps are operated by electric power or other means. The pipes are of about 15 cm. internal diameter for large capacity pumps and about 10 cm. diameter for smaller machines. Concrete can be delivered up to a height of about 40 m. vertically or 2000 m. horizontally. The power required to operate a pump at full range capacity is about 35 h. p. This type of transportation is rarely resorted to for building work.

Placing of concrete

The quality of concrete depends amongst other factors, on the care with which it is placed in the final position. Concrete must be deposited quickly in its final position and its lateral movement after deposition should be reduced as much as possible. It should be placed in even layers each of which is compacted before the next layer is placed. Each layer must be placed before the previous one has set. Layers must be of such thickness that a good quality of concrete is got depending on the type of work. After a break in the work, fresh concrete should be joined to the one which has already set. All formwork must be cleaned before any concrete is poured. Surface of the forms may be treated to prevent adhesion of concrete. The reinforcement must be fixed before concreting is started and it should be ensured that it does not displace during concreting. Except for slabs and large works, the concrete may be placed into the shutters by shovels. While depositing concrete with the aid of iron pans, it must be ensured that concrete is not dropped from greater heights as otherwise segregation would result.

Compacting concrete

The purpose of compaction is to remove air bubbles from the concrete mass to a great extent. Under-compaction results in a lot of air voids in concrete while over-compaction may lead to segregation. Compaction is carried out by hand or mechanical means. Manual compaction is carried out by rodding, tamping or ramming. Rodding is used for the vertical section, tamping for slabs and ramming for heavy reinforced concrete. Rodding consists of a rod of wood or metal being pushed into the concrete and moving it up and down until the concrete is thoroughly worked into empty places and completely filling the corners and other awkward positions. Slabs should be tamped with tamping rod which serves the double purpose of compacting and finishing the concrete to the required level. Heavy masses of reinforced concrete work are rammed with wooden or steel rammer, the face of which is usually not less than 15 cm. square. Ramming is continued till the slurry of cement and water starts to appear on the upper face of the concrete. Honey-combing must be avoided in good concrete work. This is due to inefficient tamping or due to leakage of cement grout from the shuttering. The ramming should not be heavy as otherwise there is a tendency for concrete to rise against the side of the shutters and also to exert excessive pressure on the shuttering face.

Compaction, by the use of mechanical vibration is becoming more useful these days. The advantage with mechanical vibration is that lesser water/cement ratio can be used which can give good concrete and also economise cement. The principle of compaction by vibration is that when a concrete mass is vibrated, the surface structure between the particles gets considerably reduced and thereby gives a sort of fluid nature to the concrete. As soon as the vibration is stopped such fluid properties disappear. The heavier particles sink rapidly to the bottom. Hence concrete which is very workable should not be compacted by vibration. The higher the frequency of vibration, the lesser the time needed for compaction. For higher frequency, the power consumption increases rapidly and also the wear and tear of the equipment increases disproportionately. The minimum frequency for compaction appears to be 3600 r.p.m. Drier mixes or thick slabs can be compacted with larger amplitude or with larger frequency. A larger amplitude leads to more difficulties in finishing the surface. The usual types of vibrators used are internal, external, table and surface types. The internal vibrators consist of a long rod like vibrating head which has a motor and vibrations are given to this rod. Basically they are of two types, the rigid type in which the motor is rigidly attached to the head of casing or vibrating unit and the flexible type in which the vibrating head is mounted on the flexible shaft driven by an external motor or the vibrating head is mounted on a flexible hose feeding compressed air to the motor located in the vibratory heads. Vibrating heads are available in various sizes, small sizes being used in mass concrete work and heavier sizes for reinforced work. External vibrators are designed for being attached to the formwork which contains concrete. They are operated by an electric motor or an air motor. Table vibrators employed for vibrating precast units are available in lengths up to 4 m. These are not used in building construction work otherwise.

Where the sections of concrete members are thin and they are reinforced, vibration is to be done carefully. A higher water/cement ratio would be necessary in such work. Vibration saves times and labour in placing concrete. Good surface finishes are also produced and side shutters can be easily removed. The slump should never exceed 5 cm. but lesser slump can be used when compaction can be thoroughly done. In the construction of walls, it must be ensured that the formwork is strong so that it does not get loosened on account of vibrations.

Vibration should be stopped when the water comes to the top of the concrete. Longer periods of vibration are required to compact the concrete made with angular aggregates than that of the rounded aggregates. Vibrators have to be firmly attached with the shuttering so that energy may not be lost in vibrating the formwork only. For general work the internal vibrator is well known and is usually adopted. The advantages of this type are that the vibrator actually gets into the concrete and vibrations are therefore directly transmitted. It is easily moved from point to point. The operator can also observe the behaviour of concrete under vibration. These vibrators should be used vertically and should penetrate to the full depth. They should be inserted and withdrawn slowly and removed from concrete as soon as cement paste starts to appear on the surface.

Curing concrete

The setting of cement in concrete takes place on account of hydration. Hydration continues for a great length of time but its rate decreases. Hence concrete must be kept moist till it gains sufficient strength. The mixing water is usually sufficient for initial hydration but most of the quantity of water is lost by evaporation at the surface. This is to be prevented by curing.

The period of curing depends on the type of work, the type of cement, and the climatic conditions. Normally for ordniary Portland cement, the concrete must be cured at least for a period of 7 to 10 days. This period may be reduced in the case of rapid hardening cement.

The generally adopted method is to apply periodically water from a hose to exposed parts of concrete or by covering the face of walls with sacks, hessing, or coconut matting, etc. Horizontal surfaces which can bear the presence of exterior agencies to some extent can be moistened by a covering of wet sand, earth, saw-dust or by covering with water to a depth of 3 cm. or so. This water in small ponds is kept within small clay bunds. These days large flat surfaces are sprayed with patented compounds or bituminous emulsions, and sometime the surface is covered with water proof papers. These papers consist of two sheets of white, tough, durable kraft paper joined together by a bituminous material.

A layer of Calcium Chloride spreaded on the concrete absorbs the moisture from the atmosphere and is helpful in curing the concrete but the process is expensive.

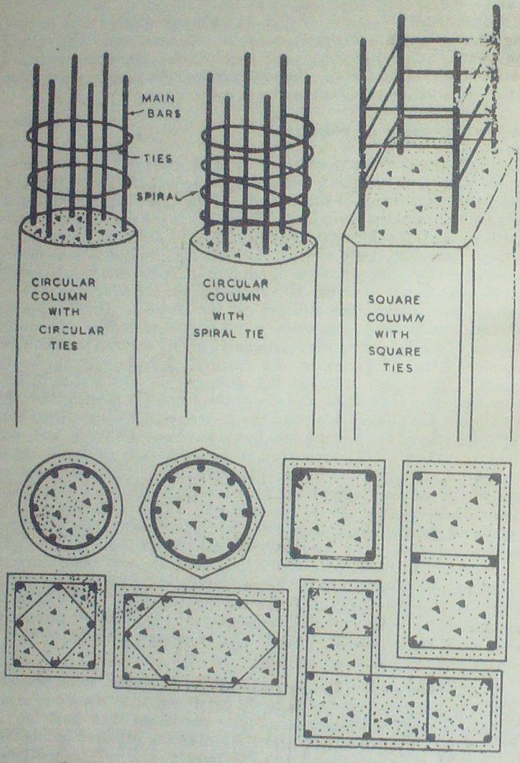
The purpose of these coatings is to prevent water evaporation. They are applied as soon as the concrete is finished. Bituminous layers are only advisable where the exterior finish is not of much importance.

A process of steam curing is widely used these days to cure precast pipes and other precast units. It accelerates the rate of gain of strength, reduces the time required for curing and enables early removal of formwork, thereby increases the rate of production of the units with a resultant saving in cost.

Reinforced concrete columns

Reinforced concrete columns are of various types. They may be of square, rectangular, hexagonal, octagonal or circular sections. The main constituents of the R. C. C. columns are the longitudinal bars which take the main load. These are tied by lateral steel bars which act as ties. These ties prevent the buckling of these longitudinal bars and keep them in position with respect to each other. Sometimes these ties are made in the form of spiral and this is called spirally reinforced columns. This spiral has got the additional advantage of providing extra strength to the column. Other types of columns usually are composite columns which consist of simple sections of steel pipes or joist sections which are encased in reinforced concrete work. Columns at the corners of buildings may be 'L' shaped. For bigger columns the arrangement of ties is to be suitably varied to account for the size of the column. The load of the column is distributed between the concrete and longitudinal bar. The total area of the longitudinal bar is not less than 0·8% and not greater than 8%. The minimum diameter of such reinforcement is not less than 12 mm. and not greater than 5 cm. A 4 cm. cover of concrete is at least provided on all sides of the main steel. The minimum diameter of lateral ties is 5 mm. and the maximum size usually adopted is 12 mm. as bending would become difficult for bigger sizes. The pitch of the lateral steel is not greater than 48 times the diameter of transverse bars or the least dimensions of the column or 16 times the diameter of the longitudinal steel. The volume of the lateral reinforcement is not to be less than 4% of the total volume of column. The longitudinal steel is suitably lapped whenever necessary. The spiral reinforcement of the column is held in place by at least 6 vertical bars.

After the column shuttering has been fixed, the reinforcement is checked and separated from the shuttering with the aid of small fillets so as to provide suitable cover to the steel. The first lift of concrete is then deposited and the shuttering is raised by another stage. The operation of placing concrete in each lift is continued but the rate of vertical progress is not to exceed about one metre in half an hour. The depth of concrete placed in a single layer is frequently specified and is not to exceed one metre. The risk of aggregates dropping towards the bottom of the shuttering or the presence of cavities being left, is minimised, whenever the bottom layer is allowed to set before the next layer is laid. Settlement is accelerated by ramming and tamping or by the use of vibrators. In the case of deep single deposits of concrete, hammering outside



Figs. 987-996. Typical details of R.C.C. columns.

would assist to consolidate concrete if it is combined with the internal tamping. This ramming should be done rarely in the corners. It is preferable to have men who do this ramming process at the top of the column. The concrete is deposited centrally in the column. In the case of tall columns it is not permissible to drop the concrete vertically from the top of the box. It should be fed in at a convenient height through a chute extending to the centre of the column. The concrete should not be dicharged directly from long chutes into the column box or else honey-combing may result. The concrete in the column is usually stopped a few centimetres below the level of the beams running into the columns. The portion of the column thus left is concreted with the beams. The consistency of concrete in column is sometimes varied. Drier concrete is used in the upper portions, as it is advantageous while placing continues.

Concreting of columns of different storeys is to be carried out very accurately. The central lines of column must be accurately one above the other for columns which are placed in different floors. This must be checked at every stage of construction. Since the loads in the top storey are lesser, the section of column also gets reduced correspondingly. The steel from the column in the lower storey is bent so as to get accommodated in the column of the top floor.

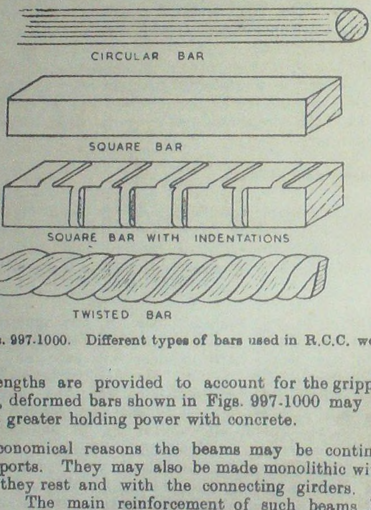
The steel or cast iron core of a composite column must be thoroughly encased in a reinforced concrete cover so that the load is carried by the concrete, the longitudinal bar and the core. The cross sectional area of the core should not be greater than 20% of the gross area of the column.

R.C.C. beams and girders

Reinforced concrete beams are being commonly adopted in building construction these days. The strength of a R.C.C. beam depends on the composite action of concrete and steel, the former taking all compressive forces whereas the latter takes all the tensile stresses.

This beam in its simplest form is rectangular. Steel is provided at the bottom in the form of bars to take tensile forces. Concrete in the lower portion does not take any force but merely keeps the bars in position. Rectangular beams are adopted wherever the slabs resting on the beams are of a different material or are not cast monolithically with the former. Since concrete in the lower portion is not useful it can be omitted and only that much quantity can be left which is sufficient to keep the steel in position. The slab is cast monolithically with the beams and if it extends on both sides of the beams, a T-beam is developed. This beam is more economical. Whenever the slab extends on the side of the beam only and is monolithic, it is termed as an L-beam and is used at the end walls of rooms. Due to the limitations of the size of the beams it may become necessary to place steel bars at the top also to take additional compressive forces. This type of beam is termed as doubly reinforced beam and is not economical due to excessive cost of steel.

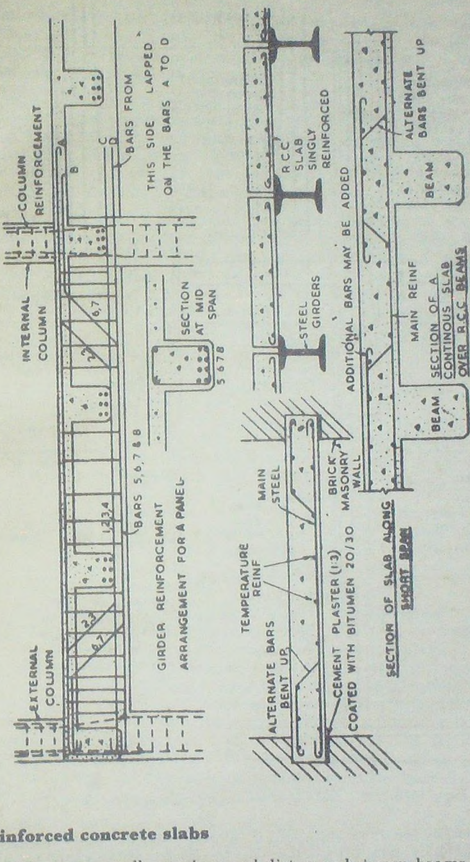
The R.C.C. beams as described above may therefore consist of steel rods running along the length of the beam and placed at bottom or both at top and bottom. Additional steel has to be provided in the vertical direction or in the form of bent bars to take care of the shearing stresses created in a beam. The bars in the vertical direction (stirrups) take a U-shape and are connected to the longitudinal main bars at one side and to additional longitudinal holding bar at the other end. For bigger beams, these U-shaped bars are suitably altered in shape so as to keep them in contact with as many longitudinal main bars as possible and thereby keeping them in correct position and also giving the desired area per unit length of the beam to resist the shearing forces. The spacing of vertical stirrups or inclined bars is suitably varied according to the shearing forces set up at a given section. Usually the spacing is least at the supports of the beam as the shearing forces are greatest there. The bars which carry the forces must have an adequate grip with concrete. For this reason, the ends are hooked



Figs. 997-1000. Different types of bars used in R.C.C. work.

or extra lengths are provided to account for the gripping action. Alternately, deformed bars shown in Figs. 997-1000 may be used as they have a greater holding power with concrete.

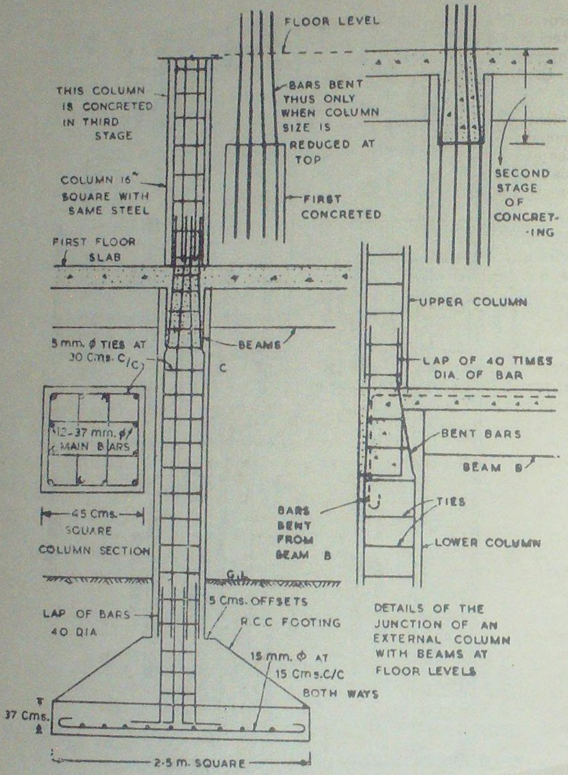
For economical reasons the beams may be continuous over several supports. They may also be made monolithic with columns over which they rest and with the connecting girders. (See Figs. 1001-1005). The main reinforcement of such beams has to be provided carefully as tensile stresses occur on the top face at the supports of these beams and in the bottom face at the mid-spans. The steel has to be provided on these faces at these points. The bars have to be suitably extended into the adjacent panel to give proper laps. They are also anchored into the columns. (*See* Figs. 1006-1009).



Figs. 1001-1005. Details of R.C.C. Beams and Slabs.

Reinforced concrete slabs

To span small openings and distances between beams, R.C.C. slabs are used. These slabs have steel bars placed at the bottom surface to take care of the tensile forces created in them. For small spans, no steel is provided at the top but for greater spans and whenever this slab rests on masonry walls a part of the bottom steel which is



Figs. 1006-1009. Details of columns and beam junctions.

greatest at the centre of the span, is taken to the top at the supports. Additional bars are provided across the length of the spans to take care of the temperature stresses.

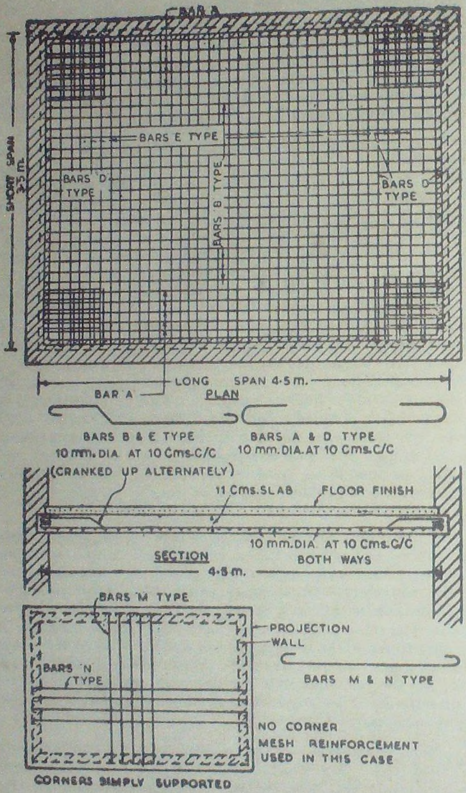
Slabs may be built monolithically with the beams and may also be continuous over a number of spans. In the latter case, tensile stresses occur over the support and as such additional steel is to be provided in the top surface of the slab over this area. The bottom steel is taken continuous over all the spans and its quantity over the supports may be reduced since very small tensile stresses are created in the bottom of the slab at this point.

For small spans the slabs are simply supported over small rolled steel joists which carry the loads in turn. For bigger spans, monolithic construction is desirable as this is going to economise the quantity of R.C.C. work. Where the R.C.C. beams intersect the slab it should be ensured that no congestion of reinforcement is created as otherwise concreting would be difficult.

The usual type of reinforcement adopted for slab work consists of round square or cold twisted or deformed bars but for small spans wire mesh or XPM Jali may be used. Where the length of the room is not greater than or equal to twice the width of the room, it is economical to put the steel bars in both the directions. This type of construction is called a two-way slab which is shown in Figs. 1010-1014. If such a slab is built within masonry walls, additional bars have to be provided over the corners to account for the excessive stress created therein due to the restraining effect of the masonry at the top. The reinforcement of a two-way slab runs from corner to corner and additional steel should be provided to take care of temperature stresses. Whenever beams are not desirable for supporting the slabs, the slab in turn may be carried over columns which have got top ends flared out. The slab in such cases gives a smooth surface, is economical for heavier loads, gives better lighting and is clean. This type of slab is called a flat slab. Such construction can also be done by thickening the area of the slab over the columns which are called drops. Flat slab construction is usually adopted in factories, big parking areas, restaurants, etc. In this type of work the distance between the columns has to be suitably arranged so as to get an economical construction.

For spanning greater lengths where no support is desirable usually ribbed slab construction is followed. This slab work consists of a series of small joists spaced very closely and cast monolithically with the top slab. These joists carry little reinforcement and concrete in them is sufficient to keep the bars in position with respect to slab. The slab is reinforced as usual. These ribs are made wide only to resist the shearing forces and the steel in them is never more than that of an ordinary slab. Occasionally it may be advantageous to support the slab on four sides and provide the ribs in both directions. The construction of ribbed slabs has been described under the chapter on "Flooring"

Before concreting the beams and slabs, the shuttering should be cleaned out. The reinforcement should be checked and the shuttering saturated with water. The ribs of the T-beams should be concreted at the same time as the slab. For larger concrete beams it is better to allow an interval of not less than one hour so that the concrete in the rib may be allowed to get initial settlement before the concrete in the slab is placed. When the concrete in the rib is placed separately, the rib is not concreted completely but a gap of about 5 to 8 cm. below the soffit of the slab is left to be concreted directly with the slab. Concreting the rib and slab



Figs. 1010-1014. Two-way slab details.

simultaneously ensures monolithic construction but the slab reinforcement is liable to be displaced. Whenever the slab and the beam rib are concreted separately the top surface of the rib should be cleaned and wetted so as to ensure a good joint between the members.

Slab should be concreted in one operation to the entire depth. The correct top level and thickness of the slab are obtained by a grading board being worked to the correct height of the adjacent slabs or other markings. To obtain level face and to guard against depressions in the middle of the panels, a small camber of 5 to 10 mm. is given to the beam. The joint in the day's work should be finished carefully and generally they should occur in the middle of the span of a beam. Due to the large area of concrete being exposed, the curing of slabs should be done effectively. Best method is to create small wooden bunds along the top surface and pond the water within them. Alternatively saw dust in wet state may be spread over the slab, frequent watering being essential. Top surface of the slab must be left rough so as to have a proper bond with any finish which is applied later on.

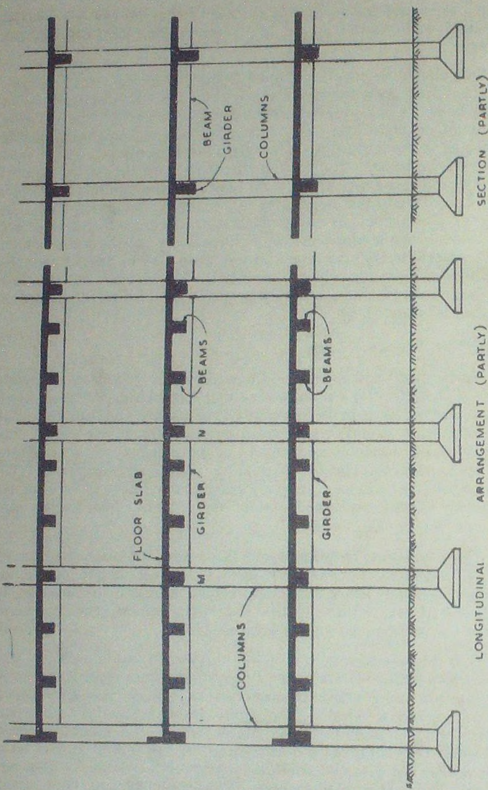
Framed buildings

Modern multi-storeyed buildings consist of reinforced concrete frames. These frames are units of columns and beams interconnected with each other so as to form a grid of the beams and girders. The slabs are built monolithically to carry the various floor loads. The foundations of these columns may be of individual type, a combined type or a raft foundation depending on the circumstances. The columns are the main load carrying members and have to be designed adequately to withstand the forces of dead loads, live loads, wind loads and earthquake forces.

The beams rest on girders and these form the main load transforming members to the columns. Whenever larger spans are involved, secondary beams spanning across the main beams can be introduced to take care of the load distribution, the slab being spanned across these secondary beams.

It is difficult to concrete such a building in one operation and hence construction joints are to be given at intervals. These joints are so located and constructed so as not to reduce the strength of the building as a whole. The joints in slabs, beams and girders should be vertical and at proper places where the shearing forces are least. The columns are concreted in suitable heights so as to give a proper lap with the sides of beams and columns which are going to come in the upper storeys. The section through the multi-storeyed buildings showing the slabs, girders and beams is shown in Figs. 1015-1016. In multi-storeyed buildings, to have rooms of smaller sizes within the floor area, it is necessary to create partitions which are of light weight materials and are of small thicknesses. Provisions are to be kept for lifts so as to transport people from one floor to the other.

The concreting of these buildings is done in a similar manner as described for individual units.



Figs. 1015 1016. R.C.C. framed building.

Reinforced concrete arches and rigid frames

The use of R.C.C. arches and rigid frame structures in building construction is becoming very popular. A simple type of construction consists of sloping roof with side columns built in a bent shape. Two beams are spanned across the main frame which in turn takes the slab. The side wall consists of thick R.C.C. slab spanned across the main frame. The frame itself is a continuous beam running from one footing to the other. To reduce the stress, the footing ends may be hinged with the aid of suitable constructional devices. Openings are left within side walls for doors and windows. A suitable flooring can be given. This type of frame work is suitable in

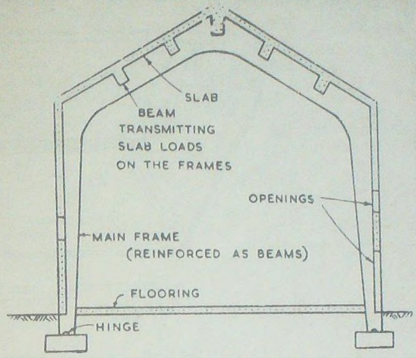


Fig. 1017. A reinforced concrete rigid frame building.

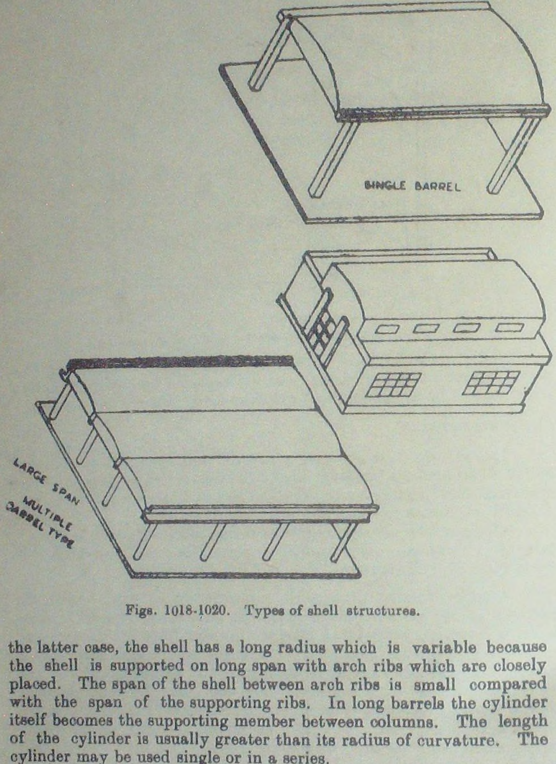
small buildings which have to act as sheds and warehouses. This portal frame, bent in shape, can be replaced by any arch section which would be continuous and can take loads in a similar manner.

Shell structures

Due to large floor spans being covered uninterrupted by columns and for economical reasons, shell roof is becoming very popular for industrial buildings, research labs, hangers and other large buildings. A shell structure consists of relatively thin slab which is curved in one or both directions and may be stiffened along its edges to maintain its curvature. Appreciable reduction of dead weight results by the use of shell structure.

A major portion of a shell is subjected to compression on account of the peculiar shape which has been given to it. Concrete being a very good material to take compressive force, its use in shell structure is evidently economical. The cost of the shell structure is further lessened as a number of them have to be constructed and the centering can be repeated every now and then. The maintenance cost of the shell structures is least. The economy of steel is an advantage. The floor space can be advantageously used because larger spans can be created with lesser columns. A good ventilation is available in the greater space volume which is created in a shell structure. A better appearance and good reflecting surfaces are possible. The construction of a shell can be carried out rapidly if proper care is taken to execute the job.

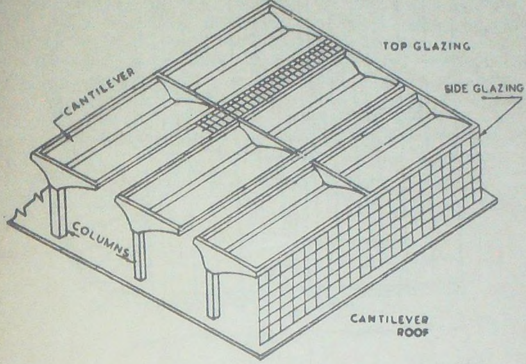
Many varieties of shell structure have been built and various shapes are always being developed. Shells of double curvature have been built in many forms such as domes of circular, elliptical or polygonal shapes, concoidal forms providing north lights, hyperbolic paraboloids and others. The shapes of the majority of shell roofs are of single curvature consisting of either long or short barrels. In

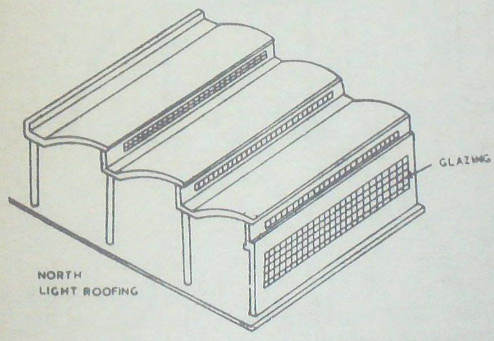


Figs. 1018-1020. Types of shell structures.

the latter case, the shell has a long radius which is variable because the shell is supported on long span with arch ribs which are closely placed. The span of the shell between arch ribs is small compared with the span of the supporting ribs. In long barrels the cylinder itself becomes the supporting member between columns. The length of the cylinder is usually greater than its radius of curvature. The cylinder may be used single or in a series.

Shells are used for covering the floor spaces in factories and as such they have north light arrangements. These shells have got edge beams at the ends and provision is kept for the lighting in the sloping walls of the roof. North light shell construction is very economical. Similarly cantilevered roof type shells are used for factory areas. In this type of construction, the shell roof is cantilevered out from a series of columns. For rigidity, ribs are introduced across the length of the shells for spanning this type of structure.

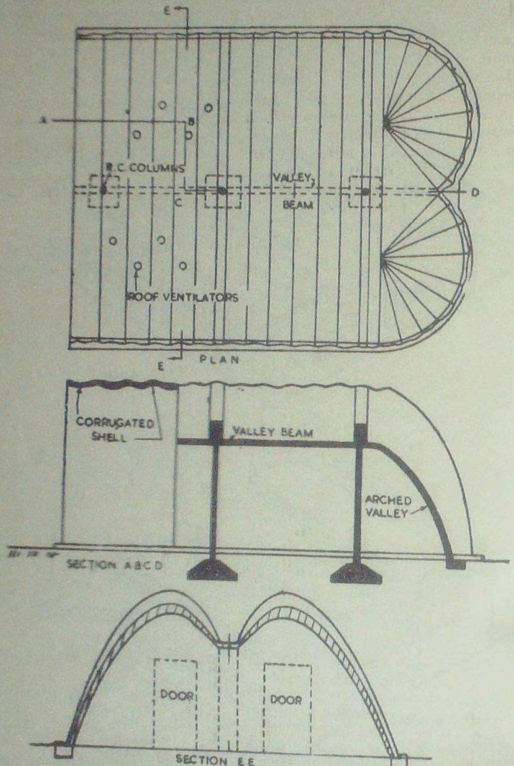




Figs. 1021-1022. Types of shell structures.

Special shapes are being developed which include the doubly curved shells, shells in the form of the spherical triangles, etc.

Similarly corrugated shells are used for economical reasons. Figs. 1023-1025 show the twin cteisphon shell which is of corrugated type and has been built at the Central Building Research Institute, Roorkee. The depth of corrugation determines largely the rigidity of the arch ring. This depth must be increased as the span increases.



Figs. 1023-1025. Details of cteisphon shell roof (corrugated type).

Generally 20 cm. depth of corrugation is adopted for spans up to 10 m. and may be increased to as much as 60 cm. for a span of 25 m. Multi-span corrugated shells are used to cover greater areas. These corrugated shells can be used for small low cost houses. They are provided with suitable ventilators and windows.

The construction of shell roofs is not difficult but they demand careful designing and handling of formwork. After a shell structure is designed the most important factor that governs its cost is the type of formwork which is used. The formwork structure must be so designed that repeated use of the same form becomes possible. In case larger units of formwork are adopted they lead to practical difficulties in handling them carefully. Mobile forms are generally used and these become specially convenient when the shell structure consists of one or more unbroken barrels with the smooth unobstructed units. Patent formwork which may consist of tubular steel fittings is increasingly used in the shell construction in other countries. Similar type of formwork has been used for corrugated shells at Roorkee. To reproduce the exact shape of the shell, a skeleton of a few arch ribs, which are prefabricated in the workshop and of straight tubes, is used. The ribs determine the type of longitudinal corrugation of the structure and the distance at which these are erected forms the basis of the depth of corrugation in the final

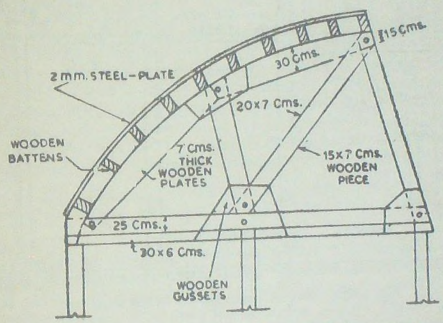


Fig. 1026. Wooden formwork for north light shell roof.

structure. These ribs are joined at the site and erected in true verticality. The ribs are secured by means of runner pipes and couplers. Hessian of about 2 m. in width is fixed at the ground and worked down along the bottom of the ribs on one side and at the other it is taken down to the valley beam. The concrete is cast over this hessian after a coat of cement wash has been given.

Wooden formwork can also be used for shell structures. The type of formwork for a north light shell is shown in Fig. 1026 and for a barrel shell is shown in Fig. 1027. The essential features of this type of formwork consist of wooden trusses which have been built to the required shape and are spaced at suitable intervals.

Suitable batten or sheeting is laid on these at the top. The curved surface may be formed by fitting 2 mm. steel plates to these battens. The top surface on which the concrete is placed should be covered with a thin coat of crude oil or a special solution so that the concrete when laid will not stick to the forms. The removal of the forms is thereby facilitated. The vertical posts or *ballies* supporting the formwork are usually rested on wooden wedges which are supported on wooden planks or otherwise so as to prevent the settlement to a great extent.

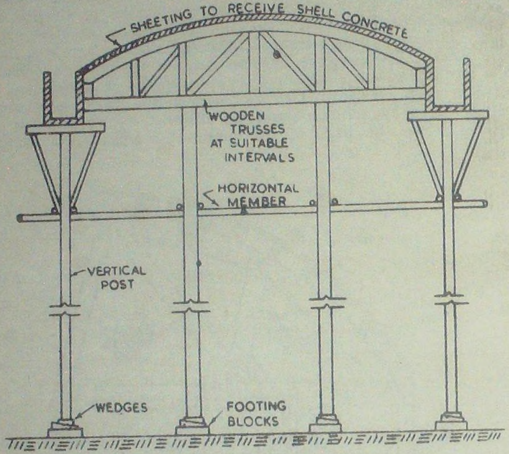


Fig. 1027. Wooden formwork for barrel shell roof.

Concreting of shells may be done in one thickness or in two or more layers in case the cover to the steel cannot be given properly. Richer mixes of concrete are usually adopted. The concrete is started from the edge beams or the end frames. Whenever concreting is restarted, thick slurry of cement is applied at the joints after cleaning them thoroughly. Suitable markings should be erected at intervals so that the exact thickness of the shell is obtained. The reinforcement should be placed carefully and its exact position may be marked with chalk on the formwork.

Prestressed concrete construction

Prestressed concrete is more economical for building construction wherever large construction is involved or whenever the handling costs are less and also where it is difficult to erect shuttering. Prestressed concrete has been used in the construction of building components like columns, beams, slabs, etc. Large areas can be covered without the use of interior columns by prestressing. Similarly ... are also being used for economical construction. Basically two methods of prestressed concrete are used, one is the pre-tension method and the other is the post-tension method. In the pre-tension method the high tensile steel is placed in the formwork so that it gets stretched. When the concrete is hardened it is released and transfers all the forces to the concrete. This type of a member when used to bear the forces of bending can stand much greater loads as the stresses which are introduced in the concrete under load are opposite to that of the stresses created by the prestressing, thereby large savings in sections are possible. Since the dead weight of the structural members gets decreased considerably it is possible to use lighter sections and thereby more economy is possible. In the ordinary reinforced concrete work we cannot economically make use of higher strength of the concrete as the steel needed for such type of work would be excessive whereas in the case of prestressed concrete we can use a higher strength of concrete and thereby economise in the section.

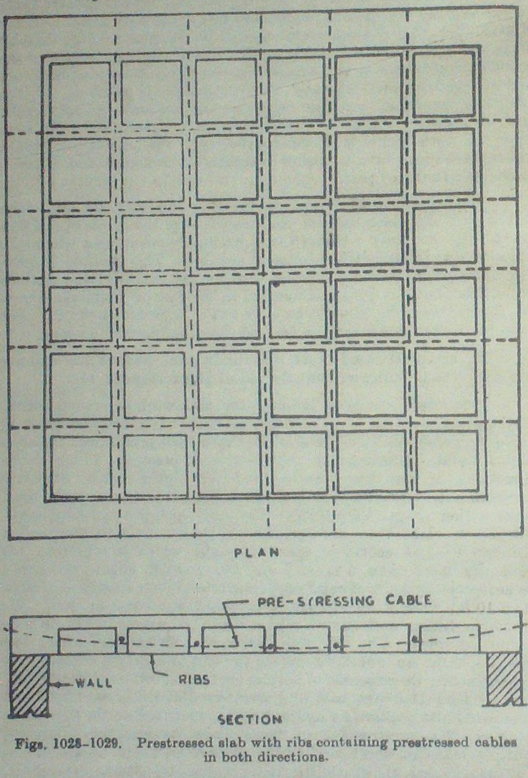
The other method of prestressing is by applying the pull to the cable when the concrete is set and transferring the forces of the pull on to the concrete member through suitable anchorages which are embedded at the ends of the concrete member. This method is gaining wider application for types of works which involve large sections to be used, but it is not so economical in the case of buildings wherein smaller sections have to be built but of a greater number. For building units the pre-tension method described earlier is used.

In all prestressed work the units are made earlier and are placed in the building without the aid of any formwork, etc.

Prestressed concrete is used for slab work in various forms. These slabs are not very economical but have been adopted in building construction. These slabs have been prestressed as continuous units. Alternatively they have been prestressed in both the directions so that they can be used for higher spans. Similarly projecting ribs can be added to these slabs to further economise their construction (Figs. 1028-1029). The only possible construction in the case of slabs is to have precast pre-tension slabs thereby saving the forms. The economic spans of slabs which are precast are generally more than 6 m. to 7 m. For smaller spans, slabs can be economically built of reinforced concrete. When spans are greater than 10 m. slabs even though precast would become too heavy for economic lifting and as such ribs as described above or beams have to be provided. The lift slab type of construction which has resulted from an effort to reduce the cost of concrete construction by eliminating the expenses of bottom shuttering can be of prestressed type. These slabs are cast and prestressed at the ground level and then lifted into position by hydraulic jacks mounted on the top of the columns. The prestressing of these slabs reduces the thickness, controls deflection and makes lifting more economical.

Prestressed floor or roof construction consists of small prestressed beams which are spaced at 1 m. to 1½ m. centres and are covered with precast reinforced slabs. For spans up to 7 m. or so the beams are precast and pre-tensioned in a factory. They are generally of a

T-section with a flange of about 12 cm. in width. Depth varies from 13 to 30 cm. depending upon the span. The slabs may be slightly reinforced if the span is more than 1 m. and the loads are excessive. The prestressed beams of smaller sections than specified above having a sort of I-shape are used for floor slab construction.



Figs. 1028–1029. Prestressed slab with ribs containing prestressed cables in both directions.

These beams are spaced at about 30 to 45 cm. centre to centre and hollow clay tiles are supported on the bottom flange of the beams. The top portion is then covered with a concrete topping (see Fig. 1031). ...eater than 8 m. post-tension primary beams are placed

7 to 8 m. apart and precast secondary beams are laid on the top of the bottom flange of these primary beams. These secondary beams are kept close with respect to each other and are covered with reinforced or unreinforced precast slabs as described above.

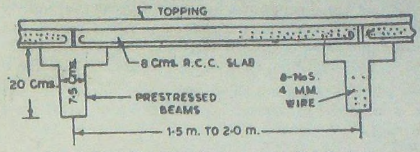


Fig. 1030. Prestressed beams with R.C.C. slabs.

For bigger spans, the beams may be of greater dimensions. These beams are usually of post-tension type and cast in situ. These beams

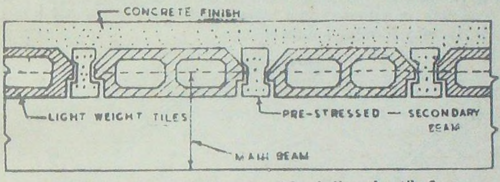


Fig. 1031. Prestressed beams with a hollow clay tile floor

have a sort of slope given to their top so that they have more depth at the centre of their span. I-beams are economical but for greater

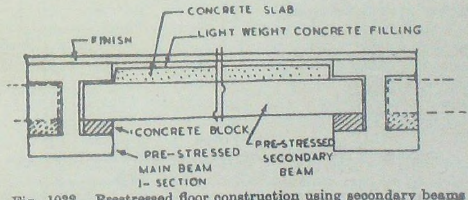


Fig. 1032. Prestressed floor construction using secondary beams and main beams.

economy the upper flange of the I-beams may be of greater width. Beams can also be of continuous type and the prestressing can extend throughout the length.

Although it is usually not necessary to prestress building columns, sometimes it may be economical to do so due to the excessive bending forces which the column has to resist. Prestressed concrete piles have also been built of large length as they are more economical. The prestressing technique has been extended to the use of shells, stairs, etc.

Precast concrete construction

Precast concrete members can be used for building construction to facilitate construction and economise in cost. As described earlier, walls of hollow block masonry are advantageous as they are easy to construct, are cheaper and have got a great thermal insulation effect. They considerably save mortar as compared to brickwork as the joints are lesser. Internal plastering is reduced as a good surface can be obtained with one coat of material only instead of two.

These blocks are built with concrete, the forms of which can be reused a number of times. Special types of forms are adopted keeping in view the types of hollows, etc., which are to be left in the blocks.

Precast concrete door and window frames can also be built. Steel bars of about 4 mm. to 4 cm. in diameter run through them. Suitable hard wood blocks are used for fixing hinges, etc., to them. The concrete is vibrated on a table vibrator as it is poured into the moulds, thereby forming a durable mix.

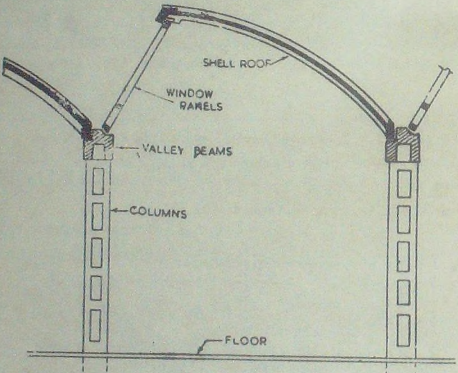


Fig. 1033. Precast R.C.C. north light shell roof construction.

Precast concrete can be used for roofing elements also as reinforced concrete battens can be used for flat roofs instead of wooden sections. They are also cast in special types of forms.

Plain concrete or lightly reinforced concrete can be used in the form of precast shells for roofing. Plain concrete, doubly curved shells have been developed at the Central Building Research Institute, Roorkee. While making them, a suitable frame is built over which hessian cloth is spread. This cloth has to be given a sort of sag and the internal tension is controlled by the depth indicating frame. Over this, a thin frame of about 2 5 cm. height is placed to retain the wet concrete and regulate its thickness. A piece of chicken mesh is next placed on the mould to act as a reinforcement. Cement concrete is poured over the hessian and manually compacted. The frame is rested to permit the hessian to sag with the wet concrete. Moulds are set up for the edge beams and suitable steel rods are placed within these moulds. These beams are then concreted. The beam sides are demoulded after an hour of casting. The unit is cured for about two days and is inverted for use. The final shape

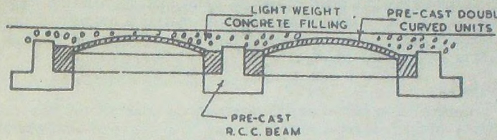


Fig. 1034. Doubly curved precast concrete unit.

of the unit as placed on small T-beams is shown in Fig. 1034. The top surface of the roof thus formed is wavy and as such the depressions are filled with concrete or earth so that a top level surface may be obtained. These units can be of 1 m. × 1 m. to about 3 m. × 3 m. in size.

Concrete finishes

Surface finishes may be obtained either from formwork or by surface treatments or by applied finishes.

The formwork finishes are the patterns which are created on the surface of concrete merely by the type of formwork used and no additional treatment is given. If proper care is not taken in the selection of a good formwork, the grains and many defects in the wooden boarding are reproduced. Twisted or warped wooden boards create uneven surface. Similarly honey-combing can be caused by the leakage of cement paste through the joints of the boardings. The effect of rough timber can be created deliberately by having boardings of unequal thicknesses.

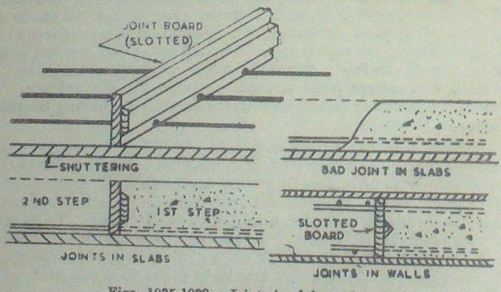
The boards may be chamfered at the edges so as to create small elevated lines on the surface of concrete. Fillets can be nailed over the concrete formwork to give an appearance of grooves along the surface of the concrete. A smooth surface can be obtained by lining the formwork with thin steel sheets or plywood. To prevent the reproduction of grains, plywood should be painted. Pleasing effects can be obtained by using linings of hessian inside the forms. For all types of linings, care should be taken that the joints of the linings are tight.

Surface treatments are sometimes adopted for giving a better appearance to the concrete. The simplest form of surface treatment is to remove the outer film of cement from the concrete and thereby expose the coarse aggregate. With all exposed aggregate finishes, it should be ensured that the concrete is well mixed and the external film is removed within 48 hours of concreting. The surface can be scrubbed with stiff brushes and water. Care should be taken to check up that concrete is sufficiently hard so as to prevent the dislodging of the bigger particles. Retarding agents which delay the setting of the cement can be applied to the internal face of the formwork and the outer surface can be demoulded easily later on. Similarly by washing the outer surface with a dilute solution of hydrochloric acid, the thin film can be easily removed. A bush hammer can be worked against the face of hardened concrete so as to create rough surface. Similarly the surface can be punched with chisels.

Applied finishes may consist of paints or application of thin coats of mortar. Over these coats of mortar a number of surface treatments can be given. These include the placing of pebbles or creating ornamental finishes.

Joints

Construction joints may be as strong as concrete in the other portions of structural members or may be a source of weakness due to faulty construction. A badly formed joint may allow water to enter and subsequently lead to defects. The first step in preparing the construction joints is to remove any laitance, scum or other loose concrete. The exposed surface of the old concrete should be thoroughly wet and given a grout of neat cement and an application of 1 : 2 cement sand mortar immediately before placing the new concrete. The grout and mortar application should be kept as thin as practicable as otherwise the line of the joint will be emphasised on the finished surface. A solution of hydrochloric acid and water is sometimes used in place of hammering to remove the cement on the exposed face at the construction joint but care has to be taken to remove all these acids completely before the grout is applied. As



Figs. 1035-1038. Joints in slabs and walls.

far as the profile of the constructional joint is concerned, the keyed joint is better indicated in Figs. 1035-1038. Suitable boards should
abs and bars should be allowed to pass through.

Construction joints should be reduced to a minimum and their position should be predetermined after careful consideration. The amount of work to be done each day should be decided and this should decide the position for the joints. Primarily the joints should be at the section where the shearing is minimum and the face of the joint should be perpendicular to the compressive forces in the member. Thus for the beams, the joint should be at the centre of the span or at the most within the middle third. The face of the joint should be vertical. If the joint in the slab is made normal to the main reinforcement, it should be placed at the centre of the span but if it is placed parallel to the main steel it may be placed anywhere so long as it is not nearer than 8 times the thickness of the slab from the edge of the parallel beam designed as a T-beam. When concreting columns, the constructional joint should be horizontal and placed a few cm. below the beam intersection. In framed buildings the constructional joint should be at the joint of counter-flexture or alternatively at a place of maximum shear.

The necessity of introducing permanent joints in reinforced structure is to allow for shrinkage, temperature changes, settlements etc. Joints in retaining walls and floors laid on solid ground must be defined correctly. Joint should be placed where concrete in one operation can be completed and thus the joining becomes obligatory. Joints are also placed where the marked reduction in the width of the slab occurs. The simplest type of joint such as that which occurs between panels of slabs laid directly on the ground may be a dry-joint. The stopping board at the end of one period of concreting is removed, the strip of water proof-paper may be placed at the end before placing the concrete in the adjacent panels. In place of water-proof paper, felt or bitumen sheeting may be used. Sometimes a gap of 5 mm. to 10 mm. is left between adjacent panels and these gaps are left open or filled with asphalt or a mixture of sand and asphalt. The joint in the roofs should be water-tight and copper strips or water bars are sometimes placed. For simpler work, rubbed or coated joints may be given. The joints in the external walls of buildings must be protected from the effects of weather and as such a simple joint behind an external column is used. A more effective joint is by incorporating a copper strip, ends of which are greased and are free to move whenever movement starts to take place.

QUESTIONS

1. What is the advantage of reinforced concrete construction ? Describe briefly one of the methods for designing a concrete mix.

2. Describe briefly the steps in the preparation of concrete with the aid of modern mechanical appliances.

3. What are the various methods for transporting concrete ?

What is the advantage of the compaction of concrete ? Briefly describe the various methods of compacting concrete.

4. Draw neat sketches of R.C.C. column with the details of reinforcement in footings and junctions with beams. How is the concreting of columns and beams carried out ?

5. Write a brief description of the various types of R.C.C. shells used in building work. Illustrate your answer with sketches.

6. Write short notes on :
   (*i*) Joints in concrete work.
   (*ii*) Concrete finishes.
   (*iii*) Precast concrete construction.
   (*iv*) Utility of prestressed construction in building work.
   (*v*) Curing of concrete.

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17

FORMWORK

Concrete construction in the modern building work has assumed a lot of importance and is being used to a great extent. Concrete, being a plastic material in the green state, has to be kept within an enclosure till it gains strength. This temporary structure which has to be built for any concrete member is called formwork. Timber is the most common material used for formwork construction. It is easy to work with and is also cheap.

The timber to be used should be free from knots and should have coarse grains. Hard woods are not used as they are difficult to be worked and nailed. Partially seasoned timber is best for formwork. Too dry timber will tend to swell with moisture while green timber will tend to dry and shrink in hot weather causing ridges on the concrete surface. Timber of a particular size should be finished to a uniform thickness so that all the pieces match together.

The use of steel forms has been on the increase in recent years. They can be obtained for all types of structures and in finished forms. The initial cost of such forms is very high but they can be repeatedly used for a number of times. Hence they are suitable for larger works only and not for small structures involving the use of a particular form only once or twice. Steel forms can be easily erected and do not need many adjustments as they are available in standard sizes. Their erection is very mechanical. Another advantage of steel forms is that they give smooth surfaces which require very little of finishing work later on.

Requirements of formwork

(1) *Formwork must be strong* : This is very essential as it has to bear the weight of concrete which weighs about 2400 kg./m^3 and exerts a lot of pressure on the members surrounding it while it is in the wet state. Resistanee to this outward push is achieved with the aid of adequate bracings and by the use of wires which get embedded in the concrete and are fastened to the outer side of the formwork.

(2) *Formwork must be smooth* : It is always desirable to have smooth surfaces on all concrete structures. This is especially desirable on exposed concrete work. All the impressions which are visible on the surrounding formwork will get transformed on to the concrete.

(3) *Formwork should be true* : This means that the formwork should be erected in such a manner that all the faces of concrete are true with respect to the drawings. For example, the side formwork of footings and walls must be absolutely vertical. To get a true surface, it is also essential that no cracks are present within the formwork as concrete is likely to flow through them thereby causing a rough surface on the outside.

(4) *Formwork must be easily removable* : Formwork should be constructed in such a manner that it can be removed easily without damaging it. It should be constructed in such a way that the nails or screws driven through it do not interfere with its removal.

Footing Forms

There are various types of forms used for footings depending upon the type of construction. Some of them are described below :

(1) *Wall footing forms* : These are the simplest to be built and consist merely of a heavy plank put in position to the required line. One side is set to the line initially and held with stakes spaced at about 2 m. apart and the other side is set from this with the aid of spreaders at a correct distance equal to the width of the footing. These spreaders are knocked out as concreting reaches them. For footings up to one metre in depth the sides are made of 2·5 cm. thick timber pieces built into panels about 2.5 m. long with battens in the centre to hold the boards together. These panels can be held to line by 5 cm. × 10 cm. wallings which can be braced to stakes or sides of the panels. (See Fig. 1039).

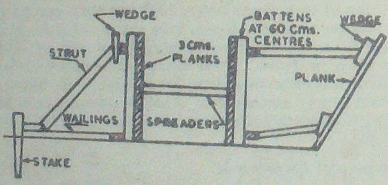


Fig. 1039. A typical form for a wall footing.

(2) *Column footing forms* : They are of the following types.

(*a*) *Square or rectangular* : The ends are built to the exact dimensions of the, footing with a cleat at each end of the footing from the outside. The other two sides are built about 30 cm. longer than the dimensions of the footing. The side and end panels are made on the carpenter's bench with holes bored for the wires, if they are to be used. Four panels are assembled by butting the end panels against the end cleats of the sides and are nailed. The corner should be braced back to stakes or to the sides of the excavation. The intermediate bracing should be done in similar manner or the cleat wired as shown in Fig. 1040.

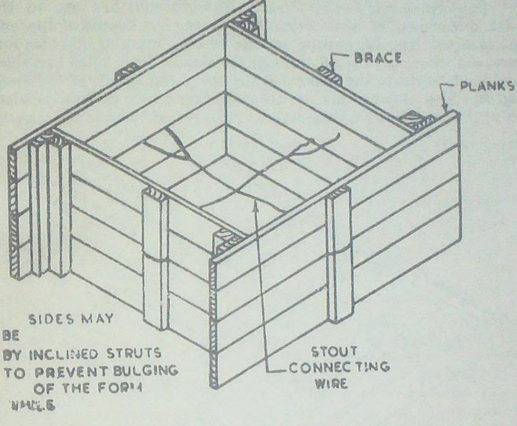


Fig. 1040. A typical column footing form.

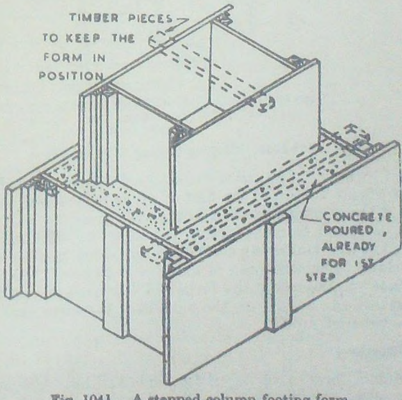
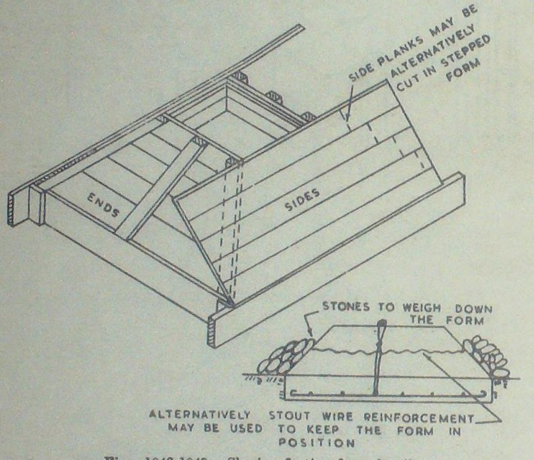


Fig. 1041. A stepped column footing form.

(b) *Stepped footing forms* : These are of similar construction as described above, the largest and the lowest forms are placed first and the concrete is allowed to set a little before placing the next form. The upper form can then be held by placing a 5×10 cm. wooden piece nailed on to the top ends of the lower form.

(c) *Sloping side footing forms* : The two ends are cut to the exact dimensions of the footing, first laying out boards of approximately equal lengths, putting on the cleats, marking the sloping lines and then sawing off through the sloping line. The two sides should not be cut to the slopes but the board can be left of different lengths. The sloping box is always set on a very shallow vertical box of the same bottom dimensions. The vertical box is set on the

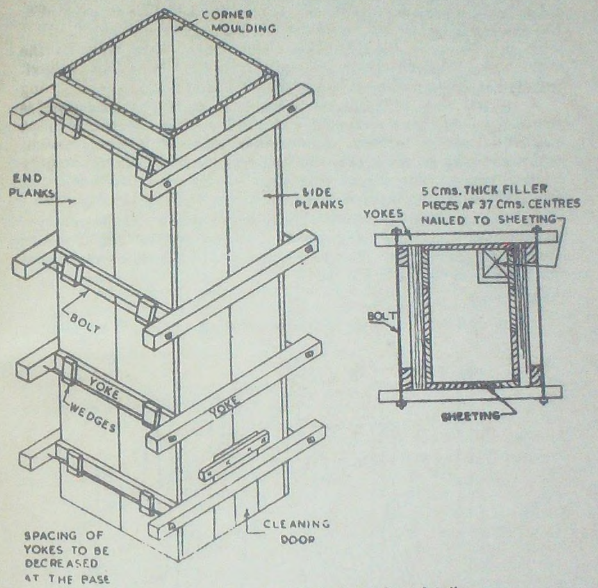


Figs. 1042-1043. Sloping footing form details.

ground and braced. The reinforcing steel is then placed and the sloping box set on the top of the first one. It is essential to prevent the lifting of the sloping sides due to concrete pressure. To prevent this uplift, wire can be embedded in the centre of the lower portion and fastened to the reinforcing steel or to any other heavily anchored member below. The other end of the wire is twisted around a piece of timber fitted to the top of the form. A few bags of sand, cement or heavy stones can be laid on the outside of the form over its sloping sides to prevent uplift.

Column forms

A column form consists of two ends and two sides each built as a unit or panel, the height of the panel being the storey height less the slab thickness and the floor sheeting. The two ends are built in width equal to the dimension of the column plus twice the



Figs. 1044-1045. A typical column form details

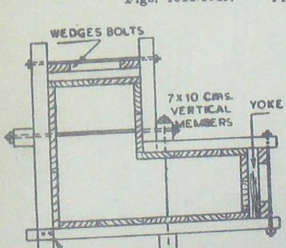


Fig. 1046. A typical L-shaped column form.

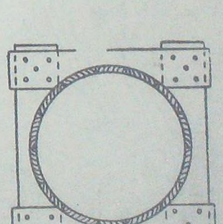


Fig. 1047. Form for a circular column.

thickness of the sheeting, the ends of the yokes and sheeting being in flush. The two side panels are similarly made but the width of the sheeting will be the same as the dimensions of the column and the yokes will project 20 to 25 cm. beyond the sheeting at each end. The spacing of yokes will be similar on both ends and sides. Bolt holes are bored in the side yokes about 3 mm. larger than the size of the bolt. Their spacing is calculated from the size of the column and timber used allowing about 4 cm. for wedging.

In the case of L-shaped column, a similar arrangement is followed except that a rectangular block of wooden sheeting is made inside the square column. This corner piece is made by nailing timber sheeting on the yokes. This arrangement is suitable for only small columns. For bigger columns, the formwork itself is made into L-shape and bolts are fixed at the corner as shown in Fig. 1046.

Wooden forms for round columns are used to a very less extent. The sheeting is cut into small widths so that it can be joined easily into a circular shape. The yokes have two different arrangements one of which is shown in Fig. 1047.

Wall forms

The wall form consists of timber sheeting supported by vertical

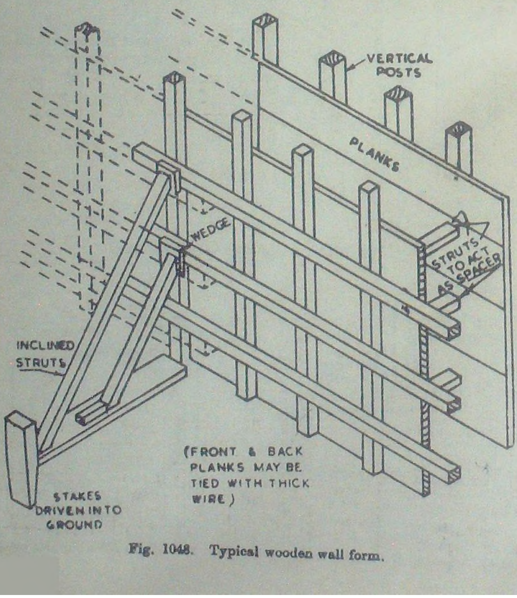


Fig. 1048. Typical wooden wall form.

studs and horizontal wailers. The studs are first set to line and temporarily braced. The sheeting is wailed lightly breaking joints preferably at the studs. If the wall is narrow and heavy reinforcement is to be placed ; one side of the wall form is completed first and the other side placed in position after the reinforcement has been laid. Spacers are used at about one metre distance vertically and knocked out when the concreting reaches to that level. If the wall is wide enough for a man to work inside, both sides may be brought up together.

To keep the two sides of the form at correct distances apart, it is necessary to employ some method of tying them up. For accurate and important work, bolts should be used while for ordinary work wires are generally employed. On large works where wall forms can be used several times, it is better to build them in panels. This has also the advantage that the panels can be made in advance and erection time saved. The size of these panels will depend upon their weight and generally 2½ m. × 2½ m. and weighing about 250 kg. are used. In this case the wailings are put on during erection and should be long enough to overlap the end studs of the adjoining panel.

Beam and slab forms

In monolithic concrete construction, beams or girders and slabs are cast as a single unit. This means that the beam formwork will be continuous with that of the slab formwork. To facilitate construction, the slabs can have their plank formwork made into panels. The size of these panels depends upon the facility available in lifting them. Two arrangements of supporting the slab formwork are usually adopted. In one case, this planking is supported by means of a wooden centring on the floor below. In the second type, these panels rest on the top of the beam and girder sides. The boarding of these panels is nailed together with the aid of battens.

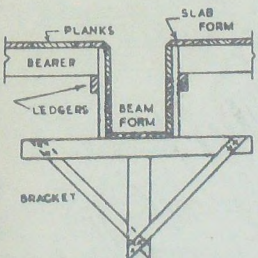


Fig. 1049. Typical beam formwork.

The beams and girders are cast within rectangular boxes shaped to the exact dimensions of the rib. The depth of the side planks will be kept as the distance from the underside of the slab sheeting to the bottom of the girder. The sides should never bear on the bottom plank of the girder but must overlap it as otherwise it is difficult to open the side formwork earlier. These planks are also nailed together with battens spaced at 30 to 45 cm. centres, using closer spacing and thicker battens for deeper beams.

To support the beams, vertical posts are used. To the top of these posts is nailed a cap of the same size as the post and about 40 cm. to 45 cm. longer than the width of the beam. The ends

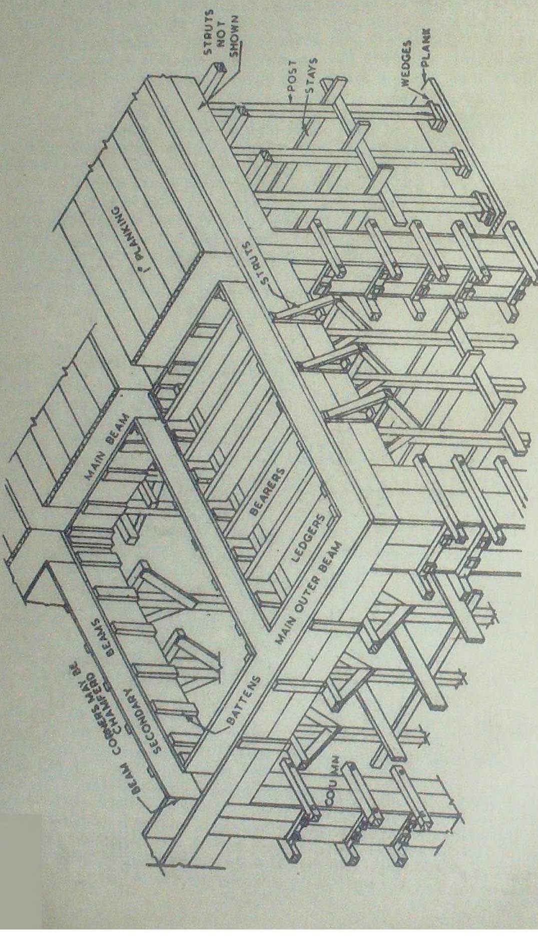


Fig. 1050. A detailed layout of the beam and slab formwork.

of this cap are diagonally braced back to the post by short pieces of timber. These posts should be cut off square so as to ensure proper bearing to the beams. The posts generally rest on wedges which are of hard wood and these wedges are further placed on a sill. The size of the sill is so calculated that the pressure on the soil does not exceed one kg./cm². If the length of these posts exceeds $2\frac{1}{2}$ m. then they should be braced horizontally and/or diagonally with each other.

In the erection of this formwork, the outside wall columns are first set in plumb and on these are placed the beam bottoms all round the building. These bottoms are properly supported with the aid of posts, wedges and sills. The girder sides are then lifted into place and lightly nailed to the bottom to hold them temporarily and braced across the top to prevent spreading. The beam bottoms between girders are next placed and shored up, followed by the beam sides. To prevent the sides of the beams and girders from spreading, these sides are held by a spike with the post cap. For deeper beams it is necessary to use bolts or patented clamps. The slab formwork is next erected followed by the strutting of the posts.

The length of time for which the form must be left in place before stripping depends upon many conditions, *e.g.*, the loads to be taken by the members, position of the form, temperature of the atmosphere, subsequent loads on the member, etc.

All formwork should be immediately cleaned after it is removed.

Other types of formwork

Stair forms : Stairs are designed to be self-supporting longitudinally from floor to landing or across wall to wall. The sloping slabs are supported by planking which is further supported on battens and posts. To give shape to the stringers, inclined planks are fixed and to these are fitted small battens against which vertical planks can be fitted to make the steps. The arrangement of a typical stair formwork is shown in Fig. 1051.

Ribbed floor formwork : It would be uneconomical to cut the formwork exactly to shape of the webs of the beams. Hence over a plank sheeting, fillers are used to take the space which would be left in between two beam ribs. These fillers may be of metal, wood, clay tiles, gypsum blocks, etc. The fillers may be left in place or removed. Removable metal fillers are economical because they can be used many times. To enable these fillers to be used for different works, they are made deep enough to suit several depths of joists and adjustable wooden battens are fitted to act as bottom.

Steel formwork

The use of steel formwork is increasing in modern building construction. Wherever the work is large, these forms are economical and also possess the advantages specified earlier. Steel formworks are very useful for round columns and caps as a very good shape can be obtained by their use. They are also used for flat slab construction. Slab panels are made up of 0·5 m. square plates with ribs. These need shoring from bottom as a support. Various systems of joists have been developed which will span the walls without any vertical support. The advantage is that no load is taken by the floor below and workmen can carry out their work without hindrance. Telescopic forms of these joists are becoming increasingly popular. Lattice girder made of very thin sections can also be used as supports. Light wall panels about 0.5 m. in size are made up of sheet metal with steel angle stiffners fastened together by clamps, wedges etc. They are made in standard sizes so that any

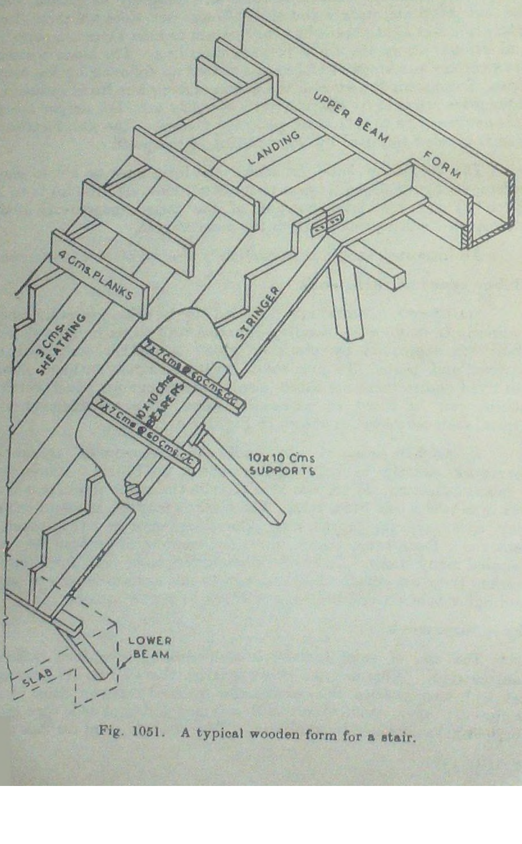


Fig. 1051. A typical wooden form for a stair.

length of the wall can be made and abjustable pieces can be used for odd lengths. Two or three courses are used one above the other, concreting 1·5 to 2 m. on the first day and 0.5 to 1.5 m. on succeeding days, the forms being stripped aftor 24 hours.

Form linings

These may be needed for the purpose of providing smooth surfaces or special markings on the concrete surface. Ordinary planks always leave ridges and fins and reproduce their grains even though the work is carried out with exceptional care. In order to minimize these defects and reduce the cost of finishing, smooth surfaces are obtained by the use of paper, sheet metal, plywood, hard-board as the linings. Water-proof paper of great toughness and durability is used and is available in rolls. Sheet metal of 22 or 23 gauge either galvanised or black with greased surface is used. Plywood is a very satisfactory type of lining and is available in several thicknesses. As plywood has got greater strength, it may be possible to space form boards at 5 to 20 cm. apart depending upon the load so as to economise the cost of formwork. Grainless boards have been used recently and they have better adaptability than even plywood.

Removal of Forms

In normal circumstances (generally where temperatures are above 20°C), and where ordinary cement is used, forms may be struck after expiry of following periods :

(*a*) Walls, columns and vertical sides of beams	24 to 28 hours as may be decided by the engineer-in-charge
(*b*) Slabs (props left under)	3 days
(*c*) Beam soffits (Props left under)	7 days
(*d*) Removal of props to slabs :	
(1) Spanning upto 4.5 m	7 days
(2) Spanning over 4.5 m	14 days
(*e*) Removal of props to beams and arches :	
(1) Spanning upto 6 m	14 days
(2) Spanning over 6 m	21

For rapid hardening cement 3/7 of the above period will be sufficient in all cases except vertical sides of slabs, beams and columns which should be retained for 24 hours.

After removal of form-work, all concrete is carefully ins and any defective work or small defects are either removed or repaired before concrete has thoroughly hardened,

QUESTIONS

1. What are the essential requirements of a good formwork ?

2. Give the details of the various types of formwork for footings. Explain your answer with sketches.

3. Write what you know about :—
   (a) Column formwork.
   (b) Wall formwork.
   (c) Stair formwork.
   (d) Ribbed floor formwork.

4. Write short notes on :—
   (a) Steel formwork.
   (b) Form linings.
   (c) Removal of forms

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18

PLASTERING AND POINTING

Plastering is the method of covering various components of a building with a plastic material to form a durable surface. This material may have such a surface as to form a decorative finish or may be treated further. The object of external plastering is to cover the surface to enable it to resist the atmospheric influences, particularly the penetration of rain. The object of internal plastering is to provide a smooth surface in which dust and dirt cannot lodge. This surface is also not liable to be affected by vermin and forms a good surface for taking colour wash, distemper or a paint.

The prime consideration in plastering is that it should adhere to the background and should continue to do so while changes of weather frequently occur. It should also be possible to apply the plaster during all weather conditions. For economic reasons, the materials adopted and the methods of application should be cheap. The type of plaster to be used at a particular location will depend upon the rainfall, the weather conditions, presence of frost, the amount of finish that it will have to take and the appearance.

Plasters usually consist of a binding material, fine aggregates and water. In special cases certain additives are added to effect an improvement in the plasters as far as its adhesiveness, life, etc., are concerned.

Various Terms

Some of the terms used in plastering are given below :

Background

The surface to which the first coat of plaster is applied.

Blistering

This is the development of one or more local swellings on the finished plastered surfaces.

Cracking

This is the development of one or more fissures in the plaster usually but not always localised in relation to and arising from the movements in the background or the surrounding structure.

Crazing

This is the development of a series of hair cracks on the finished surface plastered usually in a haphazard manner.

Dado

The lower part of the plastered wall where the plaster treatment is varied from the upper portion more often to give a resistant finish.

Dots

Small patches of plaster laid on the background used in fixing screeds, etc.

Dubbing out

This is the process of filling in hollow spaces in a solid background before the main body of the plaster is applied.

Finishing coat

The layer in which plaster is laid over the whole area is called a coat. In three coats work, it is the final layer of plaster which is laid. It is also called the setting coat, face or skimming coat.

Flaking

The scaling away of patches of plaster due to the absence or failure of the adhesion with the previous coat.

Float

This is a tool used in plaster work normally consisting of a flat wooden board with a wooden handle grip. Cross-grained float is the float having grains of wood running across the face of its blade. A two handled float used for levelling surfaces is called a *Darby*. The float used for scratching the surfaces to form a key with the next coat has got a few nails protruding from its surface.

Gauging

The mixing of various constituents of plaster is called gauging.

Grinning

This is appearance on the surface of the plaster of the pattern of joints or similar patterns in the background.

Grounds

This term is applied to the wooden strips fixed to the background and to which primary finishing may be secured.

Hacking

The roughening of solid backgrounds to provide suitable key for plastering is called hacking.

Keys

These are the openings or indentations on the surface of under coat or background on which plastering material can be pressed in a manner that it will form a mechanical bond with the surface so prepared.

Laitance

This is the thin layer consisting of fine cement particles which form a screen on the surface of the fresh laid concrete when subjected to excessive trowelling.

Pattern staining

This term is applied to the type of staining which occurs when the two sides of a composite structure are constantly exposed to different temperatures. The cause of such staining is the preferential deposition of suspended particles on the surface of those portions of the structure which on account of higher thermal conductivity are cooler.

Peeling

Dislodgment of plaster work from the background.

Under coats

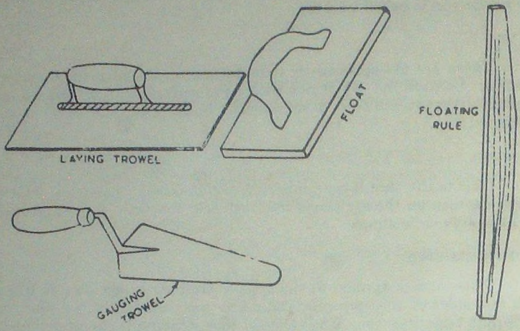
These are plaster coats, the main function of which is to provide for the application of succeeding coats. The first coat is applied to the building surface and is also called the rendering coat or the pricking up coat when it is applied on to lath work. The second coat is applied to bring the first coat to a true and finish surface.

Tools used in Plastering

Laying Trowel : This is used for spreading or laying material and for trowelling so as to get the desired finish. The blade is made of thin tempered steel and is of about 30 × 10 cm in size. For good work, two types of trowels are used. The first one with a stiff plate is used for applying the rendering and the second has got a thin blade which has a slightly springing action and is used exclusively for finishing coat.

Skimming Float : This is similar to the laying trowel but is made of wood. It is used for the finishing or the setting coat. The grains of the blade run length-wise. This varies in size from 30 × 10 cms. to about 33 × 11 cm. and is about 10 to 12 mm. in thickness.

Devil Float : This is similar to the above type except that it has got nails projecting by about 3 mm. from the surface. It is used for scratching the plastered surfaces so as to form a key with the subsequent coat.



Figs. 1052-1055. Some of the tools used in plastering.

Felt Float : A skimming float is covered with a layer of soft felt and this is used for scouring plain surfaces.

Gauging Trowel : This is used for gauging small quantities of materials on other tools for applying plasters to mouldings or to awkward places like corners etc. This is available in sizes varying in length from 15 to 45 cm. ; the ends of the blades are pointed or bull-nosed.

The other types of tools which are commonly used are joint rules, straight edges, scratchers, brushes, spirit levels, plumb rules, set squares etc.

Materials used for plastering

(*a*) *Binders*

(*i*) *Hydrated Lime* : When dry hydrated fat lime is mixed with water, it forms a solution of calcium hydroxide. When a mix in which lime is suspended is brought up to a high suction background, part of the water is drawn away while remaining part, *i.e.*, the free water, can evaporate. The mix then falls short of water and part of the dissolved lime crystallises. This process of drying and crystallisation gives the lime mix its initial strength shortly after plastering. Crystals of calcium hydroxide are formed. Some part of the lime forms silicates in contact with silica contents ofthe plaster while other parts of lime form carbonates by absorbing carbon dioxide from the atmosphere. The carbonation is usually very slow and depends on the per cent of calcium hydroxide present. The porosity of the mix is an important factor. Thus in the case of lime mortar at early stages, a porous type can be carbonated greater than that of a denser mix. The effect of the relatively slow carbonation is more effective near the layers farthest away from the surface, *i.e.*, in contact with backing. At this layer the carbonate remains in a very weak condition for a long period after the plastering has been applied and this leads to weakening in adhesion between the plaster and the backing material. Burnt lime can be slaked in a pit with lot of water so as to form a lime putty. Dry slaking process incorporates the use of just sufficient water which produces dry particles which must be spread otherwise they might lead to expansion and blows. Whenever the binding water is not necessary, lime putty can be used but in certain cases like lime surkhi, sand and lime, dry slaked lime can be advantageously used.

Hydrated lime in other countries is thoroughly slaked under controlled conditions by the manufacturers and is made available in the final form packed in strong paper packets.

(*ii*) *Hydraulic Lime* : If lime contains silica and alumina soluble in hydrochloric acid it has certain hydraulic properties which enable it to set under water. Mortars made of such lime are comparatively more suitable for use in external plastering. When it hardens, a part of the strength is due to carbonation and a part is due to hydrated strength on account of the formation of silicates and aluminates. Fat lime can be rendered to have hydraulic properties with addition of puzzolanas like surkhi or cinder. Hydraulic lime is not wet slaked but generally dry slaking is resorted to.

(*iii*) *Portland Cement* : Portland cement is commonly used as a binder for plaster work. The addition of cement makes it possible for setting under water. Pure cements are not usually suitable for plastering because they are difficult to work. In order to increase the workability of these mixes small amounts of hydraulic limes should be added. Up to 10 per cent addition of lime by weight is considered harmless to the strength of the mix. Improvement in the workability of cement plasters can also be made by adding air entraining agents. These might reduce the strength of the mix but they help to a great extent in the easy application of plastering. Water repellent agents can also be used to prevent the passage of moisture into the plaster.

(*b*) *Sand*

The only aggregate used in plasters is sand. This forms the greatest proportion of the plaster mix. The sand particles should be so graded that the binder can act as an adhesive and not merely as a filler. The object of sand is also to reduce the shrinkage of the binders. The porosity and strength of the plaster depend to a large extent on the quality of the sand. The grading of the sand and the workability of the plaster mix have a great effect on the adhesion of the plaster with the backing. The sand should be free from any organic matters, or harmful impurities. The maximum size of the particles should be limited to $\frac{1}{3}$ to of $\frac{1}{5}$ thickness of the plaster coat. The grading of sand normally recommended for different plaster coats is given below :—

SAND		% passing I.S. Sieve No. with their equivalent B. S. Sieve No.							*Silt & Clay*
		IS. B.S.	480 3/16	240 7	120 14	60 25	30 52	15 100	
Plastering (Under coats)	Min.		100	98	80	30	5	0	Not more than 5%
	Max.		100	100	95	85	50	10	
Plastering (Finishing coats)	Min.		100	100	95	30	5	0	
	Max.		100	100	100	85	50	10	
External Rendering	Min.		100	90	70	40	5	0	
	Max.		100	100	100	85	50	10	

(c) *Surkhi*

This is a material obtained by powdering burnt clay or bricks which are usually made from a clayey soil. The use of surkhi is mainly dependent upon the fine fractions consisting of secondary clay minerals and the presence of silica in such a state that their reaction with lime proceeds with adequate speed. The rate of strength is governed by the fineness of grading. Surkhi used in plaster should be all passing a sieve No. 120 and with at least 50 per cent of it passing through a 240 No. sieve. The soluble contents of salts should not be greater than 2 per cent by weight.

(d) *Cinder* :

Cinders or ashes containing lime give moderate hydraulic properties. They should be clean and must pass completely through a No. 240 sieve. Excessive unburnt carbon particles make it impossible for the cinders to be used in mortar in a wet condition. In places where exposure to moisture is expected the combustible content of the cinders should be below 10 per cent by weight. In internal application the combustible content can be greater and may be as large as 20 per cent.

Other admixtures can be added to different mixes of plasters so as to increase the workability, to increase water penetrating quality or to increase the strength. Such mixtures or compounds are available in packed containers and can be readily mixed at site.

Design Considerations for plastering

The following features have to be kept in view while selecting a suitable plaster and applying the same.

(i) *Combinations of under-coats and finishing coats, etc.*

Under-coats and finishing coats should have a good relation with each other and also with the background as regards density, strength, liability to expansion or contraction during setting or afterwards. Bond failure between the successive coats may be caused by the defects in the background or under-coats, presence of unset films of plaster produced by premature drying, salt formation at interface, excessive relative moisture movement or combination of these.

For obtaining a good mix the plastering mix must have definite properties which make it suitable for particular conditions. The properties of different types of mixes are briefly reported below :

(a) *Mix based on cement and lime or hydraulic lime for strength.* Mixes containing cement, lime and sand have got high workability and therefore are easy to apply. They can be used reasonably after long working time. They have adequate early strength to withstand modern building conditions. For setting, they need moisture and rapid drying in the initial stages must be avoided. The drying and shrinkage of the first coat must be completed before the second coat is applied to avoid shrinkage cracks. When the cement quantity is increased the workability gets decreased correspondingly. Weaker mixes containing little of cement or hydraulic lime should not be used as an under-coat for a stronger finishing coat. They are useful for application to non-rigid backgrounds. Mixes of lime and cement are not suitable for trowelled finished coats as the shrinkage on drying creates a tendency to surface crazing.

(b) *Mixes based on lime gauged with a gypsum plaster.* These are workable and the working time depends on the type of gypsum plaster used. Gypsum plaster expands on setting and tends to limit the drying and shrinkage of the lime. They are used for finishing coats.

(c) *Mixes based on gypsum and anhydrite plasters.* Basically they are divided into two main groups, *i.e.*, those which contain Plaster of Paris and retarded gypsum plaster and those containing anhydrated calcium sulphate plasters. The semi-hydrated plasters (Plaster of Paris) set quickly whereas the other type is slow setting. The setting of these plasters is accompanied by expansion which is variable in amount but when the setting is complete, no further movement takes place during drying. Hence it is not necessary to wait for long periods so as to allow the undercoat to dry before the subsequent coats are applied, but they should be sufficiently strong.

No gypsum or anhydrous plaster should be permitted to remain under persistently damp condition after it has set as this causes weakness and disintegration. Most of these plasters can be used without admixture for the finishing coats, and when used in such form expansion during setting becomes an important factor. They set to a hard strong finish which may exert considerable force on the undercoat or background which should on that account be strong. These types of plaster are relatively free from surface crazing.

(ii) Number of coats

For best work, plastering should be applied in three coats. The first coat is responsible for creating the bond between the backing and plastering. Thickness suggested for this coat is about 3 mm. The mortar for this coat should be thrown on the surface and should not be worked but left to rest. A cement mix of 1 : 2 proportions is suitable. The second coat is intended to fill up the irregularities on the back of the wall. A thickness of about 9 mm. is sufficient for this coat. This surface should be levelled with a trowel. The third coat is usually the skimming coat and mainly serves to give a good appearance.

Wood lath and metal lathing require three coats for a satisfactory finish. Brick-work and monolithic concrete work if executed carefully will normally be sufficiently good to allow the use of a single undercoat.

(*iii*) *Type of surface finish*

The usual practice is to produce the smooth finish for internal plaster work but with special techniques a variety of textures can be created. Texture finishing can be obtained in the plaster itself or by application of a textured paint. Sand finishing or other type of finishing can be given to the external plaster.

(*iv*) *Resistance to Abrasion*

As far as the hardnes is concerned, cement finishes have the greatest hardness. These are followed by anhydrite plasters, anhydrous gypsum plasters, retarded semihydrite gypsum plasters and lime plasters in order of decreasing hardness. Addition of lime decreases the hardness, while gypsum or cement whenever added to the lime plaster increases their hardness. Resistance to abrasion is directly related to the relative hardness as described above.

(*v*) *Suitability for further decoration*

The characteristics of the plaster affect the final finish to be done. The degree of alkalinity of the plaster, the dryness and its background at the time of painting are the factors which have to be considered from this point of view.

(*vi*) *Corrosive effect on metals*

The corrosive action should only occur during the initial drying periods and subsequently during the periods of heavy condensation. Plaster containing uncarbonated lime, for example, lime and cement mixes and gypsum plasters containing a substantial admixture of lime have a protective effect on iron and steel but are likely to corrode lead when they are damp for longer periods. Gypsum plasters may have an acid reaction, if they contain salts which are added to accelerate their setting. Suitable metallic or paint coatings or other types of precautions may be given to steel to prevent corrosion.

(*vii*) *Effect of Atmospheric Conditions*

Plastering should not be continued during frosty weather. Suitable precautions should be taken if the weather is very cold.

In certain localities condensation may be excessive and that may spoil the finish of the plaster work. This is specially true for gypsum and anhydrate plasters. Under hot-dry conditions the applied plaster becomes dry before the setting has taken place completely. This will be true in all anhydrous calcium sulphate plasters or cement containing rapid hardening mixture.

(*viii*) *Effect of Vermin*

This liability of plaster to vermin attack is dependent on the amount of cracking present. Freedom from cracking or serious crazing apart from that created by the structural movement can be avoided by the use of good workmanship.

(*ix*) *Fire Resistance*

Application of internal or external plasters can increase the fire resistance of all structural components. The effect of plastering a 20 cm. brick wall is not of much value because without plastering this wall has a good resistance. Plaster finishes on thinner walls or partitions increase their fire-resistance qualities considerably.

(*x*) *Accoustical Properties*

The effect of the plaster finish on the sound absorption is not much. Internal plaster finish of special types may be used to increase the sound absorption.

Background for Plastering

The durability of plastering depends not only on the properties of the mixture itself but also its adhesion with the background. A good background must be plain enough for suitable application of plaster and should have enough strength. The usual types of backgrounds that are used for plaster work are :

(*a*) *Solid Backgrounds* : These include brick-work, heavy clay blocks, in-situ concrete, concrete blocks, etc.

(*b*) *Lathing* : These include wood laths, expanded metal lathing, wire meshes, etc.

(*c*) *Boards and slabs in non-mortar construction* : Under this, slabs of gypsum plaster, fibre boards, wood-wool slabs, etc., are included.

The main characteristic of the solid background is that the nature of the surface presented for plastering is taken primarily by conditions other than those of plastering. Care is needed in such a case for proper preparation. The normal method of construction of solid background introduces varying amounts of water and as a result needs adequate drying before the application of plaster is given. The amount of water contained in concrete placed *in situ* is similar to that of brick-work and similar precautions must be taken in that case.

Local projections are more serious than depressions and these should be broken before plastering. Depressions can be dubbed out if necessary. For three coat plastering the projections should not exceed 10 mm. above the general surface and the depressions may not be greater than 20 mm. For two coat plastering they should be 5 mm. lesser than these values. The efflorescence on the bricks should be removed before plastering by dry brushing. In the case of concrete either excessively smooth surface is left by shuttering or imperfections on account of shuttering occur or greasing defects are created. Whenever concrete surfaces are to be plastered, rough sawn shutter boards should be used. Mechanical keys may be applied to the inside face of the shuttering so as to help in the bonding of the plaster later on. Alternatively metal mesh be left adhering to the concrete. The addition of hair to the first undercoat of the plaster may help in obtaining a good bond.

Lathing materials provide a strong mechanical key for the application with the undercoat. Wood laths are not suitable for cement sand finishes because of the risk of shrinkage. Boards and slabs have the advantage that a uniform thinner coat of plaster can be given. They have got relatively plain surfaces which give good results with two coats or a single coat plastering. Special treatments may be needed for soft type of boards so that the plaster adheres to them properly.

Application of the plaster

It is preferable to apply plaster mix by throwing it with great force against the walls. As this job involves great effort, the mortar is sometimes applied in practice by pressing it thereon. In the latter case adhesion of the plasters is lesser and the plaster may also be more porous. The applied plaster must be levelled and smoothened. This is done by drawing a screed across the surface after the application of the mix. When it is a backing or an undercoat the surface is scratched with a suitable trowel after the mix has hardened to a certain extent so as to get a good bonding with the coat to be applied later on. The plaster should be finished with wooden floats before it had started setting. If it is done too early the binder gets drawn, thereby resulting in the cracking of the plaster. The plastered surface is to be kept moist after application when the mix is of hydraulic type.

Slow setting under higher humidity improves the strength of the plaster.

The processes of laying the plasters of different mixes are briefly reported below :

Lime Plastering.—The process for laying the lime plasters includes the selection of the suitable mix and application of various coats. The slaking of the lime should be carried out in a large vessel in which stirring can be done fairly well. This vessel is partly filled with water to a depth of 30 cm. and lime added to cover the bottom of the vessel to a uniform layer of about 15 cm. Stirring should be commenced immediately and care should be taken that no lime gets exposed above the water surface. As the mix thickens more water should be added. The resulting milk of lime is then run through I.S. sieve No. 25 into a suitable container. It should be allowed to mature for a period of about 2 weeks and will flatten up to lime putty. It should not be allowed to dry out during this time. This operation is needed for quick lime only. In the case of hydrated lime, it should be mixed with water and stirred to a thick creamy consistency. This should remain undisturbed for a period not less than 16 hours and should be prevented from drying out.

The materials should be in the proportions of one part of cement, one part of lime, six parts of sand or one part of cement, two lime and 9 parts of sand depending on the degree of workability, hydraulic strength and rapidness of hardening desired. For greater workabilities greater quantities of lime are used. For the first undercoat, the coarse stuff should be prepared by mixing one volume of lime putty with six volumes of sand. Water should be added to give stiff consistency and the mix should be allowed to stand for some time and prevented from drying. Immediately before it is used it should be thoroughly mixed with cement in the given proportions. All the mixed material should be used within two hours of the addition of cement. For application on lath work hair may be added in the proportion of 4 kg. to one cubic metre of the coarse mix. In the case of hydrated lime-cement mix, initial mixing dry with sand in the chosen proportions, either manually or in a mechanical mixer may be done. Sufficient water should be added to make the mix workable.

The coarse stuff should be stiff enough to cling and hold when laid and should be more stiff for ceilings than for walls. On walls this material should be laid in long spreads upward and across overlapping. Sufficient pressure should be applied to force it into intimate contact with the background. The material should be laid as uniformly as possible. It should be scratched after it is firm. Before applying the second undercoat the first undercoat should be cleaned and may be washed by passing a damp brush over the surface. The necessary screeds should then be formed and the intervening spaces floated in by coarse stuff till it is flushed with the screeds. It is then ruled thoroughly with a floating rule. When the surface is true it is scratched so as to form a bond with the third coat. Adequate time is left before the third coat is given.

The finishing coat may be made from non-hydraulic or some hydraulic lime prepared as described earlier. The mix should be of one part of lime putty, one part of sand, with ¼ part of suitable anhydrous gypsum plaster. It should be used within thirty minutes of the addition of the gypsum plaster. For smaller areas plaster of Paris may be substituted, but in that case the plaster should be applied quickly. Alternatively two parts of lime putty may be mixed with three parts of sand and thus used along with or without gypsum plaster addition. Normally two applications of finishing coats are applied, the first application is laid leaving a coarse surface to receive the second and final application.

Cement Plastering. Plastering mix containing cement and sand may be used with the addition of lime. Whenever damp conditions are prevalent maximum resistance to abrasion is required, a cement sand mix should be employed. Water repellent agents may be added if excessive dampness is occurring. Mixes containing sand and cement only have a dry early strength and the drying and shrinkage sets up a considerable stress both in the applied coat and in the background. For this reason the background is to be specially rigid and must be of enough roughness. These types of plasters are suitable for application on solid background such as brickwork and to suitably finished concrete surfaces. They are not suitable on semi-rigid background.

It may be preferable to use a cement lime mix of suitable proportion to improve the working qualities of the plaster.

Coloured finish is obtained by the addition of white or coloured cement combined with coloured and graded sand. Before the application of cement plaster coats on the surface of the background, it should be cleaned with water in such a manner that a slight amount of moisture remains on the surface. The first undercoat usually of the proportion of 1 : 3 cement and sand should be stiff enough to hold to the wall or the ceilings. On soffits the mixture should be laid in long even spread outwards from the operator overlapping each trowelful and using sufficient pressure to force it into key on the background. On walls the mix should be laid in long even spreads upward and across. The material should be laid in uniform thickness as far as possible, the average thickness not being greater than 20 mm. This coat should be allowed to stand till scratching for keying with the next coat is done.

For getting a proper thickness of the plaster and a level surface it is desirable to take suitable precautions. At places about 15 cm. below the ceiling and about 15 cm. from the edge or angle of the wall a small pat of the mix is laid to form a sort of pyramid about 10 cm. square. A piece of wood or lath is pressed firmly to this so as to form the first point from which the other surface of the plaster can be checked.

The thickness of this pat, which is levelled is normally about 10 to 20 mm. so that it clears all the protruding surfaces of the walls. With the aid of plumb bob a dot (a small level plastered area) can be made correctly at the lower end. When these dots have been correctly finished with respect to each, another pair of similar dots is made on the other end of the wall. In-between these two series of dots can be laid with the aid of strings or otherwise. The distance between the intermediate dots should be less than the length of the checking straight edge so that the surface of the plaster gets checked completely later on.

The next process is the forming of screeds. The material is laid vertically between the dots in strips which are about 7 cm. to 10 cm. in width and carefully levelled off with the floats to the thickness of the dots. The wall is now divided by screeds into a series of vertical bays. When the screeds are hard enough to withstand pressure at the surface the spaces on the walls are refilled with plaster and finished to a uniform level and true surface. Similarly careful arrangements have to be made for getting a proper thickness of the surface whenever there are excessive projections.

Before applying the second undercoat, the first coat is swept clean of any dust or loose particles. Screeds may again be formed and material laid in a similar manner. The average thickness of the second undercoat should not exceed 10 mm. As the surface is formed it is keyed by the use of comb to get a regular pattern of wavy lines.

The proportion of the finishing coat may be similar to that of undercoats. Coloured or white cement may however be used only in the finishing coats. The grading of the aggregate should be appropriate for the type of finish desired. No lime is added to mix containing coloured cement. The proportion of water must be constant for each batch and no additional water is added after initial mixing. The mix is applied with a wood skimming float and afterwards finished to a true and even surface. The surface is then finished with an under float and depressions are filled in. Overworking will tend to bring too much fine material to the surface and should be avoided to reduce the tendency of surface crazing.

Plaster applied to metal lathing. Metal lathing is a term used to cover a wide variety of materials available in sheet. They are classified as (*a*) Plain expanded, (*b*) Ribbed expanded with ribs forming an integral part of the sheets or attached subsequently, (*c*) Perforated, (*d*) Dove-tailed.

Lathing which is commonly used in the domestic building is "plain expanded type". This type is used mainly for ceiling construction or partition work, by fixing it to timber supports or sometimes to steelwork. The following points are to be noted for fixing the metal lathing while being used as a base for plasters :—

(*a*) The lathing should be fixed and stretched tightly as much as possible.

(*b*) The correct gauge should be used in relation to the distances at which supports are spaced. For plain expanded metal lathing the weight should not be less than 15 kg. per sq. m. over normal supports spaced at 35 cm. The mesh of the lathing should be 5 mm. to 10 mm. (measured in the shorter direction).

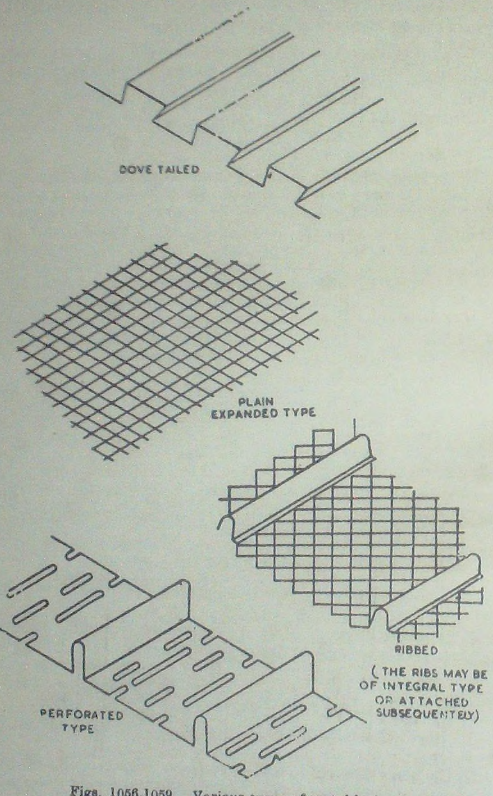
(*c*) The long dimensions of the sheets should span across the bearers.

(*d*) In fixing directly to timber supports suitable strips of hard wood should be fixed between the lathing and the supports to ensure continuity of the plaster key behind the lathing.

(*e*) All sheets must be overlapped not less than 25 mm. at the sides and the ends. Over-laps should always occur on solid supports.

(*f*) The sides of the sheets must be wired together to come between supports, with galvanised wire.

(g) When metal lathing is applied to timber supports it should be fixed by galvanised nails or screws driven across the grain of the timber at about 10 cm. centres.



Figs. 1056-1059. Various types of metal lathes.

Two main types of plastering may be used on metal lathing that is those having undercoats containing cement lime and those containing calcium sulphate plaster. Generally two coats are essential for getting a good finish. The undercoat mix adopted for metal lathing is 1 : 2 : 9 of cement, lime and sand mix. Hair may be added to help in the application to the extent of 4 kg. per cubic metre. For plastering on metal lathing it is not necessary to use a stronger mix than 1 : 1 : 6 of cement, lime and sand.

Calcium sulphate plasters have considerable advantage for application to metal lathing chiefly because they have smaller drying movements than plasters containing lime and cement. Hence a stronger undercoat can be applied without incurring the risk which is accompanied with the use of stronger cement mix. Succeeding coats can also be applied quicker. The main disadvantage of calcium sulphate plaster is its deterioration in damp conditions. The process of plastering on the lath is similar to that of the wall plastering.

Defects in Plastering

The following are the defects which may cause failures in the plaster surfaces :

(1) The backing may move after the plastering is applied due to settlement or due to shrinkage as the water introduced during construction dries out. Similar movement can occur on account of thermal expansion. To avoid such difficulties the background should be allowed to dry completely before applying the plaster.

(2) Movement can also occur in the plaster itself on account of the expansion in the case of gypsum plaster or by drying and shrinkage in the case of lime sand plasters. Lime sand plasters containing lot of fine material are liable to high shrinkage. Similar is the case if sand contains clay particles. The plaster movement can be avoided by the use of suitable type of sand which is well graded.

(3) The adhesion of the plaster may not be complete on account of the surface of brick-work or concrete not having a mechanically good bond.

(4) Failures can occur if suction of the background is not uniform. Absorbing background will suck lot of water from the plaster itself thereby affecting the strength of the plaster.

(5) Keying between various plaster coats is also important. The method of the application of the mix influences the adhesion, if the mix is thrown with some force till it sticks.

(6) Errors in the construction of the building may cause failure. Water may penetrate behind the plaster. Thermal expansion may occur if hot water pipes are present but are not insulated. The column or beams may deflect excessively. The details of construction of doors, windows etc., may be defective leading to the penetration of moisture.

(7) The surfaces to which the plastering is applied may have been inadequately cleaned during plastering.

(8) The backing may contain soluble salts and the adhesion may have been lost by their crystallisation and expansion.

(9) Incorrect working methods may lead to some difficulties. The addition of water to hydraulic lime after initial set has taken

place may prove to be harmful. Excessive trowelling may cause the binder to come to the surface. The interval between successive applications may be short. The coats may have been too thick.

External Finishes

External finishes for the walls of the buildings may be given for the purpose of decoration only or may combine with this the function of exclusion of the rain from the walls. A rendered finish to an external wall is cheaper and can be used over variety of structural materials which may not themselves be suitable for exposure. In making the decision for the selection of a suitable finish, its specifications and colour, the following factors have to be kept in view :

(1) The appearance required.

(2) The maintenance necessary for giving the satisfactory appearances.

(3) The degree of protection against rain penetration to be provided by the finish.

(4) The severity of exposure to atmospheric and climatic agencies affecting durability.

(5) The time of year during which the finish is applied.

(6) The environment and use of the building.

(7) The background materials on which the finish is to be applied.

(8) The cost.

Types of Finishes. The types of finishing treatments usually adopted for external surfaces are the following :

(*a*) *Pebble-dash or dry-dash* : This is the finish in which small pebbles or crushed stones of suitable sizes are thrown on to a freshly applied final coat of mortar and left exposed. The pebbles are sometimes lightly pressed or tapped into the mortar after throwing. This is not suitable for weaker types of bricks or light weight concrete. It can be suitable for rural area as far as aesthetic appearance is concerned. It can resist good amount of aesthetic deterioration.

(*b*) *Rough cast* : This is a finish in which the final coat containing a proportion of fairly coarse aggregate is thrown as a wet mix and is left in a wet condition. The coarseness of the texture depends mainly upon the type and size of the coarse aggregate.

(*c*) *Scraped finishes* : In this type of finish the final coat of mortar, after being levelled and allowed to stiffen, is scraped with a steel straight edge, or a board studded with nails or any other form of tool convenient for this purpose, so as to give a rough surface.

(*d*) *Textured finishes* : With the aid of suitable tools ribbed stucco or fan textures can be created in the final coat.

(e) *Smooth finish* : This type of finish has got a level and a smooth surface. The wooden float is normally used as a steel float gives surface much more liable to craze.

(f) *Machine applied finishes* : A variety of finishes in which the final coat is applied by machine which throws or spatters the material on the wall can be adopted. The machines may be manually operated or mechanically operated and a sort of gun is used to throw out the material.

As far as the aesthetic values are concerned the choice of the type or colour will depend on the circumstances within which the building is to fit in. Smooth finishes have a defect that the surface becomes crazy and has patchy appearance on account of variation in the surface structure due to floating. Lime dissolved by the mixing water either from cement or lime in the mix gets deposited to some extent on the outer surface as the water dries out, and forms calcium carbonate which tends to cover the true colour of the finish. This deposit may be more for some areas than others and thus give a patchy appearance. Such effect is marked under slow drying conditions than finishes applied in warm dry weather. Pebble dash and rough cast are least liable to change in appearance over long periods. Deposits of dirt from atmospheric pollution are more visible on white and pale colour than on natural grey colour. Dirt also appears badly on heavily textured finishes than on white textured and scraped finish.

An external rendering, unless it is painted, should not require any maintenance over a long period of time. If a light-coloured or white-coloured finish is required it may be necessary to provide for painting periodically. A rendered finish is often required to give protection against rain penetration through a wall. For this reason cracks in the rendering must be avoided as much as possible. Pebble dash or rough cast finishes are most suitable for such conditions. Provided the undercoat is resistant other types of finish may be used. Eaves protection greatly reduces the amount of rain falling on the wall. Similarly sills made with effective drips may throw away water clearly from the wall and thereby weaker types of rendering can be adopted.

The type of background on which the rendering is to be applied depends on the choice of the material to be used. For dense and smooth background mechanical keying is essential. For these surfaces spatter dash treatment can be given or a light mesh be secured to the walls for additional adhesion. In moderately strong materials like bricks, the joint should be irregular unless a spatter-dash treatment is to be used. Cement lime and sand mix are most suitable in rendering coats on these materials. Strong and dense type of mixtures such as 1 : 3 cement sand mix may not exclude rain water from the wall although it may be very impermeable as it is liable to crack. A crack in a dense rendering once formed may allow more water than the one in a porous rendering since rain water runs down impervious surface into the crack. High alumina cement mix may sometimes be useful for greater resistance to the action of the sulphates.

Materials for external finishes. The grading of the aggregates may be same as for the ordinary plasters except that whenever rough cast plaster is to be used fine grades may be added. For pebble dash finishes pea shingle, crushed hard limestone or marble chippings or other crushed stone of suitable appearance in a 5 mm. to 10 mm. grading may be used. Texture finishes require finer sand than the rough finishes. Finer sand is also advantageous for pebble dash as it holds the dry pebble better when thrown. Binders may be lime or cement containing suitable pigments in suitable proportions. The total quantity of the binding agent in the rendered finishes is governed partly by the requirement that the amount of such material shall be just sufficient to fill in the voids between the coarse sand particles. For normal sand the amount of fine material required to give the maximum density is about 30-40 per cent. A normal mix contains one part of cement binder to 2½ to 3 parts of sand or other aggregates. If it is made richer than this there is a risk of cracking. The more leaner the mix the more difficult it is to apply. The function of the cement is to provide strength and durability. A mix of 1 : 3 cement sand is more than necessary. The use of this mix particularly on rigid backing of lower strength is likely to give rise to cracking. The use of this mix should therefore be restricted to conditions where the background is strong and good adhesion can be obtained and also where a very dense and impermeable mix is essential. In pebble dash also where plasticity for holding the pebbles first thrown and retaining them is very essential, a 1 : 3 mix is suitable. For all other work mixes containing lower cement content are satisfactory and addition of lime may improve the workability. Mixes containing portland cement, lime and sand in the proportions 1 : 1 : 5 to 6 by volume are suitable.

Application of External Plasters. Scaffolding may be needed for applying the external rendering because of the greater height involved. Raking of the mortar joints in all cases is essential unless a spatter dash treatment is to be given. Similarly mechanical keying may have to be given for various surfaces. Old brick-work, or poured concrete, should be thoroughly wire brushed and washed down, before any rendering is applied.

Spatter dash treatments are applied by throwing, either from a trowel or a scoop, coarse materials on to the surface. The mixes used should be made of suitable consistency and the workability should be varied according to the degree of the suction of the backing material. The surfaces should be covered with a thin layer and no attempt is to be made to level or smoothen the coating.

Undercoats other than spatter dash may be applied by throwing the mix or by laying it over the trowel. The thickness of these courses varies on account of the unevenness of the wall but preferably should not be greater than 15 mm. or less than 3 mm. When the undercoat has started to harden, it should be combed or scratched to a depth of 3 mm. to 5 mm. except when finishing treatment is done with machines. The undercoat should be allowed to dry as long as possible before any further coat is applied.

Finishingt reatments may be laid depending on the texture, *e.g.*, pebble dash, scraped and textured finishes. The final coat may be laid or thrown while for machine finishes, automatic plastering guns may be used. The thicknesses of these coats vary between 5 mm. to 10 mm. Some machine finishes can be as thin as 3 mm. The finishing on the outside should be carried out continuously without any break. Suitable curing must be carried out to prevent rapid hardening of the binder and cracking.

Pointing

Pointing should be avoided as much as possible as this operation involves raking out of the joints good mortar. A weaker mortar replaces it as the latter cannot be worked into the joints properly. The main purpose of pointing is to give a good appearance to the brick-work or stone masonry. It also serves the additional purpose of preventing the ingress of moisture into the wall if the pointing is done carefully. For these reasons all types of faceworks are pointed.

Pointing should preferably be done when the mortar in the joints is comparatively "green" and fresh. Before pointing any brickwork, all the joints should be raked out to a depth of about 10 mm. For good work the joints should be struck after each day's work. The dust of mortar and other dirty matter is cleaned, the surface is well-wetted and washed with water. This washing should progress with the pointing.

The joints of the pointed work must be clearly defined by the pointing, the lines being regular and uniform in breadth. It is not desirable to cover the brick edges with mortar so as to hide defects in brick-work.

The surface of the pointed work may be kept flush with the brick-work. The mortar will be filled and pressed into the joints with a pointing trowel and finished off level with the edges of the bricks to give a smooth surface.

For deep pointing also called struck pointing, the mortar shall be filled in the joints flush with the masonry or brick-work with a pointing trowel and then pressed in with proper pointing tools. The pointing tool for horizontal joints may have a suitable shape so as to give weathered or struck joints as the case may be. For vertical joints the pointing tool may be triangular in shape so as to form "Vee" joints. While using the tools, care should be taken to press the mortar and not to cut it away.

For ruled pointing, the mortar is filled and pressed into the joints with a pointing trowel and finished off level with the edge of the bricks. It is then ruled along the centre of all joints with a half round tool, 10 mm. wide.

The other variety of pointing is the "tuck" type. In this case the joint between the bricks is filled with mortar, may be of a different colour. A narrow ridge with raised parallel edges of about 4 mm. in thickness is made in white colour. It fits into the backing joint, as a recess is made in that to receive the former.

For lime pointing, slaked lime is mixed with two parts of surkhi and kept under water for a period of 12 hours. This is then passed through a screen of 6 meshes to a cm. In exceptional cases, colouring matter may have to be added to match the colour of the bricks.

Whenever pointing is liable to get affected by dampness or salt action, cement pointing is used. A mix of 1 : 3 cement sand is used.

After pointing, the face of the wall should be cleared of all surplus matter adhering to its face. No washing is done till the pointing has set. Lime pointed work is kept wet for 5 days and cement pointed work for 10 days, after the completion of the job. It should be protected during this period from the extreme changes in the weather.

QUESTIONS

1. What are the objects of plastering ? Define the following terms :
Background, blistering, cracking, crazing, dubbing out, finishing coat, flaking, float, gauging, grinning, raking, peeling undercoat.

2. Describe with the help of sketches the tools used for plaster work.

3. What are the materials used in plastering ? Discuss their suitability.

4. Discuss, in detail, the design considerations for plaster work.

5. Describe, briefly, the following :
   (*a*) Lime plastering.
   (*b*) Cement plastering.
   (*c*) Plastering on lathing.

6. State the different types of plasters adopted for internal and external finishes of buildings. What do you understand by water-proof plaster ?

What types of plaster would you adopt for (*a*) an ordinary residential building of a middle class family, (*b*) a big insurance building, and (*c*) a modern cinema house ?

7. (*a*) Why is plastering done in more than one coat ?
   (*b*) What do you understand by the term 'pointing' and how is it done ?

8. What factors will you keep in mind while selecting a suitable external finish ?

Describe the various types of finishes and the materials used for them.

9. What are the various defects in plastering ? How will you rectify them ?

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19

PAINTING, DISTEMPERING AND WHITE WASHING

Painting

Besides protecting various building units from the weathering action of the atmosphere, the main object of using a paint is to provide a decorative finish to obtain a clean, colourful and pleasing surface. Such surfaces are also hygienically good and present healthy surroundings to live in.

An ordinary paint consists, essentially, of two ingredients, *i.e.*, a base which is a solid material and forms the main body for covering the surfaces and a liquid called vehicle which carries this solid matter and distributes it evenly on the surface. The vehicle also acts as a binder for the solid matter and enables it to adhere to the surface. Additional components like pigments needed for giving different types of colours, thinning agents for greater covering capacities and driers which give the property of drying at a quick rate, are added to the paints.

The base may consist of white lead, red lead, zinc white, iron oxide or graphite, out of which the white lead is mostly used. This has got an additional advantage of being easily applied and has a good characteristic of covering the surface well but this is liable to discolour on account of the fumes of hydrogen sulphide present in the atmosphere. The covering coats in such a type of atmosphere have to be given with some other materials. Zinc oxide, on the other hand, is non-poisonous and is not affected by sulphur fumes. Lithophone is also extensively used for interior work. This is a mixture of zinc sulphide and barium sulphate prepared by the process of mutual precipitation. This base is good and cheap and it is liable to change colour on account of exposure to daylight. Red lead is used for painting iron surfaces to which it adheres well and protects the metal.

The liquid vehicle generally consists of raw linseed oil, refined linseed oil, pale boiled linseed oil or stand oil. Raw linseed oil is thin but takes a long time to dry. It is, therefore, boiled and during this process a drier such as litharge is added. Then, this becomes thicker and darker. For delicate work either raw linseed oil which is thin is used along with driers or poppy or nut oils. Pale boiled or double boiled linseed oil is more suitable for painting plastered surfaces. Stand oil, made from linseed oil by allowing it to stand in the sun for getting thicker by heat treatment, forms a durable film with a clear finish.

Pigments consist of natural earth colours such as ochres, siennas and iron oxide and calcined colours such as lime black, Indian red, carbon black and red lead and precipitates such as prussian blue, chrome yellow, etc. These are liable to fade away by bleaching action and are also subjected to a change in colour under the influenee of sulphuretted hydrogen, moisture and heat.

Liquid and paste driers are used for hardening of the paints. Liquid driers are finely divided compounds of metals such as manganese, lead, cobalt, etc. and dissolved in a volatile liquid. Paste driers consist of compounds of these metals mixed with larger percentages of filling material and ground in linseed oil. Litharge, zinc sulphate and red lead are also used as driers. The main function of a drier is to absorb oxygen from the air and transfer it to linseed oil which consequently gets hardened.

The thinning agent commonly used is terpentine oil. This material makes the paint thinner and facilitates it to spread out. It helps the penetration on porous surfaces such as wood and plaster but at the same time reduces the gloss of the linseed oil. It should, therefore, be used more carefully particularly in the finishing coat.

Types of Paints

In the following paragraphs, the various types of paints are briefly described :

Oil Paint

The basic composition of oil paint is a base dispersed in raw or refined linseed oil plus driers and thinners. Additions of pure linseed oil, stand oil, dehydrated castor oil are also made. The characteristics of these paints are that they are easy to apply, have good opacity, a moderate flow, low gloss and are cheap. Such paints are self-priming and do not need any special primer or under-coat. For general decoration, it is a common practice to apply, on unpainted surfaces, at least three coats of varying compositions, *i.e.*, primers, undercoats and finishing coats.

Cement Paints

The term cement paint is applied to paints which are based on portland lime with a pigment, filler and accelerator. They are normally mixed with water before use. Titanium dioxide is used to improve the opacity. Calcium or aluminium stearates or other compounds having similar properties are added as water repellent agents for exterior use. Calcium chloride or other accelerators are added for adequate setting and hardening before it dries. Pigments are incorporated to give the required tint. Cement paint is most suitable for application to concrete and cement surfaces and also to brick-work. This is unsuitable for surfaces which are liable to be subjected to dampness. It can, however, be used for preventing rain penetration into the walls.

Synthetic Rubber Paints

Synthetic rubber paints are better than the previous types. They offer complete resistance to lime and are suitable for application over fresh concrete or other masonry surfaces. These surfaces need not be completely dry. These paints are moderate in cost and are easy to apply. Weather and sunlight have a very slow action on them. They have excellent chemical resisting property. They offer good resistance to water and stand up to heavy rains. The strong binding properties result in a low rate of mechanical attrition by rain, sun, wind or cold. The quick drying and minimum penetration of the resins contribute towards a good covering and non-mottling qualities. They are fast drying and have excellent colour uniformity.

Emulsion Paints

A simple mixture of a pigment and a binding material is not usually workable and hence thinning agents are essential. Alternatively, the pigment can be finally dispersed in water to form an emulsion ; and suitable materials like glue, casein or modified celluloses are added to keep the paint in good condition. These types of paints are called emulsion paints. The various types of emulsions are briefly enumerated below :

Alkyl Emulsion Process : The binding medium in this paint is a certain synthetic resin. They give a flat finish, are porous and are not inherently resistant to alkalies. They are available in a range of varieties. Those containing low binder content are similar to best oil-bound distempers and those having high binder content are similar to oil paints.

Polyvinyl Acetate Paint : The binding material is polyvinyl acetate which is a synthetic resin. The type of finish can range from a matt to oil-gloss. These paints are normally permeable to water vapours and allow drying to continue through them, if they are used on damp walls. However, those paints which have got a fair gloss are not permeable to water and may blister if used on damp walls. These paints increase corrosion on steel and should not be applied directly, *i.e.*, without a primer.

Styrene Based Emulsion Paint. Styrene which is a common type of synthetic is used in three different forms in emulsion paints, the most important type being the oil-modified styrene. This form gives a good finish, the film is permeable to water vapour and fairly resistant to alkalies.

High Gloss Emulsion Paint. The binder is similar to that of a styrene based paint. The finish is equally glossy but is not permeable to water vapour and is also non-resistant to alkalies. This type of paint can be used on interior surface directly if the surface is not porous or needs a suitable primer if the surface is porous. It is not suitable for damp surfaces.

Oil Bound Distempers. These consist of an emulsion of drying oil or varnish with glue or casein and usually lithophone as pigment. There is considerable variation in the quality but some attain a fairly washable quality after a few months. These are permeable to water vapour and fairly resistant to alkalies. They are not suitable for use in conditions where condensation is likely to occur, *i.e.*, in kitchens and bath-rooms.

Emulsion Paints Based on Tar or Bitumen. These are used for different purposes. They are often porous and usually resistant to alkalies. They are restricted in the range of colours if the bitumen content is high.

Advantages of emulsion paints are that they are easy to apply, the spreading of these finishes is so good that the time required to complete a given job is reduced by about 50 per cent and no marks of brushes are visible. They are fast drying paints and two coats of these paints can be applied on the same day. They have got an excellent adhesion property and form a tight resistant film even when applied over a wide range of temperature and on different surfaces. They have got good durability and can be applied over masonry surfaces or over previously painted surfaces. The colour retention is good and has pleasing effects. They have a higher life and it is seen that they can stand for a period of more than five years. Whenever the finished coats are washed, a look like a fresh paint appears. They offer resistance to alkali action.

Multi-coloured Finishes

During the last few years, multi-coloured finishes are being produced rapidly. These multi-coloured paints are a suspension of lacquer particles in a water phase which contains a collective colloid. The pigment phase is poured into water during agitation and due to the incompatibility of the two systems, smaller globules are formed. They need a stabiliser to maintain the individuality of the particles. They have a high decorative value. They have got added advantage that they can be applied on highly porous surfaces without any shrinkage. They can also be applied to damp surface without any detrimental effect. Films of 0.15 mm. and more can be spread in one application without sucking or wrinkling. These can be used on a new plaster without fear of alkali effect. These are used for decoration purposes in houses, basements and industrial buildings.

Process of Painting

The process of painting involves the application of a priming coat followed by an undercoat and one or two finishing coats. All these coats are important for giving a desired protection.

Prime coat. The prime coat has a double purpose, *i.e.*, it forms a layer which on one hand provides the adhesion of the paint to the given surface and on the other hand contains some reactive pigments which serve to protect the surface from the corrosive effect of weather. The selection of any primer for a given purpose depends upon its characteristic and the surface over which it has to be applied. For an absorbent surface, a primer should be of such a quality that a part of it should remain on the surface after absorption. This portion provides a key for adhesion. The proportions of oily and resinous materials are adjusted to suit the suction. Wood priming requires special consideration as it contains trapped moisture. In the case of steel, besides corrosion, another important factor which is to be considered is the expansion and contraction due to changes in the atmosphere and thus it has to stand this variation without any bad effect. For plastered surfaces, the presence of moisture must be taken into account while selecting a primer.

Undercoats. The main function of the undercoat relates to the filling properties, opacity, colour and support for the finishing coat. These are highly pigmented and thereby cover most of the irregularities. Heavy undercoats are generally avoided and hence suitable thinning agents must be mixed with a paint so that the painted surface is quite thin and there are not excessive marks left after the application. In the case of old work, care has to be taken that there is no loss of adhesion. A good undercoat should be such that after its drying, no clogging marks should be produced when it is rubbed with a glass paper. As this rubbing is essential before the application of any finishing coat, the tearing away of the film will result in a damage which is difficult to rectify.

Finishing Coat : The choice of the finishing material depends upon the position where this is to be applied, *i e.*, whether exterior or interior surface ; the type of finish required is glossy or matty ; atmospheric conditions, etc. For interior surfaces, a paint based on natural resin varnish is good. For cold places, the paint should not become too brittle owing to the climatic conditions. In coastal areas or extremely wet places, growth of fungi presents problems in addition to corrosion.

The application of the paint on various surfaces is briefly described below :

(*a*) **Painting Woodwork**. Selection of the right type of paint and the correct method of applying it, keeping in view the surface to which the paint is to be applied, are important for good painting. The characteristics of wood which have to be considered in this connection are its cellulose or porous nature, its liability to contain oily substances, its liability to contain water soluble substances, its moisture content and its capacity of absorbing water thereby causing swelling or shrinkage. The internal structures of hard woods differ markedly from those of soft woods. In the case of hard woods, there are smaller cellular units but they contain pores which are wider and deeper than soft woods and thereby present a difficulty in painting. Ordinary paints applied by brush or spray will neither fill nor cover these pores. The pores in the soft woods are smaller and, in general, may be filled by painting brushes. But in the case of soft woods, the presence of cellular structures leads to the absorption of the paint and hence a proper proportion of oily content and the pigments has to be maintained.

Hard woods do not contain resin and in general are free from objectionable oils. Teak and some other kinds of wood contain oils which tend to interfere with the drying, hardening and proper adhesion of a paint. They can, however, be painted successfully by the use of a special primer. In soft woods, sometimes there are excessive amounts of resins present, particularly near knots, which lead to unsatisfactory painting.

With well seasoned timber, the effect of water soluble substances is relatively unimportant but some priming paints may be of slow drying type and may not harden on hard woods rich in tannins such as wall nuts, etc. In other circumstances, similar troubles arise with soft woods. Water soluble substances may cause discoloration of paints.

The timber which is to be primed should contain about 10 to 20 per cent of moisture. The moisture content of dry seasoned timber may rise considerably higher merely by absorbing water vapours and may reach 25 to 30 per cent in places where condensation occurs. The moisture in this case is not held in the wood cells but within the fibrous cell walls which consequently are in a swelling state.

Wood in contact with water would absorb more than 30 per cent of moisture easily till the cavities are filled. The adverse effect of moisture present within the walls is due to shrinkage as the moisture is absorbed or dries out. The paints do not prevent entirely such drying or absorption. The changes in wood fibres will, therefore, weaken the adhesion of the paint film and thereby may peal off the wood surface.

Woodwork should generally be given four coats of paints, *i.e.*, one coat of primer, two undercoats and one finishing coat. For most of the soft woods of good varieties, white lead in linseed oil or similar material containing 10 per cent of red lead may be used for priming coat. Higher percentage of red lead would produce a harder film which may need extra rubbing to ensure adequate adhesion of the next coat. This is more true if the primer has been applied a month or so before the application of the next coat. For lower grades of soft wood a slightly water resistant varnish is sometimes used. For general interior woodwork, linseed oil primers are sometimes preferred to lead primers on account of their non-poisonous nature. They are also quite satisfactory. They should be made from lithophone or titanium white with or without a proportion of pigment mixed with linseed oil. Quick drying primers should not be used on soft wood joinery.

Undercoats for use on wood should contain a more penetrative medium than the undercoats used on metals although the finishing coats may be the same in both the cases. This penetrative medium seeps into the primer coat and helps to restore any undue loss of oil brought about by absorption in wood. Good adhesion between the wood and the primer and between the primer and the undercoat is maintained, thereby preventing or delaying cracking, flaking and peeling. Proprietory undercoats usually contain a proper mixture of pigment, oil, varnish, thinner, etc., which enables it to be satisfactorily used for both coats. Undercoats of lead if properly constituted with respect to the particular finishing coat are quite satisfactory for external use.

The proprietory paint used as finishing coat on woodwork is described as hard gloss paints, synthetic gloss paints and enamel paints. These paints are intended to give a hard film having a smooth and clear surface Finishing paints used for an exterior work usually differ from those on the interior woodwork.

Painting Process on New Woodwork. If possible, the moisture content in timber should not be more than 15 per cent at the time of painting. Before applying the priming coat, the new woodwork should be made ready for painting by removing or sealing off certain defects which are sources of trouble. The timber should be dried a little to reduce the moisture content. Large knots should be removed by cutting or otherwise replaced by sound wood. Projections should be smoothened with gloss paper. Knots should be given one or two coats of shellac knotting or aluminium paint. It should be ensured that the primer should work well into the nail holes, etc. The primer should be applied firmly into the wood and sufficient time allowed for it to penetrate. Some of the primers may be good in this respect but should ensure proper adhesion with wood.

Subsequent painting is done at site after erection. If the primer has been damaged, it should be touched. When the primer is dry and before applying the undercoat, nails holes, etc., should be filled in by a stiff putty. This may consist of white lead and linseed oil or glazing putty with or without some red lead. When it gets dry, it should be rubbed with a water-proof abrasive paper. Sometimes fillers are used to fill in the pores or to get smooth finished surface. They usually consist of a mixture of finely powdered slate and size. When dry, the filler is rubbed smooth with water-proof abrasive paper. Oil bound water paint is also sometimes used as filler ; but this is not so suitable as the other type mentioned earlier.

The subsequent coats should be applied carefully. Condition of the primer has to be observed before applying the first undercoat. The primer should be clean and not too hard as otherwise the undercoat will not stick well. Subsequent coats should be applied after about 24 hours' interval between each coat.

Repainting. The old paint should be completely removed if it is soft, or has cracked, blistered, pealed and shown loss of adhesion. Similarly it should be removed when it is highly discoloured or damaged by fungal growth. Small, loose patches of paint may be removed by a scraper. Interior paints should be rubbed with wet abrasive paper so as to provide a key and slightly rough surface to which the subsequent paint will adhere well. Exposed doors and windows should be touched with a primer and an undercoat as usual. Whenever it is desirable to remove old paint completely, blow lamp or other heating devices may be used. Alkaline removers should not be used on wood to be repainted. Whenever the use of a blow lamp is liable to cause damage to the paint, a paint remover of organic solvent type may be used. When the removal of the paint is complete, it should then be rubbed with wet abrasive paper and subsequent painting should be done in a manner similar to the one adopted for new woodwork.

Wood treated with tar oil as a preservative should be painted with dark coloured paints, or otherwise with light coloured paints if one or two sealing coats of good aluminium paints are given. A suitable type of paint should be used if the wood has been treated with other types of preservatives.

Painting of Iron and Steel. After the steel has been rolled, it has an oily scale on the surface. It is sometimes considered that if a continuous layer of oily scale could be maintained, the surface of steel would get an effective protective layer. But this is not possible as once the break occurs, progressive loosening takes place and uncovers the steel. Similarly the oils and greases which may be present on the surface will not permit the paint to stick.

Mill scale can be removed with the aid of many methods. If the steel is stretched, the scale will flake away. This method is not easy to apply. Sand blasting may also be effective. Immersion in hot solutions of acids will remove the scale. Films of metallic phosphates can be created which are more resistant to rusting and form a good surface for painting. Thorough drying is essential before painting. Scrapers and grinding machines are used in bigger factories. Oxy-acetylene flame may be used along with the mechanical methods, but this method is not suitable for sections lesser than 5 mm. in thickness.

Primers for painting steel should always contain pigments which resist the corrosion. Red lead and chromates of lead and zinc are commonly used. Red lead in linseed oil is the oldest primer still abundantly used, but this is unsuitable for dipping and spraying. Chromate based primers are more suitable for spraying. For dipping primers, red oxide primers containing a proportion of zinc chromate and metallic lead primer are useful.

Red oxide of iron and micaceous iron ore paints are cheap and satisfying for use as undercoats. Graphite paints and aluminium paints have a good resistance to moisture. Finishing coats of bitumen based aluminium paints can be applied advantageously. Paints based on silicones or silicone-alkyds are fairly suitable for resisting higher temperatures.

Painting Other Metals. The metal surface should provide an adequate key for the paint film and should be clean, dry, free from dirt, grease, etc. Paints of suitable type should be used with each type of metal. For aluminium, the priming paint should consist of pigments like zinc chromate. These pigments should constitute about 20 per cent of the dry weight of the film. Priming paints on aluminium should be free from pigments containing graphite or lead. For zinc a primer based on zinc oxide is considered to be very satisfactory. For stopping corrosion on galvanised iron, the surface can be treated with a red lead primer. Special care should be taken where two dissimilar metals touch. Contacts of copper, nickel, and their alloys with aluminium and zinc should be avoided. All metallic surfaces should be easily accessible for repainting. Extra paint must be applied at corrugations, etc., where the paint tries to recede just after application.

Painting Plasters, Brickwork, Floors and Other Concrete Surfaces, etc.

These surfaces present difficulties on account of the dampness or the presence of soluble salts. Usually efflorescence occurs on the surface of these materials which decrease the adhesion of the paint considerably and may lead to discoloration. When oil paints are to be used on alkaline surfaces, an alkali resisting primer must be applied.

For floor surfaces, enamel coatings are used. These surfaces have to resist alkali action, moisture, and abrasion. The floor enamel must be tough to stand the impact of the foot traffic. Floor enamels should have a high gloss. They should be of quick drying type so as to use the flow once in the least time. Oil modified phenolics are occasionally used as floor finishes.

Areas subjected to the action of water like bathrooms, etc. present special problems. Oil bound water paints do not have a longer life. They have a certain amount of porosity. While absorbing moisture they swell and contract when the moisture evaporates leading to disintegration. High-gloss paints are more resistant to moisture but since they have an impermeable film the effects of condensation are not much perceptible. Emulsion paints and synthetic rubber paints withstand washing and scrubbing and give a tougher film which makes them more suitable.

Cement paint is more suitable for application on concrete surfaces. The suction at the surface should be reduced to such an extent that the moisture is not removed quickly from the cement paint. The surface may slightly be wetted for this reason, but it should not present a damp surface. The paint available in a powder form is diluted with water to a creamy consistency. The paint is used within 2 to 3 hours after mixing. It is usually applied with coarse distemper brushes. Two coats with an interval of 24 hours are given. A fine spray of water is applied to the painted surface at intervals to cure the surface.

Silicate paints having a binding medium of sodium or potassium silicates can also be successfully used. They are sulphate resistant but may tend to promote efflorescence.

Distempering

Distempers are mainly composed of whiting, glue or casein which acts as a binder, and suitable proportions of fast coloured pigments. Generally they are available in powder form (dry distempers) and as a paste (for oil bound distempers).

Dry distempers consist of 90 to 95 per cent of whiting and 4 to 5 per cent of glue. All colouring pigments must not be effected by alkaline reactions of lime. This is one of the cheapest forms of decoration with the exception of lime wash. These distempers give a pleasing coloured appearance which will stand a certain amount of dry rubbing but can be readily removed with washing.

Oil bound distempers are prepared by grinding pigments with a medium composed of an emulsion of a drying oil in water. Linseed oil is generally used but tung oils are often employed. The emulsion is formed by agitating the oil and water together in the presence of an emulsifying agent which is generally glue or casein. To ensure full resistance to putrefaction and other types of growth, 0.3 per cent to 0.5 per cent of phenol is added. These are generally supplied in a paste form which are readily thinned with water to brush consistency. On evaporation of water these dry to a porous film, the glue acting as a temporary binder during the drying of the oils. This film hardens to stand a moderate degree of washing and is more durable for internal decoration. These types of distempers are more valuable for early decoration of new plasters, brick-work, etc., as the porousness of the finish allows it to be applied to relatively damp surfaces without entrapping moisture. A good finish is retained for a longer time. Cracking and peeling is not prevalent. However, these are not well suited for decoration of bathrooms, kitchens and other places exposed to steam or heavy condensation as wetting and drying for prolonged times induces peeling and flaking.

Distempers should not be applied before 12 months after plastering work has been completed. This is due to certain chemical reactions which take place in the plaster and which are likely to affect the distempered surface. The walls may be temporarily finished with a white wash or colour wash made of whiting mixed with water and sized and tinted as required. This is better than lime wash as it has to be removed before a new application of distemper is to be made.

New plaster for distempering should have a fine polished surface. All irregularities must be removed. The plaster must be dry at the time of application of distemper. Before starting work, the plaster must be sized with a coat of equal parts of size and alum dissolved in hot water. The size should not be made too concentrated nor too thick. Decomposed size should not be used. Sometimes a special priming coat may have to be given. All old colour wash or white wash must be removed completely with sand papers.

For application on new plasters or on which some sort of lime wash has been applied, distempers made with lime proof pigments shall be employed. Enough distemper needed for one room, is mixed at a time so as to attain uniformity in the tint. Distemper is applied quickly leaving no dry edges. The brush is dipped and strokes are applied crosswise on the wall followed immediately by up and down strokes. Two men usually work, one working from ceiling downwards as far as he can reach and the second following him applying the distemper below. Patchy overlaps should be avoided. The brushes must be cleaned at the end of each day's work and old brushes caked with dry distempers should never be used.

White Washing

White washing is made from pure fat lime which may be slaked at site. Slaking is carried out in a tub until the mixture has a creamy consistency. This is allowed to rest for about 24 to 48 hours. This mixture is then strained through coarse cloth. To each cubic metre of this mixture, 3 kg. of gum boiled with 10 kg. of rice are added.

The white wash is applied with a brush to the specified number of coats. Each coat consists of four strokes of brush, one in each direction. Every coat of white wash is to be allowed to dry before applying the next coat. When each coat of white wash dries, wash should not show any sign of cracking nor should it come off readily on fingers when rubbed.

The white wash, when completed, shall form an opaque coat of white colour through which the old wash cannot be seen. It should also present a smooth regular surface free from powdery matter.

In the case of re-white washing, the surface shall be cleaned and freed from any foreign matter and old loose white wash. If old white wash is discoloured by smoke, a wash of wood ashes and water is applied before the coat of white wash. White wash should not be applied to a very smooth trowelled plaster as it will not adhere well. The plaster should also be dry before white wash is applied.

Colour washing

This is made from pure slaked fat lime and mixed with necessary pigment to give the desirable shade. The pigment should be of such a type so as not to get affected by the presence of lime. The colouring matter is added to the prepared white wash and the mixture is thoroughly strained through clean and fine cloth. This mixture is kept constantly stirred with a stick whilst being applied. Sufficient colour wash is kept ready before a room is taken in hand so as to get a uniform tint. New or scrapped surfaces are given one coat of white wash and one or two coats of colour wash. Old surfaces having satisfactory white or colour wash should be given one coat of colour wash. If a lighter colour is to be given the older coloured surface should be scrapped off and a coat of white wash applied before the new colour wash is given. Each coat of colour wash is allowed to dry before a new one is applied. When the surface is completed, the walls should present a uniform colour free from blots, lines or cuts, and must have a regular surface. Colour should not crack or come off readily on the fingers when rubbed.

QUESTIONS

1. What are the essential constituents of a paint ? What are the functions of these constituents ?

2. What are the materials commonly used for the various constituents of paints ? What are their functions ?

3. Describe briefly the various types of paints commonly employed.

4. What are the various processes involved in painting ? How would you proceed to paint (*a*) a new wooden panelled door, and (*b*) a new steel roof truss of a workshop ?

5. Describe in detail the method of removing old paint from woodwork and repainting it.

6. Describe briefly how you will apply paint on :
   (*a*) Plastered work.
   (*b*) Brick-work.
   (*c*) Floors.
   and (*d*) Concrete surfaces.

7. What is meant by distemper ? What are the various types of distempers ? Describe briefly the process of distempering.

8. Write short notes on :
   (*a*) White washing, and (*b*) Colour washing.

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THERMAL INSULATION

A difference of temperature between the inside and outside or between the different parts of a building will result in a transfer of heat from the warmer to the cooler areas. This transfer of heat may take place by any one or more of the three methods, *viz.*, conduction, convection and radiation. The transfer of heat through solid building materials takes place mainly by conduction, the amount of heat transferred depending on the temperature difference between the two surfaces, the thickness of the intermediate media, the area of the exposed materials, the time through which the heat flow takes place and the rate of the heat transfer or the conductivity of the intervening materials.

The characteristic of the material which determines the rate of heat transfer is called the thermal conductivity and is expressed in terms of the number of thermal untis which will pass through one square metre of a material, one cm. thick, in one hour, for one degree Centigrade temperature difference. The conductivity of a material depends on the type of the material which may be a good conductor or a bad conductor of heat. For the same material the rate of flow depends on the density. Certain types of materials have an optimum density for which the heat flow is the least. Any variation from this value will increase its conductivity. If the material contains air spaces within it, the conductivity will get decreased. Any substance containing moisture in it will transfer heat quickly as the water present in it is a better conductor of heat than air. The conductivity also increases with the mean of the inside and outside temperatures although the difference in temperature may remain the same.

Convection and radiation also play an important role in the transfer of heat through building materials. Large air surfaces exist within walls or internal structures of a building. These may not contain air in a dead state and therefore the heat gets transferred by the process of convection, that is, currents of air transmit from one side to the other. Similarly the presence of polished surfaces on the exposed side of a building may retard the inflow of heat as a greater quantity would get reflected.

Briefly speaking, the following factors are most important in the transference of heat from the exterior into the interior : (*i*) Thermal insulation value of the exterior shell of the building, that is, the floors, external walls and the roof, (*ii*) the difference in temperature between the outside and the inside; for a greater difference there will be greater loss of heat, (*iii*) the area of the external part of the building ; for greater areas the heat transfer is more, (*iv*) the areas of windows and doors. The transfer of heat through a glazed window is about three times more than a typical wall construction. Hence the windows should be put in a correct orientation with respect to the movement of the sun, (*v*) the rate of air movement through any cavities in the enclosing structure. Air spaces through the roof or below a suspended floor may cause considerable heat transference unless special precautions are taken.

For determining the heat loss from a building to the outside in winter months the following additional factors have to be taken into account :—

(*i*) The rate of air change. This is the rate at which the heated air inside the building is displaced by cold air from outside. Air flows will occur through the open doors and windows or through ventilators, etc.

(*ii*) Next is the position of flues. The structure enclosing the flue is heated by the gases which pass through it. If the flue is built in an external wall, a greater proportion of heat will be lost through this wall directly by conduction.

(*iii*) The type of heating appliance and the design of the flue throat. In the heating appliance of flue, appreciable heat loss can occur if an excessive heated air passes up the flue. The restrictions to the air flow provided by the appliance and by the cross sectional area of the flue throat are important.

The heat transmission losses are calculated by multiplying the area A by the proper co-efficient U for a particular type of construction or material and by the temperature difference between the two surfaces. This can be stated by the equation,

$$H = A \times U \times (T - To)$$

where H = Heat transmitted through the materials of walls, roofs, etc.

A = Area of the surface.

T = Room temperature.

To = Outside temperature,

U = Overall co-efficient of transmission or the amount of heat transmitted per unit area of surface for a temperature difference of one degree between the air of inside and the outside.

The heat transmitted through each surface is calculated separately and the total transmission loss for each room or space is the sum of individual transmission losses through each surface of the room. Due allowance is also given for the infiltration losses which occur on account of leakage of air through the crevices etc. present in the walls or doors.

To achieve insulation effects, it is essential to either use insulating materials or devise special construction methods or alternatively adopt both. For a material to be considered as a good insulating substance it must have a low heat conductivity, that is, a high degree of heat resistance per unit of thickness and must be installed in an adequate thickness. Generally it should not have a greater thermal conductivity than 1260 Calories. The thickness must be sufficient so as to provide adequate heat resistance of the material.

Types of insulating materials

The types in which these substances are fabricated are (*i*) loose fills, (*ii*) blanket insulation, (*iii*) bats, (*iv*) insulating boards, (*v*) slab or block insulations, (*vi*) reflective sheet materials, (*vii*) light weight aggregates, etc.

Loose fill insulations consist of fibrous materials like rock wool, slag wool, glass wool, cellulose or wood fibre wool. They also consist of granular loose materials of mineral or vegetable nature. Mineral wool is a fibrous material and is made of three materials—rock, slag and glass. These materials are conveyed to a large melting pot and the rock is melted under a high temperature. As it leaves the furnace, it is acted upon by a blast of steam which carries the beads of wool into an annealing chamber.

An inert light weight granular insulating material known as vermiculite is manufactured by exploding an aluminium-magnesium silicate material. This treatment is done under the action of high temperature which causes the flakes of the mineral to get converted into cellular granules.

Blanket insulations are flexible fibrous materials supplied in rolls or otherwise. They are made principally from mineral wool, processed wood fibre, cotton and animal hair. They vary in thickness from 1 to 8 cm.

Bat insulating materials are similar to the above type but are smaller in size and greater in thickness, common thicknesses being 5, 7 and 9 cm. They are available in smaller sizes suitable for framing units. Structural insulating board is made by reducing wood cane or other materials to a pulp and then reassembling fibres into boards. Adhesives are used to keep the fibres in correct position. Various types of insulating boards are available in different sizes and thicknesses.

Slab insulations are small rigid units of about 2.5 cm. in thickness and range in size up to 60×120 cm or more. Slab insulations are also known as blocks or boards and consist of cork board slabs, mineral wood slabs, vermiculite slabs, cellular glass slabs, cellular rubber slabs or wood fibres bound together with cement.

Reflective insulations depend entirely on their surface characteristics for their heat resistant properties. They are generally used along with the air spaces so that the reflective insulation surface is exposed. Bright metallic surfaces are more efficient. Sheet or blanket aluminium reflective materials, aluminium foils, surfaced gypsum boards, steel sheet reflective insulations or reflective coating applied to paper or other surfaces are the various types of reflective insulations commonly adopted.

Cement and concrete products have lower heat resistances but with the use of light weight aggregates such as blast furnace slag, burnt clay aggregate, vermiculite etc., the insulating resistance of concrete materials gets increased.

Method of application

Fill insulations may be poured in between the vertical studs after the outside sheathing is placed and as the walls to be insulated are receiving the plaster base or interior finish. This insulation should be poured in heights not greater than 1 metre at a time and must be packed to a proper density between the covering sides. If a vapour barrier is to be provided it should be kept on the warmer side of the wall. These types of insulating materials may be poured from bags into the spaces between the ceiling joists to the desired depth. Whenever intricate inner spaces are present these materials may be placed with the aid of compressed air.

The blanket insulations of widths greater than the distance between the vertical studs are used. This enables the edges to be folded and nailed or stapled into the wood framing members. Special nailing or stapling flanges are provided in certain cases to facilitate the application of the insulation. Whenever possible the blanket insulation may be installed in a manner so as to leave sufficient air gaps on both sides of it. While fixing this type of insulating material to a masonry wall special furring strips are used to hold it and the interior finish.

The bat insulations are installed between the exterior finish and the interior covering material and air space may be left on one side.

Structural insulating boards are themselves used as materials for walls or roof sheathing, as a plaster base or other decorative finishes. They are nailed to the woodwork supporting them. They may be covered with different finishing materials like wooden planks, concrete blocks, plaster, shingles etc.

Insulation of roofs

In drier tropics where there is a marked day-night temperature range, it is desirable for the buildings used during the day to have a type of construction which will warm up slowly. The underside of the roof slab in such a case will be the warmest when the general temperature is falling. The extent of this time-lag depends on the mass of the roof, the heavier the roof the longer the lag. With a 10 cm. solid concrete slab it is about 2½ hours, whereas with a 20 cm. solid slab it will be about 6 hours. The heavier the slab the smaller the variation in temperature on the underside. In more humid tropics where day-night temperature range is less, the mass of the roof is less important provided the temperature of the underside is prevented from rising above the shade temperature. To ensure this a white surface treatment or some form of sun-shade is essential.

For rooms which are used only at night the roof should be capable of cooling down as rapidly as possible and a light structure is then more appropriate.

According to the recommended practice the thermal transmittance value for roofs of houses and flats should be about 0.2 to 0.39. Generally it is better to put a thermal insulation above the slab but it may sometimes be advantageous to place it underneath for other reasons.

Thermal insulation may be provided by the slab itself wholly, a water-proof layer at the top being given reflection treatment sufficient tokeep it reasonably hot. A sound absorbent ceiling may be added which would contribute to thermal insulation. Another typical construction would consist of the concrete portion acting as a screed placed on wood wool slabs carried on inverted T-sections. This type of roof is light, has a high thermal insulation and is free from condensation troubles. Suspended ceilings, along with a constant depth of water being maintained over the slab, may be useful for industrial structures.

Insulation of air spaces or cavities

Air spaces or cavities form an integral part of many modern constructions. The dimension of the cavity, the emissivity of the surfaces facing the cavity and the ventilation rate are important as the heat transfer takes place mainly by convection and radiation. It is now accepted that for a vertical air space unventilated and enclosed by surfaces of high emissivity, the resistance to heat flow across it will be the greatest when its width is at least 20 mm. In a horizontal cavity such as that in a flat roof or floor the convection currents tend to cross the width of the cavity when the direction of the heat flow is upwards ; with downward heat flow they try to get eliminated as the air is warmer at the upper part of the cavity. A value of 1.10 is adopted for the resistance of cavity when the cavity is unventilated, is at least 20 mm. wide, is horizontal, vertical, or inclined and has enclosing surfaces of ordinary building materials having an emissivity of 0.9. If a similar cavity is faced with material of low emissivity such as an aluminium foil (having emissivity of 0.1 or less) a value of 2.00 is considered to be a suitable resistance for this cavity. Ventilation by cooler air outside will reduce the thermal resistance of a cavity.

Economics of insulation

The following factors are taken into account while evaluating the economic feasibility of a particular type of insulation :

(1) Cost of providing and fixing the insulation.

(2) The areas of exposed surfaces and windows.

(3) The cost of heating or cooling.

(4) The standard of insulation maintained.

The insulation material may also be used as a load bearing member so that it could economise in the constructional cost of the building itself. Such use can only be made of rigid type of insulating materials. It should also be ensured that the insulating material has got an adequate resistance to fire, fungi and insect attack. The insulating material should also not absorb excessive quantities of moisture. It should not also be liable to change in its size due to expansion or contraction.

Condensation

Condensation on the interior surfaces of factories in which higher percentages of humidities are maintained is usually common. Moisture usually deposits on the underside of the ceilings. In residences, wall and ceiling condensation is not so important as the window condensation. The water vapour, instead of getting deposited at the inner surface of the ceiling, may pass through the roof or get deposited within the wall.

Whenever warm humid air comes into contact with surfaces which are below the dew point temperature, condensation of water vapour will take place. To prevent condensation on any surface, it is necessary to maintain the temperature of that surface above the dew point. The probable dew point temperatures can be estimated by knowing the relative humidity and the temperature conditions which are existing or going to exist in a building. After the dew point temperature has been established the next step is to determine as to how much insulation must be added to the wall or roof structure to maintain the interior surface above the dew point temperature at all times. The thickness of insulation must be sufficient to prevent surface condensation in the coolest possible weather. Whenever extremely severe conditions are encountered and excessively thick insulations are needed, additional precautions are taken. If the moisture is an outcome of manufacturing process, the humidity may be reduced by passing air through a dehumidifier. If high humidity is essential for the product under manufacture, ceiling condensation may be prevented by installing a vapour-tight ceiling under the roof deck and passing warm dry air through the space between roof and ceiling.

The water vapour within the living space gets first diffused within the building which consequently increases the relative humidity and vapour pressure. This vapour will then be removed by either leakage or through permeable spaces in walls or ceiling as most of the building materials are permeable. The rate of movement of vapour through a material is a function of the vapour pressure through two sides. This permeability is based on the area, pressure difference, thickness, time and the property of the material called permeance. The unit of permeance is called perm and this is the vapour transmission in grains per sq. ft. per hour per inch of mercury vapour pressure difference. For asphalt roofing felt, the value of permeance is about 6.62 ; for card board it is about 2.5 while for wood it ranges from 4.2 to 19 depending on thickness, etc.

The inside vapour pressure is usually higher in winter than outside and hence the direction of travel is usually from inside to outside through the walls or the ceilings and condensation occurs wherever the temperature goes below the dew point. Materials which restrict the movement of water vapour to one perm are used as vapour barriers. Vapour barriers are of two types, namely, the paint or liquid type and the sheet or membrane type. In general a continuous heavy coat of any water resisting material such as wax, varnish or bitumen is likely to have adequate vapour resistance. The vapour barrier should retain its vapour resisting qualities for the life of the building or if a paint is used until it is renewed. In the liquid type oil bases, rubber bases, asphalt and aluminium paints are included. The other type of vapour barriers consist of two sheets of heavy kraft paper with asphalt between them, aluminium foil mounted on one or both sides of paper and asphalt coated papers having bright finish.

Vapour barriers should always be installed on the warmer side of the wall and at a place where it will be above the dew point of the air-vapour mixture of the room. When insulation is applied to the top ceiling and the attic space is unheated the underside of the roof and the attic walls may become cool and increase the possibility of condensation if water vapour is permitted to pass through the ceiling to the attic space. To prevent such a condition attic spaces should be suitably ventilated. Definite areas of ventilation have been maintained for different types of constructions by the various building authorities.

Thermal treatments in tropical and sub-tropical regions

Indian climate can be broadly classified into three types, *viz.*, hot arid, hot humid and warm humid types. There are cold regions also but considerations of thermal insulations are more important in the first two types named above; and hence these are dealt with briefly in the succeeding paragraphs.

The hot arid climate is characterised by high air temperatures, dry air and dry ground. Under these conditions there will be little clouds or moisture in the air to screen off the sun's rays so that the resulting high intensity of direct solar radiation heats the ground further. The dryness of the ground reduces the plant life considerably and as such the soil reflects the solar radiation to a great extent. The evaporation can take place easily and hence a lot of heat can be radiated to the outer place.

One of the most important protective functions of the house is to screen the occupant from the incoming radiation. This may lead to difficulties as the enclosure of the house would get hot and thereby pass some heat into the interior. This would further deteriorate the conditions if the space within is not freely ventilated. It is better that this enclosure is exposed as little as possible and also it passes less heat into the interior. Roof is the surface which is exposed to the greatest radiation in the zone from 30° north to 30° south latitude. The walls facing the equator are subjected to a moderate heating effect during the day. East and west walls are subjected to somewhat higher heating effects for a part of the day. Internal barriers such as trees may be useful for screening the building from the radiation effects. Bushes, shrubs or artificial screens set on the eastern and western sides of the house are more effective for protecting those walls as the low altitude of sun in the morning and evening gives the main heating load. The wall facing the equator does not gain advantage by this effect as that precedes high angle sunshine. Houses in the east-west alignment may help each other unless the ventilation problems are not affected. Advantage can be taken by placing walls of store-rooms on western or eastern sides of the building. Grass or other covered vegetation may be grown in front of the building so as to reduce the reflection of heat. Projections of the sloping roof can protect the walls as they will cast shadows on the wall surfaces. Either one projection or different at different elevations can be used. Such projections are more effective with a high altitude sun and can be ideally used on the wall facing the equator or on both north and south walls for a building situated near the equator. Such projections are advantageously placed over door and window openings. Vertical projections can be used to exclude morning or evening sun from window openings on walls facing the equator.

Spraying roof or wall structures which are exposed to sun can be effective in reducing the heat load on the structure. Spraying should be intermittent to permit effective evaporation from the surface.

The smaller the surface presented by the house to the solar radiation, the lesser will be the heat gained. Least proportional heat load is experienced in hot seasons by the tall building with its long axis running east-west. A tall building of square floor design is also suitable irrespective of the orientation but it is not of great advantage during cold season. A single-storeyed building has the highest heat load under hot conditions but is fair to retain the same under cold conditions when it would be more desirable. In tropical regions where the sun is at a fairly high altitude during the most part of the day the slope of the roof has little effect on the total heat load. This is because of the fact that there is no effect on solar projection of the house by having a pitch which is lesser than the altitude of the sun.

Surfaces exposed to strong radiation will be heated by that part of radiation which is not reflected but absorbed. Movement of air over the surface will remove some of the heat and thus reduce the quantity of heat conducted into the interior. Selection of the site and construction of the building in a manner that it does not affect the freedom of wind movements is very important.

Insulation against the transference of heat may also be adopted. In hot climates heating is not constant ; it rises during the day and decreases by night. Under these circumstances any insulating material which will store a large quantity of heat during heating period and give it back when heat is removed is most suitable. This property of a material depends on its thermal conductivity, specific heat and also its density. When heat is continuously applied to one side of an insulating material, time is required to reach equilibrium and there will be a temperature gradient across each part of the insulator and the property which determines the rate of heat transference between certain distances at fixed temperatures is the thermal conductivity. This situation gets changed when the heat is applied to the outer surface. It is used up in warming particles of that surface and only after they have been warmed heat passes on to the next layer. Here the heat gets delayed again till it passes through the next layer. The rate at which the heat front advances through the material will be affected by the amount of heat needed in warming each layer. The rate at which heat newly applied to surface is diffused is called thermal diffusivity and it involves thermal conductivity, density and specific heat of the material. Materials like wood and clay are good as they have low diffusivity and are therefore usually employed as a building material. The storing capacity of heat of a material is more important in the case of roofing material. The quantity of heat transmitted should be small and hence such a type of construction should be adopted that the maximum temperature of the internal surface comes about twelve hours after the maximum temperature of the external surface has occurred. The heat in such a case will arrive at the interior surface when it is not objectionable for the comfort of the people.

Ventilation of the rooms must be suitably controlled to ensure comfortable living. The entry of external hot air should be reduced during the day-time in summer. Small doors or windows fitted with movable shutters can be helpful in this connection. These windows can be placed higher up in the walls to reduce the chances of radiation falling directly on the occupants of the room. If any air spaces are kept within the roof they should be suitably ventilated.

If the air is drawn through the ground at greater depth say about 4·5 metre from the ground level, cooling can be obtained in summer and heating in winter with its help. Basements in buildings utilise this principle but greater comfort can be derived if the air is passed through a fairly long tunnel before it is taken into the building.

Air passed over water gets cooled and its water content is increased. Under hot dry conditions use of wet towelling materials or screens which are kept damp and placed in such a position that air can be passed through them before coming in contact with the occupants are adopted as a simple means of giving comfort. This screen should be relatively thin as movemont of air is done naturally through it. A box cooler containing absorbent materials like cinders or wood wool over which water drips and air being pulled through the device by a fan is effective in cooling rooms.

The internal heat developed within the room must be suitably controlled. The size of combustion must be provided with openings so that the air is removed quickly within the combusting area to prevent transference of heat from this chamber. Reflecting materials can be used to diverge the heat towards the interior.

Warm Humid Climates

These areas have got moderately high temperature but are accompanied by moist air and damp ground. The presence of moisture in the air reduces certain amount of radiation. The moisture combined with moderate heat is favourable for growth of vegetation which further reduces the reflectivity of radiation. The amount of heat that is to be removed from a human body is mainly by evaporation which is usually difficult. Air movement which would facilitate evaporation gets reduced on account of plantation.

The problem in such climate is more important as people cannot have more comfort in sticky conditions and difficulties are created on account of prevalence of insects, dampness, etc. Special attention has to be paid to the flooring of a building. In an humid area an earthen floor would be more difficult. Impervious material resting on earth like concrete will keep a constant temperature and it will be relatively dry unless its temperature falls below the dew point of the atmosphere of the house. Although the average intensity of direct solar radiation is less it is still considerable on roof. Walls on the other hand are subjected to much less reflected radiation from the ground. As the trees are usually abundant they can be used to shade the roof and the walls. Mutual shading of houses is not very desirable as the measures would restrict the air movement between and through the houses which is very essential. Full advantage should be taken of the vegetation in preventing the reflection from ground. Use of attached shading elements such as sun breakers is helpful. The heat absorbed by these shading elements is returned and not added to the house itself. The solar projection of the roof should be minimised with a high altitude of sun. This is proportional to the horizontal area of the roof. The shape of the roof is important only when its slope exceeds the solar altitude. The roof of a multi-storeyed house would be better than that of a single-storeyed house. However, on account of greater wall heights it will become difficult to give proper shading effects.

Use of high reflectivity materials is helpful in reflecting major portion of the heat radiation but the superiority of such reflecting surfaces is not felt fully in warm humid conditions.

It is desirable to have air movement as much as possible on outer surfaces especially those which are of a damp nature. In dry periods spraying may be used on roof to supplement this effect. Similarly higher buildings are liable to have greater movements.

Insulation is less effective in this case than in hot dry climates. For walls which are suitable there will be no requirement for insulation against radiation.

Since the transference of heat by conduction is of lesser importance in warm humid climates, basements and other devices for heat exchange with the ground are not generally effective and may lead to difficulty due to higher water table.

The vapour pressure inside the house may become excessive due to washing, cooling, etc. and it is desirable that the external air replaces the internal. Natural air currents may be effective in this connection or else some type of fans may be used. The velocity of incoming air can be kept within limits with the aid of partitions, etc.

For other types of climates the factors enumerated above may be kept in view so as to conform to the particular prevailing conditions.

Treatment of different units in a building

Special considerations are necessary for some of the units in a building from the comfort point of view. In addition to the previously stated principles the following considerations should be kept in view :

(*a*) *Sleeping areas* : In hot dry areas full advantage should be taken at night of relatively cool sky as well as of cold air. This would mean that sleeping in the open air would be beneficial. Rain, early morning sun, etc., may be minor difficulties in this connection. In warm humid areas or when sleeping outside is not possible, quarters on the north-eastern sides with good opportunity for cool air are better. Openings should preferably start from the floor level. Where air conditioning or fan is available, its use may be justified in sleeping areas so as to remove the disturbing degree of heat.

Verandah which is simply an attached shading device is more functional in warm humid than in hot dry weather. Its disadvantage may be that it converts main rooms of the house into darker areas.

(*b*) *Kitchen* : In hot climates it is easier to separate the kitchen from the house, so that the heat and the smell will not fill in the living area. The shady side of the building is a better position for the kitchen within the house and attention should be paid to direction of breeze. In hot dry climates special ventilation may be restricted to the carriage of heat from cooking areas. In warm climates free ventilation directed outwards from the cooking range is desirable.

QUESTIONS

1. What are the factors responsible for heat transference ? How will you calculate the transmission losses ?

2. What are the various materials used for insulation ? Describe briefly their methods of application.

3. Write short notes on :
   (*i*) Insulation of roofs.
   (*ii*) Insulation of cavities.
   (*iii*) Economics of insulation.
   (*iv*) Condensation.

4. What are the various considerations of thermal treatment in tropical and sub-tropical regions ?

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VENTILATION AND AIR CONDITIONING OF BUILDINGS

In buildings the air change must be sufficient so as to remove any smoke, odour, etc., to an acceptable level. Ventilation may simply be defined as a process of removing or supplying air by natural or mechanical means to or from an air source. Apart from the necessity of supplying air for breathing, the quantity of air that is needed will depend on other conditions such as control on the concentration of bacteria within limits, presence of smoke or odour, keeping the humidity within limits or other factors. In an unventilated room there will be an increase in the amount of dust, excessive amount of carbon dioxide, unsuitable humidity or relatively uncontrollable air movements present.

The functional requirements of ventilation system are :

(*a*) *The rate of supply of fresh air*. This has to be different for various types of buildings depending on the type of work of the occupants and their number, the period for which they have to be in an enclosure, and other factors.

The main standards of ventilations as per I.S.I. requirements are :

Living room and Bedrooms : In case of living rooms and bedrooms, a minimum of three air changes per hour should be provided.

Kitchen. Large volumes of air are needed to remove steam, heat, smell and fumes generated in cooking and to prevent excessive rise of temperature and humidity. However, for the requirements of a kitchen in which cooking is done for a family of not more than five persons, a minimum of six air changes per hour shall be provided. In the case of restaurant kitchens, a minimum of twelve air changes per hour are provided.

Bathrooms and Water Closets : Considerable ventilation of bathrooms and water-closets is desirable after use and a minimum of six air changes per hour are provided.

Passages : The period of occupancy of passages, lobbies and the like is very short and as such no special consideration is necessary in designing these areas from the point of view of ventilation.

Factories: No standards have been laid down under the Factories Act (1948) as regards the amount of fresh air required per worker or the number of air changes per hour. Section 16 relating to safeguarding requires that at least 14 m^3 to 16 m^3 of space are provided for every worker and for the purpose of that section no account is taken of spaces in a work room which is more than 4.25 m above the floor level. The minimum fresh air required in a work room where there are no contaminants to be removed from air, is such as to effect three air changes per hour.

Recommended values of ventilation for hospitals, schools and other buildings are given in the following table :—

Recommended minimum rates of fresh air supply to buildings for human habitation

Type of building	*Recommended minimum rate of fresh air supply to buildings*
Assembly halls	100 cu. m. per hour per person
Canteens	100 cu. m. per hour per person
Factories and workshops	
work rooms	80 cu. m. per hour per person
Lavatories and W. Cs.	2 air changes per hour
Hospitals :	
Operating theatres and x-ray rooms	10 air changes per hour
Wards	3 air changes per hour
Houses and Flats	
Bath rooms and W.Cs.	2 air changes per hour
Halls and passages	1 air change per hour
Kitchens (cooking for not more than six people)	200 cu. m. per hour
Living rooms and bed rooms	
30 cu. m. per person	72 cu. m. per hour per person
40 cu. m. per person	60 cu. m. per hour per person
50 cu. m. per person	42 cu. m. per hour per person
Pantries	2 air changes per hour
Kitchens (large)	up to 20 air changes
Office buildings :	
Offices	
20 cu. m. per person	100 cu. m. per hour per person
30 cu. m. per person	72 cu. m. per hour per person
40 cu. m. per person	60 cu. m. per hour per person
50 cu. m. per person	42 cu. m. per hour per person
Lavatories and W.Cs.	2 air changes per hour
Places of entertainment	100 cu. m. per hour per person
Restaurants	100 cu. m. per hour per person
Schools:	
Occupied rooms (class rooms, laboratories. etc.)	150 cu. m. per hour per person
10 cu. m. per person	100 cu. m. per hour per person
20 cu. m. per person	72 cu. m. per hour per person
30 cu. m. per person	62 cu. m. per hour per person
50 cu. m. per person	42 cu. m. per hour per person
Cloak rooms	3 air changes per hour
Corridors, lavatories and W.Cs.	2 air changes per hour
Shops	100 cu. m. per hour per person

(*b*) *Air movements*: Air movements whether affecting a change of air or not tend to relieve stuffiness and contribute to a feeling of freshness. Too vigorous air movements may lead to an effect of chilliness and complaints of draughts. The speed at which an air current becomes noticeable depends on its temperature, this critical speed decreasing as the temperature falls. A velocity of 7 to 15 m. per min. is desirable in winter in living rooms and other rooms. It is needed for light manual operations. To provide comfortable conditions in summer, air velocities up to 30 m. per min. may become necessary. Where heavy manual labour is done the desirable air movement both in winter and summer may be greater than these figures. When the nature of a manufacturing process demands conditions of temperature and humidity above normal range for personal comfort, such conditions require extra consideration, particularly if the dry bulb temperature is above the body temperature.

In naturally ventilated buildings, cross ventilation is normally relied to secure air movement. In mechanically ventilated buildings, movement may be got by either increasing the rate of fresh air supply in summer or by recirculation of a part of air in water. The air movement will depend on the velocity of incoming air and the disposition of the inlets. With either mechanical or natural ventilation fans may be used to increase air movement. The air current should preferably be varied both in velocity and direction. The velocity should be greater at the top than at the floor level. Air currents falling on the back of the body may be a sort of discomfort and must be avoided. The distribution of ventilated air should be such that no stagnation is caused.

(*c*) *Temperature of air*. In winter, the incoming air should be warm before it enters the room, if possible Whenever the velocity of the incoming air is high, its temperature should not be lower than the room temperature. Similarly large temperature differences can be tolerated by occupants doing heavy work. But for light work the temperature difference should be small. In summer the incoming air should preferably be cooled. The general temperature difference between inside and outside temperature should not be more than 8°C.

(*d*) *Humidity*: Relative humidity within the range of 30 to 70 per cent may be acceptable up to temperature of 20°C. When work is done at a higher temperature, low humidity and greater air movements are necessary for removing a greater portion of heat from the body. For theatres a higher value of humidity is desirable.

(*e*) *Purity*: The ventilating air should be free from organic impurities and harmful inorganic dust. It should not come from the neighbourhood of chimneys, kitchens or latrines or such other sources. Air containing less than 0.5 mg. of suspended impurity per cubic metre and less than 0.5 part per million of sulpur dioxide is considered to be clean and may not need any special treatment. Where clean air is not available it may be necessary to ventilate air which should be free from bacterial pollution.

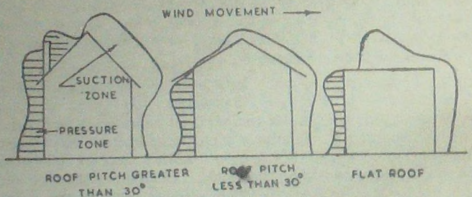
Types of ventilation

Mechanical ventilation and natural ventilation are the two basic methods employed.

Mechanical ventilation is to be adopted in all cases where satisfactory standard of ventilation cannot be maintained with the aid of natural means. The method is usually desirable when a room is occupied by more than 50 persons and where space per occupant is less than 10 cu. m.

Natural ventilation should be affected where accurate control over the air condition and the rate of change of air is not needed. Control over rate of air change is often poor, and it is difficult to ensure that the recommended rates can be obtained, especially on calm days in summer when air movement is most needed. When the provision of windows is possible, care has to be taken that atmospheric pollution or large transference of noise into the interior is avoided. Natural ventilation is suitable for domestic houses and flats.

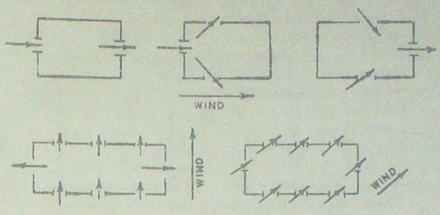
Natural ventilation : Natural ventilation depends for its action on wind effect and an effect due to temperature difference called "stack effect." Wind is not controllable and only limited control of stack is possible, as the latter depends on the value of external air temperature. Suitable openings have to be provided for structure to



Figs. 1060-1062. Wind pressure effects on buildings.

allow the air change to take place. The size, position and the design of these openings are important.

Wind creates pressure differences and when it blows against a building, a positive pressure is created on the windward side and leeward side. Suction will also occur on the other side and the wind will blow from the windward side to the other side if there is any opening. If the direction of wind is at about 45 degrees to one of the faces the positive pressure will be created on the two inward faces and negative pressure on the leeward faces. The pressure at the opening of a sloping roof will depend on the pitch of the roof and also to some extent on the length of the roof. It has been seen that roof pressures in general are negative except on the windward side of a roof with slope greater than 30°. With a flat roof the negative pressures occur at the windward side and thereby give positive pressures farther along the roof.



Figs. 1063-1067. Movement of wind through buildings.

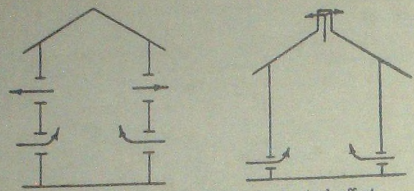
Rate at which the air change will occur will be governed by the pressure difference between the inside and outside. The greater the air speed the greater will be the pressure difference and some times air changes can occur quickly. While calculating the air changes the effects of stagnation have to be accounted for although they are difficult to be calculated. If the inlet areas is the same as the outlet area the rate of flow of air is given as :

$$V = 16630 \times A \times v$$

where V is the rate of flow of air in cubic metre, A is the area in square metre and v is the speed of wind in km. per hour. Suitable adjustments have to be made whenever the area of the inlets and outlets is not the same.

Total area of outlets / *Total area of inlets*	*Value to be used instead of 16630*
1	16630
2	21120
3	22460
4	22970
5	23230
3/4	14250
1/2	10560
1/4	5710

Ventilation due to stack effect : If the air temperature inside is higher than that of outside, the warmer air tries to rise and pass through openings in the upper part of the building. Cooler air coming in from outside through the opening at lower elevation replaces it. The rate at which such changes will occur will depend on the temperature difference between inside and outside air, on the height between the inlet and outlet and the area or the design of the openings. The rate of air flow when the outlet and inlet areas are the same can be calculated by the Formula $V=(C/A\sqrt{ht}$ where V is the air flow in cubic metre per hour, A is the area of the inlet in sq. metre, h is the height between inlet and outlet in metres, t is the temperature difference between inside and outside of the building and C is a constant in °C.



Figs. 1068-1069. Ventilation due to stack effect.

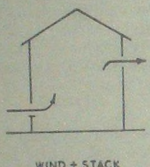


Fig. 1070. Action of wind and stack effect.

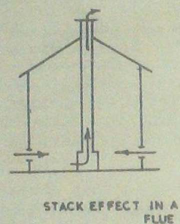


Fig. 1071.

The ventilation rate obtained by the natural effects will show variations throughout the year. Average values of air required for ventilation can be found out from the above formula. But if for any building constant rate is essential controls must be used ; the ventilated air should be greater than needed. The variation in wind speed and temperature must be taken into account.

Inlets and outlets : Inlet opening should be located at low level on windward side. Outlet should be in the leeward side near the ceiling in the side walls and in the roofs. Inlets and outlets should preferably be of equal size but when outlet is in the form of a roof opening the inlet should be larger. Where the wind direction is variable, opening should be provided in all walls, with the means of closing them. Openings at the same level but on the opposite sides of the room may cause short circuiting. Hence for this reason wherever a flue is used as outlet, the inlet may be placed near the ceiling away from the fire-place wall. The height of the room has a little effect on the ventilation by wind force. Increased height gives better ventilation by stack effect.

Long narrow rooms may be ventilated by opening in the short side or by series of openings in both the long sides. Rooms which have windows at high elevations are difficult to be ventilated by openings at two levels in the back wall. Opening over the door in the back wall is of great value for creating cross-ventilation. Infiltration of air through masonry or plastered walls is negligible. The infiltration between doors or windows and their frames may be considerable.

It is important to ascertain the degree of ventilation provided by wall ventilators, flues and windows. In a flue room having a capacity of 100 to 150 cu. m. with doors and windows closed and ventilated by a single ventilator 20×15 cm. in size, the volume of ventilated air is about 60 to 120 cu. m. per hour which is about three-quarters of air change per hour. This includes the movement of air which takes place through the closed doors and windows on account of leakage. With larger openings the volume of air increases as shown by the table below :

RATES OF AIR FLOW THROUGH WALL VENTILATORS

Free area of opening sq. cm.	*Volume of air (cu. m. per hr.)*
50	60–120
150	110–200
250	160—300

On a day when the air velocity is less, the ventilated air will be reduced and on the windy days the volume of ventilated air will be doubled. The direction of wind has some effect especially with large openings and greatest air change is obtained when the wind blows directly on to the opening. The ventilation produced by a single ventilator as considered in the above table is affected only when the velocity of air is less.

A flue generally produces greater ventilation than an air grating in an external wall. A 10 cm. diameter flue will introduce a flow of about 100 to 150 cu. m. per hour ; and ordinarily cools twice this capacity, without special openings for the admission of air. The air transference capacity of a flue is greatly increased when it is warm. The rate of air is affected by the presence or absence of adequate openings for air to enter or leave. If windows as well as flue gratings are opened, high rates of air changes are possible. Open windows on both sides of a room may provide 20 to 30 changes per hour equivalent to volumes greater than 10,000 cu. m. per hour. Even when there is a slight leakage from the window the air changes may be 2 to 3 times more than when the windows are completely closed. Where gas or fuel burns, arrangements should be made for supply of sufficient air for the purpose of combustion of the gas and for the ventilation of the room. For those appliances which require a flue, this should not be smaller than the outlet of the appliance and the flue pipes should be taken to the highest level to carry away the products of combustion in all weather conditions.

Mechanical Ventilation : The types of mechanical ventilation in common use are :—

(a) *Simple extract* : Small extraction fans usually of propeller type are installed in outside walls or in roofs. These should be connected to a system of duct work so that air from all areas of the room or a number of rooms is carried away.

(b) *Simple input* : Small input fans, of the propeller type or axial-flow type are installed in outside walls, and these may be connected to a simple duct system.

These two systems are essential to make ventilation in crowded rooms or offices or any place where fumes and odours are prevalent. These systems are difficult to control and may not provide comfortable condition throughout the year. A combination of input and extract fans may be provided for better working

(c) *Plenum ventilation* : A plenum ventilation system consists of a centralised fan plant with a system of trunking for distribution throughout the building. The air inlet is selected on the side of the building where the air is purest. In this opening, screens or filters may be fixed. A fine stream of water may be impunged in the path of air. Disinfection with the aid of ozone may be done by means of injecting a stream of ozone into the air. Heating of the air may be resorted to if needed. The distribution system is properly planned to achieve a smooth flow.

(d) *Plenum and extract ventilation* : Additional extraction fans are installed along with the plenum system. Such type of system is used when air is very slow in movement due to complication of design, etc. This method is also helpful in discharging abnoxious gases into specially isolated areas.

(e) *Air conditioning* : In such a system, provision is kept for humidifying or dehumidifying, heating or cooling, filtration. etc., of the air. Such systems are highly effective in creating comfortable conditions and are described in the following pages.

AIR CONDITIONING

Air conditioning is defined as the science of creating, controlling and maintaining indoor atmospheric conditions best suited to the physiological requirements of man or to the needs of industry. It may be employed to preserve and maintain health, comfort and convenience of people in their homes. Industrial air conditioning is to do with materials and may be used for the preparation of materials such as artificial silk or preservation of fruits. Commercially air conditioning is employed for theatres, restaurants, shops, offices, etc. for maintaining comfort of the occupants within these concerns.

Air conditioning consists in refining of air in order that it may be used to the best advantage within an enclosure for the better health, comfort and convenience of people. The outside area as unconditioned has got a very high or low temperature, unsuitable humidity, velocity, etc., and may be full of dust, etc. Conditioned air would mean an atmosphere having controlled temperature, humidity and velocity conditions with dust cleanliness as much as possible.

In summer the air is hot and for conditioning the processes needed are to cool, dehumidify, clean and circulate the air properly. For winter months the air is to be heated, humidified, cleaned and circulated properly.

A feeling of comfort is a good indication of healthier atmospheric conditions. The control of temperature, air motion and relative humidity, is absolutely necessary in an air conditioning system. It is evident that a human being will feel comfortable in a certain temperature, air velocity and humidity. But since people move from one room to another or from one place to another and perform different duties, hence such conditions are different for different people. The feeling of comfort will also vary with outside weather conditions. Research has been carried out in different countries to develop the values of temperature, humidity as well as air velocity which give comfortable conditions for different seasons of the year. The investigators have made considerable tests to determine the temperature range which is suitable to majority of people ; and this is called the comfortable zone. There is difference between the comfortable zone in winter and summer. This is due to the clothing worn in the two seasons and also due to the changes in the body. The winter comfortable zone includes an effective temperature zone range from 18°C to 22°C while 20°C is considered to be a comfort line. The summer comfort zone lies between 20°C and 23°C while 21°C is considered to be a comfort line. These temperatures are not exactly the same which may be suitable for our country, but they just give an idea of the nature of the temperatures which are suitable. Although effective temperature is a measure of the comfort of the human body under most conditions of humidity and air motion, there is a difference of heat lost from a body by radiation or convection and of evaporation for the same effective temperature for different persons.

For practical reasons the limits, which have been set up, have to be modified to keep in view the working conditions of the people. In hot weather when a person comes to a cold room at 22°C a feeling of extreme cold or shock is created. Similarly when he leaves this cold room and comes in contact with the outside temperature he feels a sense of discomfort because the room is cold and he is subjected to a higher temperature instantaneously. Hence large temperature difference between indoor and outdoor air must be removed, as they are harmful to the body. In summer the human body adapts itself to higher temperature than in winter. When conditioned spaces are used by people only for short intervals of time, a difference of 8°C between outside and inside air should not be exceeded. Whenever people have to sit for longer periods within an air-conditioned enclosure, *e.g.*, those working in offices, etc., higher dry bulb temperature can be maintained. A temperature of 21°C to 22.5°C is required in such cases for comfort regardless of outside temperature.

Regulation of air velocity is very important. The increased air velocity adds to the effect of decreasing the effective temperatures below outside temperatures. Unequal air movement upsets the regulation of conditioned air. Suitable air velocity should be adopted which can circulate properly. This is generally taken as 6 to 9 m. per minute which is considered relatively still air. Air velocity just near the outlets will be a bit higher than this but since these outlets are at greater heights a feeling of discomfort does not get created.

Humidity control is equally important with conditioning air. If air is very dry a great strain is put on the membranes of nasal passages which may become dry and irritated. For practical reasons relative humidity is kept between 35 to 65% whereas desirable limit between 40 to 60% may be adopted. During the hot season 40 to 50% relative humidity is most comfortable and for cold weather 50 to 60% is best. But these values for winter season in cold areas may create condensation on window glasses.

In India not much research has been done on the comfort of people at different temperatures and relative humidities. But by experience it has been seen that the comfort zone for this country extends from 23.5°C with 60% relative humidity to about 30°C with 45% relative humidity. These values assume that velocity of air does not exceed 10 metre per minute. It should be economically possible to achieve these values and hence it is always desirable to have a temperature difference of 8°C between interior and exterior temperatures as stated earlier. In the plains of our country the climate is dry and hence if correct relative humidity is maintained along with a suitable velocity of air a comfortable condition can be maintained. For health reasons, air conditioned spaces where people leave or enter frequently, it is desirable to have entrance lobbies which have a temperature midway between interior and exterior enclosures so that a person may not get sudden shock while leaving or entering. For efficient and economical air conditioning it is desirable to keep the inside atmosphere as free as possible from direct heat transmission, humidity or dust from exterior. For this reason suitable solid barriers in the form of doors, windows, roofs, etc. are created to offer resistance to these elements. The object of selecting a particular barrier is to prevent the transmission as much as feasible; and hence for prevention of heat transmission, materials having low conductivity should be adopted. Doors and windows may be made of double glazed type. A tight construction using impermeable materials helps in reducing their air leakage. Creation of exterior barriers like sun shades, sun breakers, etc. prevents the direct effect of sun's rays into the room. A combination of various barriers would be more helpful.

Systems of air conditioning

Basically four systems of air conditioning are adopted :—

(1) *Central system* : A central system uses conditioned air for all the requirements and for one or more seasons at one focal or

central point. The conditioned air is then distributed to the various rooms or enclosures which are being treated.

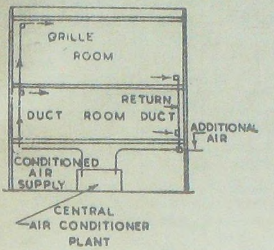


Fig. 1072. A central system of air conditioning.

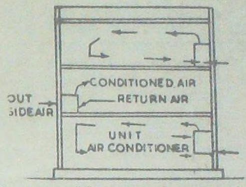


Fig. 1073. Self-contained (unit system) of air conditioning.

(2) *Self-contained system* : The self-contained system (*e.g.* a room unit) conditions air within the unit itself.

(3) *Semi-contained system* : This usually conditions air for all the common and one or both the seasonal requirements within unit but the heating and cooling mediums are generated at other point and delivered to the individual units.

(4) *Combined system* : A combined system may consist of the combination of (*a*) central and self-conditioned system, (*b*) central and semi-contained system, and (*c*) self-and semi-contained system.

Air circulation

Circulation of air is an essential requirement in an air conditioned system. The minimum fresh air requirements as per I.S.I. code of practice are indicated in table on page 476.

Basically air circulation can be achieved by the following apparatus :—

(1) Air pumps.

(2) Air delivery system consisting of supply and return ducts.

(3) Air distribution system consisting of inlets and outlets.

Air pumps are of the following two types as used in air conditioning :

(*a*) Flow, propeller or fan type.

(*b*) Radial flow, centrifugal or blower type.

The propeller type is used to produce air at relatively lower pressures. They generally have two to eight blades of various grades, thicknesses and shapes. The static pressure against which

MINIMUM FRESH AIR REQUIREMENTS

Sl. No.	Application	Smoking	m^3/min Per Person: Recommended	m^3/min Per Person: Minimum	m^3/m per m^2 of Floor Area
1	2	3	4	5	6
(1)	Apartments	Some	0.56	0.28	—
(2)	Banking space	Occasional	0.28	0.21	—
(3)	Board rooms	Very heavy	1.40	0.56	—
(4)	Department stores	None	0.21	0.14	0.015
(5)	Directors' rooms	Very heavy	1.40	0.84	—
(6)	Drug stores*	Considerable	0.28	0.21	—
(7)	Factories	None	0.28	0.21	0.03
(8)	Garages	—	—	—	0.30
(9)	Hospitals :				
	(a) Operating rooms (all fresh air)	None	—	—	0.60
	(b) Private rooms	None	0.84	0.70	0.10
	(c) Wards	None	0.56	0.28	—
(10)	Hotel rooms	Heavy	0.84	0 70	0.10
(11)	Kitchens :				
	(a) Restaurant	—	—	—	1.20
	(b) Residence	—	—	—	0.60
(12)	Laboratories	Some	0.56	0.42	—
(13)	Meeting rooms	Very heavy	1.40	0.84	0.38
(14)	Offices :				
	(a) General	Some	0.42	0.28	—
	(b) Private	None	0.70	0.42	0.08
		Considerable	0.84	0.70	0.08
(15)	Restaurants :				
	(a) Cafeteria	Considerable	0.34	0.28	—
	(b) Dining room	Considerable	0.42	0.34	—
(16)	Retail shop	None	0.28	0.21	—
(17)	Theatre	None	0.21	0.14	—
		Some	0.42	0.28	—
(18)	Toilets (exhaust)	—	—	—	0.60

*In case exhaust air required is more than fresh air specified, then fresh air requirements will take exhaust considerations into account.

fan will deliver air depends on its design. Fan operating against relatively high static pressure will deliver air from outer corners of the blades or propellers owing to the high linear speed of these sections. These fans have advantage of lower initial cost and economic operation. However, they create excessive noise.

Multi-blade or centrifugal fans are generally of straight blade, forward curved blade, and backward curved blade types. The forward curved multi-blade fan is very suitable for air conditioning works because of its low speed, quiet operation and large capacity. The backward curved blade fans are also suitable for air conditioning work. These have also the advantage that they operate more quietly and their higher speeds permit direct connection to motors. Their power requirements also do not increase considerably as the static pressure increases. While selecting a particular type of fan, its efficiency, cubic contents of the air which it gives, static pressure required by the system, type of available motive power, permissible noise level, etc., must be kept in view. Air conditioning fan must give to the air the needed velocity and pressures to overcome the resistance to the overflow set up by the ducts and also must maintain the desired velocity of the air at the exit from the supply grilles.

The air delivery system consists of the supply ducts, the return ducts, dampers and duct insulation. Ducts should be made of sheet metal to the required size and shape. The supply ducts are carefully calculated, shaped and designed for volume velocity and pressure so that proper distribution with the aid of the supply outlet may be obtained in each room or enclosure. Similarly care should be taken for return ducts. Dampers manually or automatically operated are placed in the ducts to control the direction, velocity and volume of circulating air. Supply ducts from the air conditioned unit to the supply outlets should be properly insulated to save loss of heat, etc.

Outlets or inlets should be in the form of grilles or registers. The grille is an outlet or inlet having no damper or air control device for control. The position of the outlet and the inlet and their relation to one another are of great importance. The outlet for the supply of the conditioned air to a room is best placed in the ceiling or one side of a wall high enough from the floor to prevent direct discharge of air upon the occupants. In the case of rooms with high walls the outlets should be placed lower down to prevent distribution within the upper side of unoccupied spaces. As a rule, for wall outlets, the height is not less than 2 metre from the floor and not less than 45 cm. from the ceiling. Supply outlets are usually placed on interior or cross-partitions. The object of the supply outlet should be to distribute conditioned air into the room without any draught. Inlets for the return of fowl air from individual rooms are placed at the beginning or the receiving end of the return air duct. They may be either grilles or registers depending upon the control desired and economical limitations.

Cleaning of air

Atmospheric dust consists of minute particles of sand, ash, soot, chemicals, bacteria and other micro-organisms. Clean country air usually contains small concentration of dust ranging from 0·2 to 0·5 grains per 100 cu. m. of air and hence it is not harmful for inhabitants. In large steel and manufacturing concerns the dust content may be as high as 1·5 grains per 100 cu. m. which is harmful to human body. The purpose of obtaining clean air into a room is to reduce the concentration of the dust to a small fraction so that it becomes harmless. To accomplish this it is necessary to provide air filters or cleaners. Their object is to remove harmful particles from the air efficiently. They should be workable under a wide range of velocities. They should have a low frictional resistance to the flow of air. They should also be capable of holding a moderate amount of dust without decreasing their efficiency further and should be able to be cleaned automatically or manually. The air that passes out of them should not get contaminated with the moisture or chemicals used in the cleaner itself. According to the principles of working, air cleaners can be classified as under :

(1) Viscous filters—(*a*) Automatic type.
(*b*) Unit type.

(2) Dry filters.

(3) Washers.

(4) Electric precipitators.

Viscous automatic filters are mechanically operated in a continuous cycle consisting of the cleaning of air, removal of air pollution particles, replacing the viscous filter medium and placing the refreshed area of the filter medium into the air stream for further utilisation. The dust, etc., is collected in liquid storage vessel from which it must be periodically removed. The cleaning or washing is done either by revolving the filter medium through a bath of liquid or by admitting the liquid through or over the stationary filtering area. This type of filter gives a constant resistance to the air flow but is very costly.

Unit type of viscous filters are made of screens made of split wire, spun glass fibre or other material with a viscous adhesive unit type filter varying in sizes from 40 to 65 cm. and having approximately 15 sq. cm. area. This size renders the handling of filter easy and quick removal for cleaning, etc. As the dust laid in the air passes through the filter, its direction of flow changes many times. These filters are very efficient in removing the dust and even bacteria to some extent.

Dry filters are made of cloth such as flannel, cellulose, felt, etc. The air passes through this filter material and gets trapped within its passages. The velocity of air is low and hence a large filtering area is needed.

Spray washers are mostly used for cleaning purposes. Dust and fumes can only be removed if particles become actually wet or absorb moisture from the spray. It depends largely on the type of dust and the length of time the particles are in contact with the spray. They can remove as much as 65% dust from the air.

Electric precipitators work on the principle that dust particles when subjected to a strong electric field get charged and thereby are attracted to the negative electrode. On this electrode, they get deposited and when a sufficient deposition is formed, the deposit gets detached and falls down. This type of cleaning equipment is the latest one which is used.

Method of removing the excessive heat from air

The excessive heat which finds its way into the air-conditioned space or gets created must be removed by cooling and dehumidifying equipment. The latent heat is first changed to sensible heat which is achieved by condensing the excessive water vapour in the air. The exact amount of heat that is required to evaporate the moisture in air gets reduced when water vapour is condensed. This heat transfers into sensible heat in the condensing medium and results into an increase in temperature of medium. The latent and sensible heat in a building raises the temperature of the moisture content of air inside the building. This air is circulated through the heat removing equipment where the excess moisture and sensible heat are removed. After the excess heat has been removed the air together with additional amount brought from outside for ventilation purposes, is also passed through cooling equipment and then circulated through the building.

The methods of cooling generally adopted are (1) surface cooling, (2) spray cooling, and (3) evaporative cooling.

In surface type cooling the air is passed over coils or fins in which cold water or refrigerants are circulated. The temperature of these cooling media must be below the desired temperature of the air. Where air passes over the coils the dry bulb and wet bulb temperatures get reduced to the dew temperature of the air. When air is cooled below this point the moisture is removed. The amount of coil surface needed to cool and dehumidify the air depends on the average temperature difference between the air entering the coil and leaving the coil. This difference is 6°C to 12°C when water or brine is used. Where refrigerant is itself evaporated in the coils, there is little difference between entering and leaving temperature. In this process of cooling and dehumidifying air, the air leaves at about 80% to 85% saturation, although the coil temperature may be at the dew point ; their air leaving the coil has got a temperature a few degrees higher.

For a spray type the air passes through the spray of water which has been cooled to a temperature below the desired dew point of air and then passed through the eliminator plates which have vertical baffles to take out any water that is present in the air in the form of fog or small drops. When air enters the fine water spray a sufficient amount of water is evaporated and the heat required to evaporate this water is supplied by the sensible heat of the entering air. As this heat is taken from the air, the dry bulb temperature gets reduced.

In evaporative cooling the air to be cooled passes through a spray of air, the air by dehumidification gets cooled to the wet bulb temperature until the dry and wet bulb temperatures are the same. Refrigerants can also be used for cooling the air. Various methods for accomplishing this are used. In one of the methods the air is passed directly over the medium which absorbs the latent heat from the air and cools it. Alternatively water is passed over ice and cold water is circulated through the cooling tubes. Volatile refrigerants of inflammable or non-inflammable character may be used. Carbon sulphide, methyl chloride, chloroform, ether are the substances of the former category, while carbon dioxide, sulphur dioxide, etc. belong to the latter category. The vapours of the volatile refrigerant enter the cylinder on the compression side and get compressed. It is then passed through a condenser which is supplied with cooling water at a suitable temperature so that high vapour pressure is changed into a still higher vapour pressure, but the temperature being reduced. This liquid after being collected in a vessel is allowed to pass through an expansion valve into a chamber or set of tubes. At this place the pressure gets suddenly reduced and the liquid gets transformed into vapour. While doing this it absorbs large amount of heat from the material surrounding the tubes which may be air to be used in air-conditioning.

Dehumidifying air

Dehumidification may be accomplished by condensation or desiccation. Condensation can be done with the aid of surface cooling or spray cooling as described earlier. The desiccation is the removal of moisture from the substance and is carried out by two methods, namely :

Adsorption and Absorption : Materials which hold moisture on their surfaces are called Adsorbers. The moisture does not get absorbed into these materials but mainly remains on their surfaces. Usually activated alumina and silica jels are used as adsorbents. The air is passed through the beds of small particles of these adsorbents and dries in this manner. After the adsorption of a certain amount of moisture, the adsorbent is reactivated by heating it to a higher temperature.

Absorbents usually are solutions of ammonia, calcium or other salts, and these remove moisture from air. These salts are mixed with water and kept at certain concentration and temperature. The salt solution after being cooled is sprayed over glass wool or other material. The air to be dehumidified passes over the material and the excess moisture in air is absorbed by strong salt solution. This type of working removes all excess latent heat but does not remove sensible heat which can be removed by cooling further.

Humidification

In winter the outside air, because of its lower temperature, has very low humidity.

When air is humidified the heat evaporation must be added. This heat may be added to the spray water before actual humidification or it may be taken as sensible heat from the air and transformed to latent heat of evaporation for humidification. Humidification may be accomplished by (*i*) injecting a direct spray of water into room, (*ii*) introducing moistured air, (*iii*) a combined process. Washers may be considered as an indirect class of humidifying agents. The humidification of air with washer may be affected by the use of recirculating spray of water without prior treatment of entering air. Otherwise air may be pre-heated ; or alternatively a heated spray of water may be used while injecting fine water sprays into the air inside any enclosure. It should be ensured that the sprays are very fine so that water does not spread on any object within the enclosure.

Heating

For supplying heat to a building generally the steps are (1) fuel is burnt, (2) the generated heat by the combustion of fuel is used to heat the air or water, and (3) the heated air, water or steam is used to supply the heat lost from the building. For heating, the following methods are generally used :—

(*i*) *Use of steam* : In this, heat is transformed from the boiler to the heating system, by means of pipes in the form of steam. The vacuum steam heating system having mechanical air expeller and a water pump which can be used below atmospheric pressure, is also used.

(*ii*) *Hot water system* : In hot water heating system, water is the medium for carrying the heat from the boiler through pipes to the heating unit.

(*iii*) *Use of warm air* : This system consists of a heating unit enclosed in a jacket, the heat being carried from these units to the rooms or spaces to be heated. The heat to be supplied to the rooms first passes over heating unit surfaces where it is heated and after that it flows through pipes or ducts to different rooms.

QUESTIONS

1. What are the main requirements of a good ventilating system ?

2. Describe briefly the various types of natural and mechanical ventilating systems.

3. Write short notes on :
   (*i*) Plenum ventilation.
   (*ii*) Stack effect.
   (*iii*) Positioning of inlets and outlets in buildings.

4. What is the object of air conditioning ? What do you understand by the term 'comfort zone' ?

5. What are the various factors which have to be taken into account while designing an air conditioning system ?

6. Briefly describe the various systems of air conditioning. How is the correct circulation of air within air-conditioned building ensured ?

7. Write short notes on :
   (*i*) Cleaning of air for an air-conditioning system.
   (*ii*) Humidification of air.
   (*iii*) Cooling of air for an air conditioning plant.

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22

ACOUSTICS AND SOUND INSULATION

Acoustics is a science which deals with the design and construction of different units of buildings to get proper acoustical conditions and also with the correction of the corresponding defects in existing rooms. It also includes the sound absorption or dissipation of exterior noise.

Sound is transmitted in the form of waves which are a series of compressions and rarifications created in the medium through which it travels. The average sound travels at ordinary temperature with a speed of 340 m. per second. This velocity depends on the medium through which it travels. The velocity of sound through water is 1310 m. per second and through brick and steel is 3600 and 4900 m. per second respectively.

Reflection of sound is one of the important considerations in any acoustical design problem and this leads to most of the difficulties. Repeated reflection between parallel walls sets up flutter of sound which is undesirable. In smaller rooms this sets up disturbing resonance. In the case of curved walls which are convex, the reflected sounds get diverged. Walls of focusing nature are objectionable as they concentrate the reflected sound at definite places.

If the reflected sound reaches the audience 1/15th of a second after the direct sound from the speaker, an echo is heard If the time lap becomes less than 0·05 second, a beneficial effect called "reinforcement" results. If the compressions of direct sound combine with the compressions of the reflected sound, the result would be the creation of louder sound than either of the two alone. A similar case occurs when rarefactions get combined. If, however, the compressions of direct sound combine with the rarefactions of the reflected sound the resulting sound will be weaker. If a whole number of half waves get set up between parallel walls, reinforcement of sound or resonance is created. If the reflected sound reaches the audience later by 0.05 second than the direct sound, then blurring of speech gets created. If a series of sounds of slightly different frequencies combine at about the same time, an effect of loudness called beats is created, as at certain intervals the compressions of one wave get combined with the compressions of the other wave.

Sound in a building is generally classified as speech, music and noise. Three characteristics, *i.e.*, frequencies intensity, and tone structure are important for common types of sound. Frequency is defined as the number of cycles per second. Range of frequency is greater for music than for speech. Intensity of sound is defined as flow of sound energy per second through unit area. For average sound this energy is small. In ordinary units range of intensities that can be perceived by the ear is enormous ranging from one unit for a faint sound to 1,012 units for a very loud sound. For convenient expression of these units a term decibel is used which means as ten times the logarithm of the intensity. Some values for various types of sounds are given in the table below :—

Feeling	*Intensity i.e. Sound energy per second through unit area*	*Decibels*	*Type of Sound*
	1,000,000,000,000	120	Thunder, artillery
Deafening	1,000,000,000,00	110	Nearly riveter Boiler factory
	1,000,000,000,0	100	
Very loud	1,000,000,000	90	Loud street noise Noisy factory Police whistle
	1,000,000,00	80	
Loud	1,000,000,0	70	Noisy office Average street noise Average radio Average factory
	1,000,000	60	
Moderate	1,000,00	50	Noisy home Average office Average conversation Quiet radio
	1,000,0	40	
Faint	1,000	30	Quiet home or private office Average auditorium Quiet Conversation
	100	20	
Very faint	10	10	Rustle of leaves Whisper Sound proof room
	0	0	Threshold of audibility

The acceptable indoor noise levels for various buildings are indicated in table at next page.

The tone characteristic is that particular property by which sounds of the same frequency and intensity can be distinguished from each other. To achieve good results, it is necessary to note the limitation of hearing which a human person can have. The range of frequencies which can be neard by human ear varies from 13 to 16

TABLE : ACCEPTABLE INDOOR NOISE LEVELS FOR VARIOUS BUILDINGS

Sl. No.	Location	*Noise Level dB (A)*
(1)	(2)	(3)
(1)	Radio and TV studios	25-30
(2)	Music room	30-35
(3)	Hospitals and auditoria	35-40
(4)	Apartments, hotels and homes	35-40
(5)	Conference rooms, small offices and libraries	35-40
(6)	Court rooms and class-rooms	40-45
(7)	Large public offices, banks and stores	45-50
(8)	Restaurants	50-55

thousand cycles per second and the intensity varies by about 120 decibels in the region of 1,000 cycles.

When a speaker addresses an audience, the sound he utters proceeds outward in the form of spherical waves until they strike the boundary of the room where they can be redected, transmitted and absorbed in various amounts depending on the character of the walls.

Though the reflection of sound produces some beneficial effect in the loudness, it unfortunately introduces possibilities for defective acoustics. When the walls of the room are hard and smooth, very little energy is lost at each impact and many reflections take place before the sound dies down. This prolongation or reverberation as it is called is the main difficulty in the auditoriums. If sounds persist too long, then successive words of a speech will overlap and produce confusion. Special materials acting as absorbers can be introduced which work by reducing the time taken for the dying down of a sound. Reverberation is less objectionable for music than for speech since the prolongation of musical tones is usually desired but the mixing of words of a speech is highly disadvantageous. While constructing halls used both for music and speaking, it is common to choose an average time of reverberation that is somewhat too long for the best conditions for speech and somewhat too short for music, yet it is somewhat satisfactory for both. Reflection of sound may create echoes, interference, diffraction, blurring and resonance. Perfect acoustical conditions in an auditorium may be expected when an average sound has a suitable loudness for all its audience with no echo for distortion of the original sound and when it dies out quickly so as not to interfere with the succeeding sounds.

In certain auditoriums, public address system or sound amplifying systems are generally used. These consist of microphones that pick up the sound and convert sound energy into an electric current which is amplified and reconverted into a louder sound. The suitable amplifying system allows the audience in the room to hear easily. This system also raises the general sound level which tends to draw the attention of the audience more effectively than the usual weaker sounds. Care in this system is to be taken for avoiding the reflection from the roof, walls and preventing concentration of sound at definite places.

Reverberation as stated earlier is the most usual difficulty in acoustics. Large experimental work on corrections of reverberation in auditoriums was done by Prof. W. C. Sabine. He devised a formula $T=0.16\ V/A\times S$, where T is time of reverberation or the standard time taken for sound in a room to decay to one millionth of its initial value, V is the volume of the room in cubic metre, A is the average absorption of the material, S is the total area in sq. metre of all surfaces of the room. When making correction in the reverberation, the sum of absorption value of each material in the room is taken into account.

Sound Absorbing Materials

All materials absorb sound but some to a lesser extent. The sound energy has to be converted into the heat energy ultimately. On striking the solid material the sound waves experience greater resistance than while travelling in air. If sound waves strike a resilient and porous surface, considerable energy will be dissipated as heat in passing through its pores which are interconnected through a series of small channels. The resultant absorption is relatively very high. An open window does not interfere with the free passage of sound and it is considered as 100% absorbent, since it transmits the entire sound. The absorbing capacity of other materials is compared with this open window unit as a standard. The capacity of different materials in absorbing sound depends on the frequency of the sound. The rough value of coefficient of absorption of sound of some of the materials is given in the table on page 487.

Absorption materials may be classified into four groups : The first group includes soft materials like hair felt which are very good absorbers as they have large pores with inter-connected channels. They are now replaced by rock wool, asbestos, etc. Semi-hard materials in the form of porous fibre-boards that are stiff serve as sound absorbent materials as well as building panels. This forms the second group of these materials. In the third group are included the porous tiles of masonry and other products which are installed on the wall surfaces. In the fourth group are the classified acoustical plasters which have the advantage that they resemble the ordinary plasters and can be used where the tiles do not fit in the architectural design. However, they need extra care while fixing and may have to be specially treated. The main properties of a good absorbing material

No.	*Material and method of fixing*	*Absorption coefficients*		
		Low frequency 125 c/s.	*Medium frequency 500 c/s.*	*High frequency 2,000 c/s.*
1	Board roof : underside of pitched slate or tile roof	0.15	0.1	0.1
2	Brickwork-plain or painted	0.02	0.02	0.04
3	Carpet (medium) on solid concrete floor	0.1	0.3	0.5
4	Carpet (medium) on joist or board and batten floor	0.2	0.3	0.5
5	Concrete, constructional or tooled stone or granolithic finish	0.01	0.02	0.02
6	Cork slabs, wood blocks, linoleum or rubber flooring on solid floor (or wall)	0.05	0.05	0.1
7	Curtains (medium fabrics) hung straight and close to wall	0.05	0.25	0.3
8	Curtains (medium fabrics) hung in folds or spaced away from wall	0.1	0.4	0.5
9	Fibre board (normal soft) 12 mm. th.ck mounted on solid backing	0.05	0.15	0.3
10	Floor tiles (hard) or "composition" flooring	0.03	0.03	0.05
11	Glass : windows glazed with up to 32 oz. glass	0.3	0.1	0.05
12	Glass ; 6 mm. plate or thicker in large sheets	0.1	0.04	0.02
13	Glass wool or mineral wool 25 mm. thick on solid backing	0.2	0.7	0.9
14	Plaster, lime or gypsum on solid backing	0.02	0.02	0.04
15	Plaster, lime or gypsum on lath, over air space on solid backing or on joists or studs including fibrous plaster and plaster board	0.3	0.1	0.04
16	Wood boards on joists or battens	0.15	0.1	0.1

are its sound absorbing efficiency, its initial cost, fixing cost, its durability, appearance, fire and vermin proof qualities, weight and reflection of light.

Optimum time of reverberation : The time taken for the sound of a room to decay is the main factor for getting good acoustical conditions. Too long a time results in an overlap of speech. The reverberation time of greater than 5 seconds is considered to be very bad, between 5 to 3 seconds as bad, between 3 to 2 seconds as fairly good, between 2 to $1\frac{1}{2}$ seconds as good and between $1\frac{1}{2}$ and $\frac{1}{2}$ seconds as very good. This shows that the shorter times of vibrations are better. It has been seen that the presence of people in an auditorium reduces the time of reverberation. It would be desirable to make the rooms independent of the volume of the listeners. While considering the optimum time of reverberation the frequency of sound is to be taken into account. Short optimum reverberation is needed for reproduced sound than for original sound as some reverberation is already introduced at the time of recording. The values of optimum reverberation time which are corrected for the presence of audience are given in the table below :

Type of building	*Optimum reverberation by Sabine formula*	*Audience factor for design purposes*
Law Courts, Conference and Committee Rooms.	1 to 1.5 secs.	one-third.
Parliament House, Council Chambers.	1.5 to 1.5 secs.	Quorum.
Public Lecture Hall.	1.5 to 2 secs.	one-third.
Music Concert Hall.	1.6 to 2 secs.	full.
Cinema Theatres.	1.3 secs.	two-thirds.
Churches.	1.8 to 3 secs.	two-thirds.
Very Large Halls.	2 to 3 secs.	two-thirds.

Acoustical correction : The important elements of acoustics of an auditorium are the elimination of echoes and focal concentrations that set up unequal distribution of sound in a room and a reduction in the time of reverberation. Uniformity in the distribution of sound is brought about by adjusting the shape of the auditorium and its interior surfaces so as to control the reflection of sound. The reduction in time of reverberation is usually accomplished by installing sound absorbing materials. The formula for the optimum time as stated earlier is $T=0.16\ V/AS$. This means that if the volume can be reduced considerably there can be a reduction in the optimum reverberation. This solution is not practicable as the size of the room is always to be fixed at a certain value.

The reduction of the factor 0.16 does not seem to be possible. The value of 0·16 as a factor means the reduction of a sound level of 60 decibels to about 15 decibels which is hardly heard.

The usual practice is to increase the factor $A \times S$ and this is possible because it needs only the increase of sound absorbing materials which can be added. The procedure for the acoustical correction would be as below :

1. To calculate the total volume of the vacant spaces within the enclosure which has to be corrected.

2. To measure the surface areas of the different portions of the enclosures and note down their corresponding absorption coefficients.

3. To calculate the total absorption units available in the room by multiplying the surface of different materials by corresponding absorption coefficients and get total absorption quantity available in the room.

4 Compare the optimum time which should be obtained from Sabine formula with the data collected above.

5. If the absorption as provided is insufficient, then make up the deficiency by adding absorption units to obtain optimum reverberation. The additional units of absorption needed may be got by adding surface areas of materials with greater absorption coefficients.

Acoustical design of auditorium

It is better to design an auditorium for acoustical considerations before it is actually built. The important factors affecting the acoustical design of auditorium are the volume, the shape and the sound absorption.

The volume of the room should be decided in proportion to the intensity of the sound that will get generated in it. For band concerts the volume should be quite large so that there will be sufficient space for the proper distribution of music. Theatres, on the other hand, involve comparatively weaker sound and may have lesser volume of cubic contents although modern amplifying system can make the sound more clear in bigger halls also.

The shape of the room is a more important consideration as with the use of sound amplifiers, the difficulties of echoes or other types of reflections are mainly due to the shape. Concave walls are not good for acoustical considerations because they concentrate the sound. Plain walls are quite suitable but convex walls are best as they reduce the echo possibilities to a great extent. The radius of curvature of the ceiling should be at least twice the ceiling height. With a larger radius the ceiling will be quite flat approximating a plain surface while for a very small radius it will be so narrow that a portion of sound will strike it which will be rapidly focussed and diverged thus producing only slight disturbance.

To control reflection from walls, solid convex segments may be added in the wall areas. The reflecting surface may be made in a zigzag form of segments which will reflect adjacent bundles of sound in different directions, thus avoiding the focusing effect. Section of grill-work may be inserted in the wall that will allow the sound to pass through with correspondingly small reflections. If the entire wall is made of grill-work practically all the sound will be transmitted.

The installation of sound absorbing material in an auditorium is important and absolute care must be paid to this item. Wires and sounding boards are thought to be good as far as acoustic is concerned. It has been seen now that wires are not of much benefit when they are stretched in a room. A wire stretched in an auditorium responses to only one tone and little effect is thus produced. Sounding boards or reflecting boards are of some use in correcting defective acoustics when suitably designed and placed in a proper position but they do not have the necessary absorbing capacity so as to correct the reverberation. When a speaker stands within the focus of this board, sound gets reflected in the form of practically, parallel waves and hence the echo effect is reduced because a part of the sound does not reach the dome-shaped roof.

To keep optimum reverberation time within limits, suitable soft plaster or other absorbing materials may be used. These materials have a higher coefficient of absorption than hard plaster. Audience for an auditorium absorbs 70 to 80 per cent of sound compared with 100 per cent of an open window. Seats and backs of chairs have a great advantage as they absorb a lot of sound. The reverberation time may not be uniform throughout the auditorium. It may be more at one place and less at the other depending on the position.

The difference in length of the possible paths by which sound can reach the audience must not exceed 20 metre. This means that the ceiling must be low in the area near the speaker. If a high ceiling is used, it should be broken up into steps.

The general acoustical design of a cinema hall is similar to that of a theatre. Loudspeakers should be grouped so that they direct their sound in to the absorbent materials which may be cushioned chairs and the audience. The seating accommodation should be suchas to cover an angle of 90° horizontal and 30° vertical. These arrangements will lead to a low ceiling. If a small stage is provided behind the screen, the same should be reverberant. Whenever the sound from the loudspeaker is to be synchronised with movements on the screen, special care must be taken. The loudspeakers are mounted on each side of the screen or behind it in order that the effect of the sound coming from the picture appearing on the screen is felt. If the audience is affected by diffused sound coming from various directions such sort of feeling is not created even though no over-lapping of sound takes place. The reflected sound should be removed by the absorbent material as far as possible.

A fan shape in plan with converging, side-walls has been considered to be best from practical point of view. This offers good sight line for the spectators and distributes sound energy in a uniform manner. The proportion of height, width and length should be in the ratio of 1 : 2 : 3. Usually the surface near the source of the sound should be polished or should consist of reflecting materials and those of the distant walls must have absorbent materials. Curved spaces should be avoided as much as possible.

Broadcasting rooms

Special arrangements are required in broadcasting rooms to keep reverberation within limits. It is essential to absorb sounds of all frequencies. Special precautions may be taken for absorbing sounds of lower frequencies. Flexible materials which can vibrate can be suitable. They can have spaces behind them for this purpose. Use of different absorbing materials in irregular fashion on the walls or ceilings gives a good effect. Similarly carpets on the floor of these rooms may add to the absorption. Curtains that can be drawn over certain walls may be effective in reducing the reverberation for adjustment with different frequencies, etc.

Class-rooms

Rooms having dimensions of 8.5 m. in width, 7 m. in length and about 4 m. in height are considered to be satisfactory for a class of about 40 students. The acceptable noise in school-rooms is about 40 decibels for ordinary class-rooms and as low as 35 decibels for music rooms and other rooms in which specially quieter atmosphere is desirable. The noise insulation factor between adjacent rooms should not be less than 40 decibels for school rooms and not less than 45 decibels for music rooms. The amount of absorptive material that must be added to each class-room in order to provide optimum reverberation will depend on the room size, purposes for which it is used, capacity and age of the students. If the room is to be used by children under six years of age the amount of sound absorption on their account will be less. Hence it will be essential to use greater amount of absorptive material for the walls and the ceiling than would be required in rooms for adults. The optimum reverberation time in a small recitation room is 0.75 sec. at frequencies of 512 cycles to 2,048 cycles and about 1 sec. at 128 cycles. In larger rooms such as those used for lectures and debates, the volume should be kept as small as possible, *i.e.*, about 12 cu.m. per seat. The audience should be seated near the lecture platform, the seats should be elevated appropriately and the walls and ceiling should be designed to give beneficial reflections of sound. The ratio of length to width may generally be taken as 1.2 to 1. In general, narrow rooms are less satisfactory than short and wide ones. The average noise level in good lecture rooms should not exceed 40 decibels.

Library

The noise level in a library is to be kept as low as possible. If the noise level in the unoccupied room is reduced to 40 decibels satisfactory acoustical conditions will prevail when the room is not used. Absorptive materials should be employed extensively in libraries. If the ceiling is not high and if the room is of a rectangular shape it will be sufficient to treat the entire ceiling with a highly absorptive material. The walls are often lined with book-shelves which would provide absorptive surfaces. The floor should be covered with carpet or similar material which will reduce the noise of the people travelling within these spaces.

SOUND INSULATION

The desirability of insulating studios, theatres, office buildings and hospitals where disturbing sounds are of higher magnitude is important. Both the internal noise and external noise must not be transmitted either outside or inside as the case may be.

The noise which is present in a building comes mainly through the air while a part may be transmitted through the structure itself. The latter part may be due to the noise of the machinery in contact with structure or due to impact of the people travelling on the floor spaces, etc. Broadly speaking, the sound energy may be transmitted into an adjoining room by three ways, namely :—

(1) By passing through the air passage in the openings of ventilators, windows, skylights, etc.

(2) By setting the separating wall in a vibration so as to create sound waves on the other side.

(3) An elastic wave motion in which compressions and rarefactions of the sound are transmitted from particle to particle in the wall and the same are communicated to the air on the other side.

Mainly the first type of transmission is important. The second type becomes prominent only when the enclosing walls are of thin construction and the third type is prevalent wherever mechanical vibration is present.

The insulation of sound can be basically achieved by three things :—

(*a*) Use of specially rigid structure so as to reduce the vibration.

(*b*) Controlling of sound in the air passages, ventilators, ducts, etc.

(c) Reducing the progress of vibration through the building structures by means of sound absorbing materials and a springing type of construction. To give proper sound insulation to any building, some standards, by which to judge the sound insulation capacity of different materials and construction procedures, are to be fixed. The Building Research Station of the United Kingdom has done some work in this connection. The different grades of sound insulation are classified by them under the following heads :

(*i*) *House party wall grade* : This grade is based on the performance of 20 cm. thick brick party wall. With this grade the noise from a neighbour is reduced to a level which is acceptable to the majority of the people. A higher degree of insulation than this is not possible economically for houses.

(*ii*) *Grade I for flats* : This is the highest insulation under practical conditions which can be attained in a row of flats It is on the basis of the performance of concrete floor construction with a floating floor which gives the best floor insulation obtainable by normal structural methods. Noises from neighbours cause only minor disturbances.

(*iii*) *Grade II for flats* : With this degree of insulation the neighbourer's noise is considered to be uncomfortable for living by many dwellers while some of the dwellers may not get seriously disturbed.

(*iv*) *Worse than Grade II for flats* : If the insulation between flats is lesser by 8 decibels than grade II the noise from the neighbourer is often found to be intolerable.

The levels of air-borne and impact sound insulation for different frequencies have been worked out. To qualify for a particular grading the insulation should not be less than the value evaluated for each frequency.

Wall constructions are required to meet grade for air-borne sound only and floor constructions for air-borne and impact sound insulation. A typical example for grade I in flats is that the insulation of sound at 500 cycles per second frequency should be about 47.5 decibels and at the same frequency for grade II the insulation needed would be about 41 decibels. These values are for air-borne sound insulation. For impact insulation at the same frequency a given material to be classified in grade I or grade II should give a sound insulation of 62 and 73 decibels respectively.

Wall Insulation

Based upon these considerations the acoustical properties of different wall constructions are briefly dealt with in the following paragraphs :

(1) *Party walls in houses* : For semi-detached and terraced house 20 cm. brick wall plastered at both sides is quite good.

(*a*) Solid concrete wall : In solid party wall, concrete or other material plastered on both sides having the same height as 20 cm. brick wall will be suitable. If ordinary dense concrete is used the thickness needed is about 15 cm. For open textured concrete or light weight concrete, plastering should not be omitted from any part of the surface. Any flue from fire-places, etc. should be lined or rendered so as to seal off all air passing through the porous material.

(*b*) 25 cm. cavity brick wall : This was used sometimes as it gave higher insulation figures but now it has been observed that it does not have any advantage over 20 cm. solid wall. The cavity should not be less than 5 cm. wide and special wall ties should be used so that suitable insulation values are obtained.

(c) Other cavity walls : Cavity walls of other types may be used instead of brick as long as they are plastered and the weight of the wall remains the same.

2. *Party walls in flats* : The highest grade recommended for party walls in flats is less stringent than that recommended for houses. Usual types of construction for houses will be equally suitable for flats. Any of these constructions may be made in panels within the bays of normal heavy steel frame or R.C.C. frame buildings without affecting the insulation grading, provided the connection between the frame and the wall panel is both air-tight and rigid. Inserting strips of non-rigid material such as copper and felt around the edges of the panel so as to separate it from the frame is not suitable.

Floor Insulation

Grade I insulations can be got from the types of constructions listed below :

(*a*) Concrete floor with floating concrete screed.

(*b*) Concrete floor with a floating wood raft.

(*c*) Concrete floor with suspended ceiling and soft floor finish or covering

(*d*) Concrete floor with 5 cm. light weight screed and soft floor finish or covering.

(*e*) Heavy concrete floor with a soft floor finish or covering. Grade II can be attained with a concrete floor having a soft floor finish or covering. The essential features of these constructions are briefly described below :—

Floating Floors : The wood raft floating floors consist simply of floor boarding nailed to battens to form a raft, which rests on a resilient quilt laid over the structural floor slab. The battens must not be fixed to the slab. Plain jointed boards should preferably be of tongued and grooved type and must not be less than 20 mm. in thickness. The battens should be about 4 to 5 cm. deep and not less than 5 cm. wide. The resilient layer is a very important feature of the floating floor. Glass wool and mineral wool are substances which are commonly used and quilts of long fibre type are most satisfactory. A nominal quilt of 5 cm. thickness at a density of 2 to 3 kg. per cubic metre is adopted. It compresses to about 2 mm. under battens of a wood raft floor. Thicker quilts give better insulation but allow too much movement of floating floors. The quilt should normally be turned up a little against the surrounding walls as a means of separating the floating floors from the walls. Soft wood is generally used for floating floors in usual buildings. If hard wood is used special care must be taken on account of the moisture changes which will occur later on.

Concrete screed floating floors consist of a layer of concrete not less than 4 cm. in thickness resting on a resilient quilt laid over the structural floor slab and turned up against the surrounding walls at all the edges. It is necessary to provide a layer of waterproof paper over the quilt to prevent wet concrete running through it. Wire mesh reinforcement may be provided for the floating screed and this is directly laid on the water-proof paper. This mesh reduces the risk of cracking of the floating floor and protects the quilt and the paper from mechanical damage due to the placing of concrete. This type of floating floor may not be suitable for bigger rooms than about 20 sq. m. area on account of the slight amount of curling which occurs at the corners.

Hard floor finishes do not contribute to the sound insulation of a floor. Floor finishes of any type merely add to the resistance of the floor to impact insulation. Thick carpet or under felt will give nearly grade I impact insulation. If a concrete floor is heavy enough to have an air-borne insulation of grade I and is then fitted with carpet a sound of insulation against all types of sound of grade I is created. Floor finish of about 5 mm. thick cork, tile or soft rubber may give grade II impact insulation.

Partitions should not be built on the top of floating floor which may otherwise overload the resilient quilt and reduce its insulating properties. Services such as electric conduits, water pipes, etc., should be accommodated within the thickness of the slab, but sometimes they may have to be fitted within the depth of the floating floor. Pipes do not cause difficulties with a floating screed provided they do not extend more than 2.5 cm. above the base, and they do not move while the floating floor is being laid. They are haunched up with mortar on each side so as to give a continuous support to the resilient quilt.

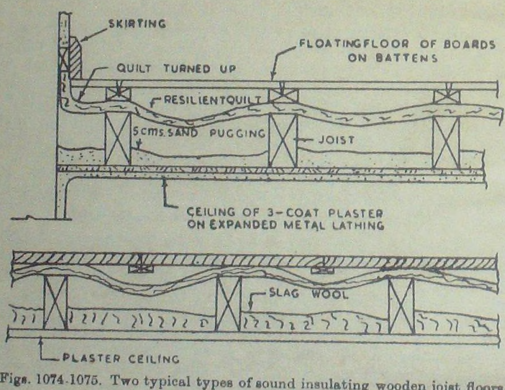
Light weight concrete screeds give a certain amount of air-borne insulation but are of the same character as ordinary concrete floor as far as impact insulation is concerned. A resilient floor finish is, therefore, necessary in addition to a light weight concrete screed in order to give the floor an insulation rating of grade I for all types of sounds. An impervious air-tight layer should be provided above the light weight screed. The provision of an air-tight layer sealing the top of the light weight screed is important. A dense concrete topping above the light weight concrete may be necessary to ensure a suitable base for the floor finish. Wooden boards directly nailed to the light weight screed are not satisfactory.

Suspended ceilings are chiefly of advantage against air-borne sound and can be compared easily with light weight screed as they can be used to raise the sound insulation of normal concrete floor upto grade I provided a stiff floor finish is also used to give the necessary improvement in impact insulation. The ceiling should be moderately heavy, that is. it should not be less than 20 kg. per sq. m. The ceiling should be air-tight so as to eliminate direct sound penetration through air paths. The joints of suspension from the floor structure, should be as few and flexible as possible.

Ceilings of soft insulation fibre-board are not good for sound insulation because of their light weight and porous nature. Plastering on expanded metal or on ceiling boards is usually satisfactory. The air spaces above the ceiling may range from 5 to 30 cm., deeper air spaces being more satisfactory.

The sound insulation of wood joist floors is influenced by the variation of the amount of direct and indirect sound transmitted through the walls. Once the floor has been given enough insulation to ensure that the amount of sound transmitted through it is not more than that going down the walls, then further treatment of the floor will be of little value for sound insulation unless the amount of sound transmitted through the walls can be reduced correspondingly. This can be done by making the walls thicker or making the floor heavy enough and stiff to reduce the vibration of the walls. Concrete floors can automatically restrain the walls, but this is not possible with wooden joist floor. Hence while determining the insulating capacity of wood joist floor it is necessary to give sufficient consideration for the wall system also. For classification as a thick wall system, two or more walls below the floor may be at least 20 cm. thick, the walls above the floor need not be so thick. Metal anchorages connecting floor joists with external walls are sometimes employed in order to give lateral support to the walls. The additional stiffness added to the walls in this way is insufficient to give any improvement to sound insulation. An untreated wood joist floor is worse for sound insulation than an untreated concrete floor.

Basically two types of wooden joist floors which give good amount of sound insulation are used. They are shown in Figs. 1074 and 1075.



Figs. 1074-1075. Two typical types of sound insulating wooden joist floors.

When the walls are thin, say about 10 cm. or less, most wood joist floor will fall below grade II by about 2 decibels. A ceiling of expanded metal and 3-coat plaster loaded directly with a plugging of 5 cm. of dry sand supported by the ceiling and properly constructed is considered to be satisfactory. When the walls are thick it is possible to use lighter form of wood joist construction. The plugging can be reduced. The ceiling supporting it can be of plaster board with a single coat of plaster finish.

The floating floor, in the case of wooden types of flooring, consists of floor boards nailed to battens to form a raft which rests on a resilient quilt draped over the joists. The raft must not be nailed to the joists at any point and it must be isolated from the surrounding walls either by turning up the resilient quilt at the edges or by leaving a gap round the edges to be covered by skirting. The floor boards should not be less than 20 mm. thick and are preferably tongued and grooved. One method of construction for the raft is to place the battens on the quilt along the top of each joist and to nail the battens in the normal way. The other method is to pre-fabricate the raft in separate panels. The battens across the panels are positioned so that they are in-between the joists when the panels are actually laid on the joist. The battens also project a few cm. beyond the sides of the panels in order that the panels can be screwed together to form a complete raft. As the flooring is not nailed to the joists special care must be taken to level up the joists which carry the floating floor.

Glass wool and mineral wool quilts are preferred for wooden floors. They should have a nominal thickness of 25 cm. with a density of about 20 to 30 kg. /cu. m giving a weight of about 2 kg. per sq. m. exclusive of the paper covering. It is a good practice to turn up the quilt around the edges against the walls.

Recommendations for sound insulation in Residential Buildings

The main sources of outdoor noise in residential areas are traffic (aeroplane, railways, roadways), children playing, hawkers, services deliveries, road repairs, blaring loudspeakers and various types of moving machinery in the neighbourhood and building operations.

As far as indoor noises are concerned, conversation of the occupants, footsteps, banging of doors, shifting of the furniture, operation of the cistern and water-closets, playing of radios, gramophones, etc., contribute most of the noise emanating from an adjacent room or an adjacent building. Noise conditions vary from time to time and noise which may not be objectionable during the day may assume annoying proportions in the silence of the night when quiet conditions are essential.

In the case of flats the main sources of noise are from other flats and from stairs and access balconies. The most troublesome noise is from the flat above and where floor insulation is not sufficient, plumbing noise is another main cause. In semi-detached buildings, outdoor noises from streets are noticed more than indoor noises from neighbours.

The most desirable methods is to locate the residential buildings in a quiet area away from the noisy sources like the industrial areas, rail tracks, aerodromes, roads carrying heavy traffic, etc.

To minimize ground reflection the maximum amount of planting and grassed areas should be provided around dwellings and the minimum amount of hard surfacing. This applies particularly to high density areas. Where for maintenance reasons a large amount of hard paving is necessary, it should be broken up by areas of planting and grassing. Narrow hard paved courts should be avoided between adjacent tall buildings.

Roads within a residential area should be kept to a minimum both in width and length, and should be designed to discourage speeding. Precinctual planning, with closes and squares from which vehicular traffic is altogether excluded will greatly help to reduce noise. Through roads should be excluded from residential areas, but where sites have to be developed adjacent to existing major roads the same principles should be observed in the siting of blocks as with railways.

Play areas for older children should be sited as far away from dwellings as possible. Special care should be taken with old people's dwellings. They should not be placed immediately adjacent to service entries, play spaces, or to any entrances where children may tend to congregate.

The orientation of buildings in a locality should be planned in such a way as to reduce the noise disturbance from neighbourhood areas. The non-critical areas, such as corridors, kitchens, bathrooms, elevators and service spaces may be located on the noisy side and the critical areas, such as bedrooms and living space on the quiet side.

Windows and doors should be kept away from the noisy side of the building as given below where possible :

(*a*) When windows of a building particularly those of bedrooms in apartments or flats, face roads carrying heavy traffic or other noises of the order of 80 to 90 dB (A) (measured at a distance of about 3 m from the source of noise) the building should be located at a distance of about 30 m from the road, but a distance of 45 m or more, where possible should be aimed at for greater relief from noise.

(*b*) When the windows are at right angles to the direction of the above type of noise, the distance from the road should be arranged to be about 15 m to 25 m, and

(*c*) In case another building, boundary wall or trees and plantations intervene between the road traffic and the house/flat futher noise reduction is achieved and in such cases the above distances may be reduced suitably.

It is desirable that rooms adjoining party walls and above or below party floors should be of similar use. By this means, bedrooms are not exposed to noise from adjoining living rooms, and there is less risk of disturbance of sleep. In semi-detached houses, the staircase, hall and kitchen should adjoin each other on each side of the party wall, thus providing a sound baffle between rooms requiring quiet conditions. Open fire places on party walls should be avoided as far as possible. Bedrooms should not be planned along side acess baloonies and preferably not underneath them. Where the approach is by an internal corridor a sound baffle may usefully be provided by arranging internal passages and bathrooms between the corridor and the living room or bedrooms. Water closets should not be planned over living rooms and bedrooms, whether within the same dwelling or over other dwellings. Night soil pipes should not be carried in ducts which adjoin living rooms or bedrooms unless the side of the duct next to these rooms is a solid wall containing no inspection openings. Refuse chutes should not be planned next to living rooms or bed-rooms.

Suppression of noise at the source itself : All items of equipment that are potentially noisy should be selected with care. Water-closet cisterns should not be fixed on partitions next to bed rooms or living rooms. All ball valves should be fitted with silencer pipes. Lift motors should be mounted on resilient supports. Access doors from machine rooms to internal staircases should be well fitted and of solid construction.

Refuse chute hoppers should be fitted with effective sound-deadening gaskets and refuse chute containers if made of metal should have sound-deadening linings. Refuse chute linings should be solidly embedded in heavy non-resonant material.

TABLE : SOUND INSULATION BETWEEN INDIVIDUAL ROOMS (AIR-BORNE)

Sl. No.	*Situation*	*Overall Insulation in dB*
(1)	(2)	(3)
1.	Between the living room in one house or flat and the living room and bedrooms in another	50
2.	Elsewhere between houses or flats	40
3.	Between one room and another in the same house or flat	30

Note : 1. Where communicating doors are provided, all doors should be so designed as to provide recommended insulation between the rooms.

Note : 2. There are cases when a set of houses or flats have to be built for the people who work at night and sleep during the day. It is desirable to consider the design of at least one such room in each of the houses or flats which will provide an insulation of about 45 dB in that room.

Note : 3. The insulation values referred to are applicable with doors and windows shut.

QUESTIONS

1. What is meant by the term 'acoustic' ? Briefly describe as to how defects are created in a room from acoustical point of view.

2. How is the acoustics corrected in an auditorium ?
What is the optimum time of reverberation for a public lecture hall ?

3. What is meant by 'sound insulation' ?
How is the sound transmitted from a room ?

4. Describe the various types of floor constructions which are sound proof. What steps are taken to make the wood joist floor sound insulated ?

5. Write short notes on :
(*i*) Acoustical treatment of a class room.
(*ii*) Sound absorbing materials.

6. Give the recommendations for sound insulation in a residential building.

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3. **H.M.S.O.** : *Sound Insulation of Dwellings—May* 1956.
4. **H.M.S.O** : *Sound absorbent treatments—September* 1954.
5. **H.M.S.O.** : *Sound Insulation of Dwellings—June* 1956.
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23

SHORING, UNDERPINNING, SCAFFOLDING, Etc.

SHORING

Shoring is used to prevent a structure which has become damaged due to foundation settlements or other causes which may make the structure to fall and collapse finally. It is also used to give temporary supports to a structure which is undergoing alterations or where alterations of adjacent foundations are being carried out. This type of support may be given externally or internally and in certain cases shores may be placed from both sides of the wall to produce additional stability.

Temporary shores are generally made of timber but for heavier loads steel beams or suitably braced sections are adopted. A shore may also be made of concrete or masonry. Timber shores suffer from the usual defect of shrinkage on account of the changes in weather. They are, therefore, to be attended to regularly.

Walls when supported by shores may be considered to be acted upon by the vertical and horizontal forces and also inclined thrust of floors, roofs, etc. To maintain equilibrium the overturning forces must be resisted by the supporting shores. Therefore it is essential that the lines of action of the overturning forces in floors and roofs, the forces in walls and the reaction of the shores must meet at one point.

The type of shores based on their supporting characteristics are usually classified as raking shores, horizontal or flying shores, dead or vertical shores.

Raking shores

These consist of timber pieces, placed in an inclined position with one end resting against a defective wall and the other supported on the ground, may be on suitable sole plates so as to distribute the pressure on the soil. An inclined timber shore can be used for considerable height of wall and usually shores of 9 to 12m. in length are used. Far greater heights additional supports are given at lower elevation for more restraint. Braced timber shoring is used when heavier loads are to be supported, the bracing preventing the timbers from buckling.

Walls which are likely to bulge or crack, vertical timber plates and a series of two or more shores may be required in such cases. Similarly, for additional strength along the length of the wall, horizontal timber members are placed at the head of the shores. Steel sections may be used alternately if greater pressures exist. When a large area of wall is cracked or likely to crack both vertically and horizontally, the shoring system should be provided with both horizontal and vertical wall plates. These consist of pieces of timber inclined at suitable angles. For practical purposes these angles vary from 60° to 75°. These shores are fixed in systems having one or more timbers placed in the same vertical plane but at different angles to support the entire height of the wall. The horizontal distance is not generally greater than 2.5 m. but they may be placed at the piers which support the wall. A wall plate consisting of a 5 to 7 cm. plank is placed against the wall to receive the ends of the shores. This is fixed with wrought iron wall hooks driven into the joints of the masonry at the back. One piece wall plate should be preferred. Wooden needles with cleats housed into the wall plate are used, as a support for the top end of the raking wooden shore. This end of the raking shore should normally be placed where there

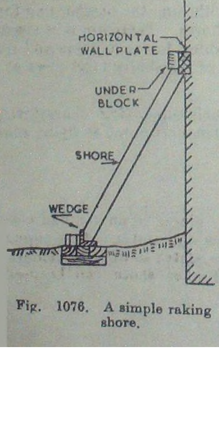


Fig. 1076. A simple raking shore.

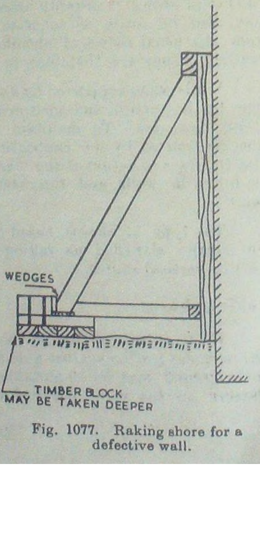


Fig. 1077. Raking shore for a defective wall.

is some resisting member such as a floor or a roof at the back of the

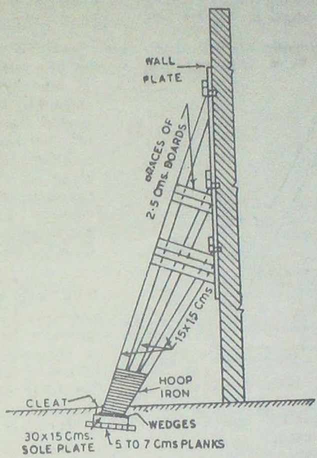
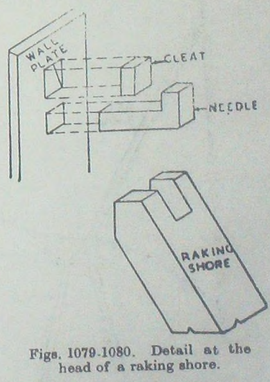


Fig. 1078. A set of raking shores to take heavier loads.

wall. The shore should be notched so as to prevent its lateral movement. The foot of the shore rests on a sole plate embedded into the ground in an inclined position. This sole plate consists of thick wooden planks and is not inclined exactly at right angles to the shores but is fixed at about 1 in 24 out of the perpendicularity to enable easy tightening with a crowbar. On soft ground the sole plate should be of such an area so as to distribute the pressures evenly. The shores are tightened with a crowbar inserted in the foot of the shore. Wedging should not be done at this place as the vibrations caused thereby might be detrimental to the building. Once the shore is placed in position it is fixed firmly with iron dogs.



Figs. 1079-1080. Detail at the head of a raking shore.

When more shores are used in one plane, wooden boards are nailed to the sides of the shores at intervals. They may also be nailed to the wall plate. The bottom portion of the shores may be connected with hoop iron. Where excessive settlements are anticipated, permanent cleats may be left so as to permit jacking operations.

Occasionally balanced shores may be used for supporting walls from both sides. For example, in case of a retaining wall which is unstable on account of the earth backing being removed, a permanent and reinforced concrete shore to a retaining wall may consist of an R.C.C. frame made in the shape of a right-angled triangle. It has got a tie which prevents the shore from bending back.

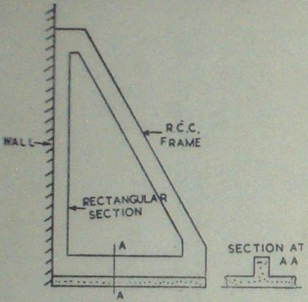
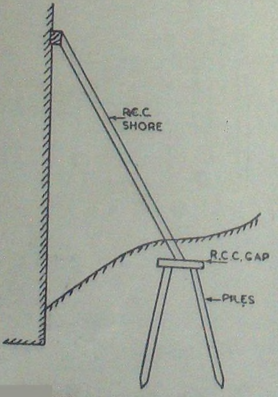


Fig. 1081. R.C.C. framed shore.

For adequate support to a wall in the case of permanent shores, effective measures have to be taken to ensure a proper distribution of load. When the bearing pressure is reasonably high, mass or reinforced concrete foundations can be used. For low bearing capacities cast-in situ piles are used.

Horizontal shores

These are also called flying shores and are used to temporarily



082. R.C.C. shore with piles.

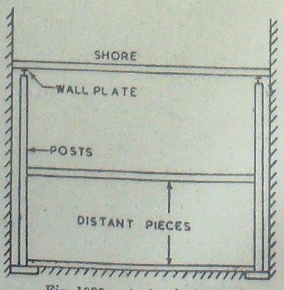


Fig. 1083. A simple type of horizontal shore.

support two parallel walls. Generally, the maximum distance which can be supported with the aid of flying shores is considered to be 10 m. Such type of shoring work is used in residential areas where out of a number of houses, one house has to be removed.

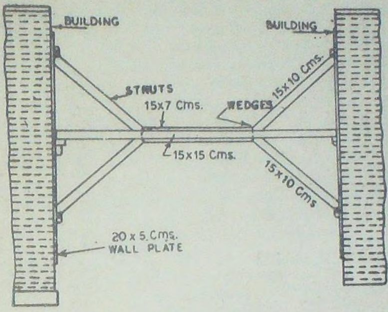


Fig. 1084. Flying shoring between two adjacent walls.

Horizontal timbers are placed or steel joints are placed running over horizontal members which are duly supported on vertical

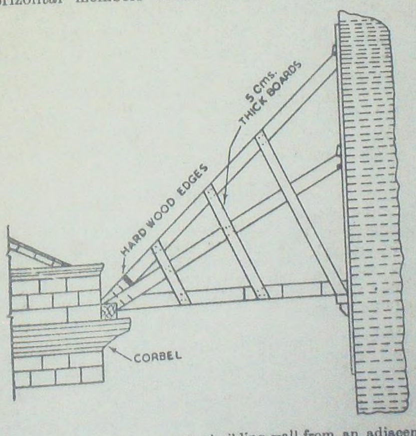


Fig. 1085. Flying shoring of a building wall from an adjacent old building corbel.

columns. A horizontal beam is placed at the footing of these columns to keep the distance between the columns constant.

Whenever the head room below the shores has to be kept clear, special methods have to be adopted. These consist in fixing vertical wall plates on the two plates in a manner similar to raking shores. Horizontal timber shore is placed on needles which are fixed into the wall plates. This horizontal shore is tightened with wedges on one side. Inclined struts are added for additional strength. The foot of these struts is stopped against a horizontal straining piece, the other foot being fixed to the wall plates. For bigger building two or more flying shores may be used which are suitably braced with each other.

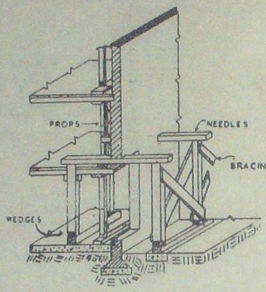


Fig. 1086. Use of dead shores for creating an opening in a wall.

Dead or vertical shores

These shores are placed vertically and are used for temporarily supporting walls, the lower parts of which are to be removed for repairs or otherwise the whole load of the roofs, etc., is supported by these shores. Wooden needles consisting of thick sections are used to transfer the load from the walls. They are first inserted into small wall opening which is made just sufficient for size. Horizontal beams are laid along the floors to support the dead shores, the load is evenly distributed on the base. The dead shores are introduced and wedged tightly in-between the beams and the needles. Before removing the desired portions from the walls the usual walls are supported with props, so that no damage is created. Similarly the windows or other openings are duly strutted.

UNDERPINNING

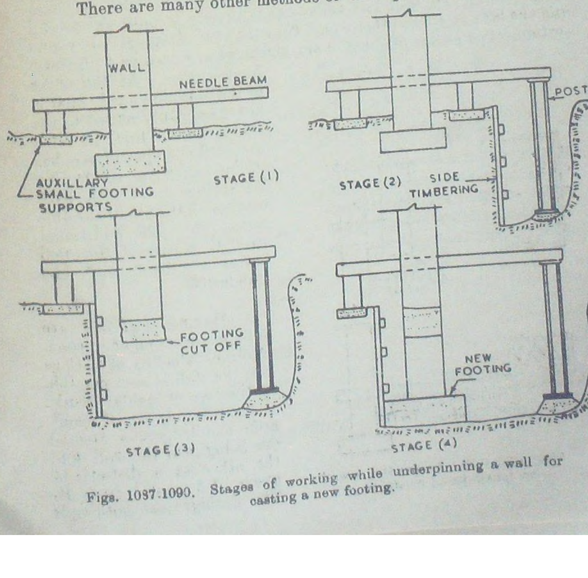
This is the method of supporting structures while providing new foundations or carrying out repairs and alterations without affecting the stability of the existing structures. No damage to surrounding buildings can be tolerated. It has also to be ensured that no obstruction is created to the passage of people or vehicles in the adjoining areas.

Generally underpinning is carried out by excavating slowly n steps and supporting the structure thus opened with the aid of ieedle beams. An example of under-pinning for replacing the ooting of the wall and constructing the same at a deeper depth is hown in Figs. 1087-90. In the first place, suitable holes are driven hrough the walls for engaging needle beams. One end of the needle beam is supported on a small concrete block and on the other side a major portion of it is left without support while a small concrete block supports the needle pin just near the wall on that side. In the second stage, excavation is started below the unsupported end of the needle beam. Once the excavation is suitably supported with the aid of side timber ring and carried down to the required depth, the unsupported end of the needle beam is supported on the vertical post supported on a concrete base. In this manner, the concrete block gets relieved of any load. The excavation trench is widened further and the soil below the wall footing is also removed. The additional offsets of the old footing are cut and thereafter the new footing is constructed at the required depth. This process is repeated in small stretches so as to complete the desired length of the wall.

Another method of underpinning is depicted in Figs. 1091-92. This method is used where enough space is not available for the repeated use of the needle beams due to some obstruction on the other side. The longer arms of the needle beams are placed on the inside of the building, the other end supporting the wall.

Heavier weights are placed on the unsupported ends of the needle beams and a fulcrum block is placed near the wall so that these needle beams act as cantilevers in supporting the walls. After these beams are placed in this manner, the footings are removed and repaired.

There are many other methods of underpinning depending on



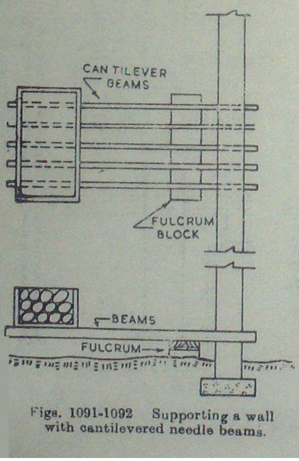
Figs. 1087-1090. Stages of working while underpinning a wall for casting a new footing.

the type of structure to be supported and the circumstances within which it lies. Underpinning of columns may be carried out by erecting four small grillage footings on its sides and spanning the beams over these footings. The load of the main column which is to be underpinned is transferred to these beams through strong jacks and the column footing can be repaired.

SCAFFOLDING

These are temporary erections constructed to support a number of platforms at different heights raised for the convenience of workers so as to enable them to work easily and raise the needed materials. Generally scaffolds are classified into two types, namely, bricklayer's and mason's. They are constructed of timber either sawn or in circular sections. In India Sal "Ballies" (round poles of 10 to 15 cm. diameter) are abundantly used. For important and large works steel tubular scaffolds are used.

The bricklayer's scaffold consists of a number uprights called standards and usually placed at not more than 2.5 m. centres. They may be circular in section of about 12 to 15 cm. average diameter. These rest on hardwood planks with wedges, on stone slabs laid on rammed ground, or in a drum containing rammed earth. For adequate stability they may be driven a few metre into the ground. Horizontally placed poles called ledgers are lashed to these standards and spaced at a vertical distance of 1.5 to 2 m. apart. Such frames of standards and ledgers are placed at about 1.5 m. away from the building face. They are connected to the building with putlogs, which bear on the wall, and are laid as the latter is built at one end and the ledgers at the other end. They may be of square or round sections. The planks of about 4 cm. thickness are used as a platform for workmen. At the edges of the staging guard boards are fixed duly nailed to the standards. While building the scaffolds special care has to be taken on connecting the various units with each other with the aid of suitable ropes. To give additional strength, a pair of diagonal braces are fixed with the standards.



Figs. 1091-1092 Supporting a wall with cantilevered needle beams.

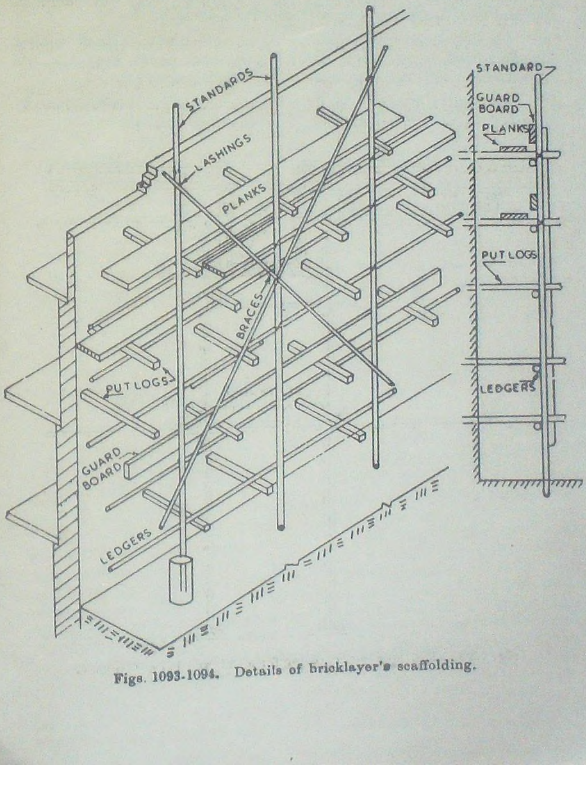
Mason's scaffolds are to be made stronger in construction. Placing of putlogs into the wall is not possible in the case of ashlar work. Hence a double set of standards and ledgers is erected one being near the wall and the other at a distance of about 1.5 metre from it. The putlogs rest both ends on these sets. The remaining construction is similar to a bricklayer's scaffold.

Steel centering and scaffolding : Tubular steel scaffolding is being extensively used in place of timber scaffolding for temporary staging and also for posts and bracings as centering to support heavier loads. The advantages are :

(1) *Adaptability* : Tubes of one size and three or four standard fittings can be used to support vertical loads of all types.

(2) *Availability* : Large stocks of steel centering can be had easily while it may be difficult to procure timber in large stocks.

(3) *Simplicity* : This type of centering is very simple as only a few shapes and sizes have to be dealt with.



Figs. 1093-1094. Details of bricklayer's scaffolding.

(4) *Interchangeability* : Scaffold tubes can both be used for making a scaffolding or formwork.

(5) *Ease of erection* : The methods of erection are standardized and easier erection is possible as no tedious cutting or lengthening is necessary as is the case with timber.

(6) *Scrap value* : Their scrap value is high as they do not get damaged while fixing or dismantling.

(7) *Strength* : Their strength is constant while that of timber varies on account of the flaws, etc.

(8) *Resistance to fire* : They are not liable to damage by fire.

Disadvantages are :–

(1) *Initial cost* : They need a lot of investment.

(2) *Fittings* : The fittings may get lost as they are small in size and they are difficult to be replaced later on.

(3) *Connections with timber* : It is difficult to attach timber members with steel tubes economically and hence they are left supported on the centering without any rigid connection.

(4) *Skilled labour* : To fix a tubular centering, it is essential to employ very skilled labour which is always not possible.

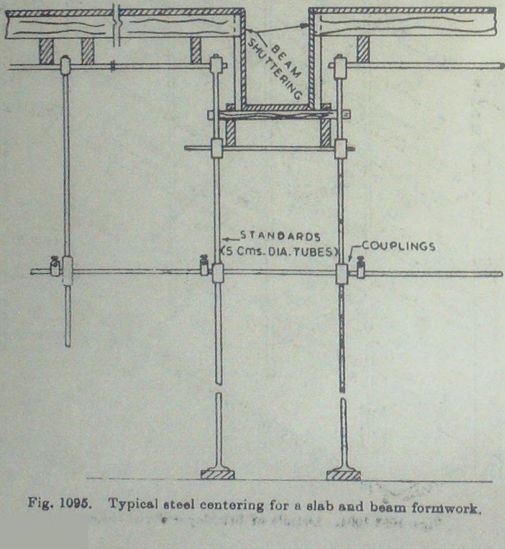


Fig. 1095. Typical steel centering for a slab and beam formwork.

(5) *Painting* : These tubes have to be painted periodically to keep them free from corrosion.

The usual methods of constructing timber forms should be modified when tubular supports are to be used as the loads must be carried near the couplers to avoid bending and deflection in the horizontal tubes since the uprights are at greater distances apart and do not take load concentrically. A typical type of centering for supporting beam and slab formwork is shown in Fig. 1095.

There are several other arrangements possible.

Some method of adjusting form heights is always required as it is not easy to wedge up the timber formwork resting on the tubular centering. Suitable screwed adjusting couplings are used and they work on the principles of jacks.

EARTHQUAKE RESISTING BUILDINGS

Earthquakes consist of a set of waves originating from the centre of disturbances and causing horizontal and vertical ground movements or vibrations. The movements are complicated due to superimposed vibrations. The horizontal vibrations are greater in magnitude than the vertical ones and these are mainly considered in the constructional aspects of buildings. Properly designed and constructed buildings can resist the strongly recorded earthquake shocks.

The horizontal acceleration is expressed as a fraction of the gravitational acceleration and is denoted in terms of Rossi-Forrel scale. Acceleration greater than 0.025 g. creates damaging forces. The mostdestructive forces are caused by horizontal earth motion. When the underneath surface of a building gets moved slightly, the building tends to remain in its original position because of its inertia. The acceleration of the horizontal movement varies and its maximum value is only adopted for measuring the intensity of earthquake forces. If the acceleration of the horizontal earth movement is one-tenth of the acceleration due to gravity, it is assumed that the stresses in the structure caused by the earthquake are similar to those produced by the horizontal static forces of the same magnitude acting on the building.

The earthquake may occur in any direction but the movements can generally be split up into two components one acting along the main axis of the building and the other perpendicular to it.

As stated earlier a building is to withstand horizontal seismic acceleration at any plane. In order to obtain the horizontal acceleration the mass or dead weight above the plane under consideration is taken into account and also the effective live load above that plane is considered. Every building has its natural period of vibration When vibrations are introduced in a building by an earthquake having the same period of vibration as the building itself, vibrations get intensified in magnitude and the building is liable to get damaged. The vibration period of earthquakes is about 1 to 2·5 seconds. The self-vibration period of

R.C.C. buildings varies from ·3 to ·5 seconds for buildings upto 30 m. in height; for greater heights the vibration may be similar

Intensities of acceleration due to earthquakes

Rossi-Forrel scale	*Horizontal acceleration*	*Remarks*
1	0·0005 *g*.	Almost imperceptible, being felt only by an experienced observer.
2	0 0001 *g*	Feeble, being felt by a small number of persons at rest.
3	0·0025 *g*.	Very slight, being felt by several persons at rest.
4	0·001 *g*.	Slight, being felt by several persons in motion and resulting distributance of movable objects, doors, windows, etc.
5	0 01 *g*.	Weak, being felt generally by everyone and resulting in disturbance of furniture, etc.
6	0·0125 *g*.	Moderate, resulting in general awakening of those asleep and disturbance of trees and shrubs.
7	·025 *g*.	Strong, resulting in fall of plaster, no serious damage to buildings but general panic.
8	0·05 *g*.	Very strong, resulting in cracks in walls of buildings, fall of chimneys.
9	·1 *g*.	Severe, resulting in some buildings being partially or wholly destroyed.
10	·3 *g*.	Violent, destructive resulting in disasters, landslides, cracks in ground, etc.

to those of earthquakes. This means that resonance is likely to occur in buildings which are higher than 30 m. and greater heights should, therefore, be avoided.

India has been divided into three zones: Zone I comprises those areas in which minor damages are caused to the structures in the event of an earthquake; zone II comprises those areas in which moderate but appreciable damages are caused; and zone III comprises those areas in which severe damages are caused. For the purpose of design the acceleration in the three zones is given below:

Seismic zone	*Rossi-Forrel scale*	*Horizontal acceleration*
I	1 to 5	0·0005 *g* to 0·01 *g*
II	8	0·05 *g*
III	9	0·1 *g*

The magnitude of the horizontal force is obtained by multiplying the mass of the equivalent dead load by the seismic acceleration enumerated above for the different zones.

The horizontal force at a plane is thus determined by calculating load on the building above the plane. Application of the force is similar to that of horizontal wind loads. For multi-storeyed building the coefficient of seismic acceleration may be reduced by the factor $\frac{4 \cdot 5}{m+4 \cdot 5}$ to allow for increase in flexibility with the increase in the number of storeys. (m is the number of storeys above the one under consideration.)

For parapets and cantilever projections near the exterior walls the seismic coefficient may be taken as 40%g. For chimneys projecting above the roof its value may be taken as 20%g. Tall structures standing side by side but not monolithic with each other should have some distance between them. Structures such as retaining walls, which depend for the stability on their weights should be designed for the same amount of vertical forces as horizontal forces.

The overtaking moment of building should be kept within 50 per cent of its moment of stability.

General recommendations

It is necessary to aim at symmetry of a building both in plan and in elevation. Unsymmetrical buildings can be divided into separate parts and each part considered as a separate structure. Adjacent buildings or parts of the same building dissimilar in mass for stiffness should be separated by a space sufficient to prevent damage due to different amplitudes of vibration. Cracks of any magnitude must be guarded against as they will present planes of weakness during an earthquake.

Additions and alterations to the structure should be avoided. If they are necessary, the new portion should be treated in different manner and separated from the main structure.

All corners should preferably be rigid. The structure should be of an indeterminate type. The centre of gravity of the building should be kept as low as possible. Bents of columns should be straight and should run through the building in both directions. Through planes of weakness should be avoided by staggering openings in the opposite walls.

Parapet walls, cornices, etc., should be avoided. Whenever used they should be firmly tied to the structure so as to form an integral part with it.

All roof trusses must be adequately anchored. In masonry structures the roof also may rest on a concrete band without any direct tie, provided the slab is prevented from moving laterally by offsets in the slab by fitting over the concrete band. No wooden plate or studs should be built or sunk into masonry walls. Ceiling joists should be firmly fixed with steel clips to at least every third joist. Plaster ceiling should not be used excepting a three coat work.

For framed buildings, the design should be such that the structure can be analysed as correctly as possible. Wall panels in such buildings may consist of masonry concrete or any other type of material. For R.C.C. walls reinforcement should be calculated to meet the stresses. Panels should be adequately tied to the frame at the points of support. When hollow concrete block or brick masonry is adopted with the panel the same should be reinforced with two 5 mm bars at every sixth course for panels in external walls and at every 8th course, for panels in internal walls for spans upto 4 m. For longer spans the reinforcement should be placed after fewer courses. At openings, the wall reinforcement must be kept within 5 cm. on each side of the opening. Main beams must be doubly reinforced and should have stirrups throughout the whole span. The longitudinal reinforcement should not be less than 0·7% at the top and 6·7% at the bottom. The slenderness ratio of the R.C.C. columns should not be greater than 15. The main longitudinal reinforcement should not be less than 1·25% of the effective area. Columns should have binders throughout their length. Reinforcement at the junction of the beams and columns must be suitably anchored.

Treatment of foundations

As far as the foundations are concerned, two things have to be taken into consideration :

(1) The effects of the soil properties on the earthquake ground motion.

(2) The effect of the earthquake on the structure of soil and consequently on the structure which stands on it. Earthquakes involve displacements and accelerations which pass from a harder medium to a softer one. Consequently the shaking of structure resting on alluvial soils is more than those which are founded on rock. The elastic deformation of the given soil affects the period of vibration and reduces the earthquake stresses induced in a structure. Generally structures erected on alluvial soil need special attention. Effects of earthquake on firm soils are negligible. Loose soil deposits or soils which are heavily charged with water may be consolidated by the vibrations set up by an earthquake.

In the case of firm soils, the increase of footing pressure on the soil lasts momentarily as the vibration of the structure will be over compressing the soil only for half of the period of vibration at a time. This temporary over-pressing in not as effective as the consistent overstress due to static loads. Hence it may not be necessary to reduce the bearing capacity of soil in all cases. But the general practice is to reduce the soil pressure in different types of seismic areas.

The foundations should be in one horizontal plane and stepping should not be permitted. They may be of isolated, continuous or raft type and must be designed to resist in every direction the moments set up in walls or columns and further to take up moments due to the earthquake effects. Isolated foundations should be inter-connected or tied at least in two directions to form a complete foundation frame. Each connecting member should be capable of resisting direct compression or tension. Solid concrete raft, where provided shall be cast integrally with ribs and beams.

FIRE PROTECTION

Protection of a building against fire can be attained by the use of the materials and construction techniques which aim at giving adequate resistance to the spread of fire within the building through its external walls. The building components should be structurally stable for a reasonable amount of time so that the occupants can leave within a reasonable time. In the planning of the building also care should be taken that sufficient appliances are available to the occupants so that they can leave the building safely and quickly.

The characteristics of a typical fire-resisting material would be that it should not get disintegrated under greater heat ; the expansion of this material should not be excessive so as to damage the structure : and its contraction on account of sudden cooling from a hot state should not be so rapid as to break it into pieces. None of the materials has got all of these qualities but many of them can resist the action of fire for a considerable amount of time. Stone is a bad material in this respect as it cannot resist sudden cooling. Once it becomes hot and is cooled, it breaks into pieces. Granite when subjected to excessive heat crumbles to sand or cracks and falls to pieces with a series of small explosions. Lime stones get calcined and turn into quick lime. Sand stones resist fire better but also disintegrate after some time. Bricks are practically fire-proof and fire-bricks from their refractory character are the best. Terra-cotta is better for fire-resisting qualities than bricks but is very costly. This material is however used in the construction of fire-resisting floors. Cast iron breaks into fragments if contracted suddenly and hence is not a suitable material from fire resisting considerations. Wrought iron and steel try to get twisted due to softening of material and the consequent reduction in resistance to the effects of tension and compression. At about 600 degrees centigrade yield stress is reduced to one-third than at normal temperature. It also expands considerably and hence allowance should be made for these movements.

Timber is a combustible material but on exposure to fire it gets charred. This charring gives a protective coating to inner portions of the timber and prevents it from rapid combustion. At higher temperature volatile gases get created which finally catch fire. Timber can be made fire-resistant by using thicker sections instead of employing a number of smaller sections. A number of corners and the area of exposed surface should be reduced as much as possible.

Timber should also be not treated with oil paints which are liable to catch fire.

The fire protection which concrete can give depends largely on the type of aggregates used. Natural stone aggregates expand on heating and thereby try to crack the concrete. Crushed brick aggregates or slags are more resistant but a concrete with these aggregates may fail on account of dehydration of cement. Pumice foamed slag, blast furnace slag, crushed brick, crushed lime-stone form better type of aggregates. Siliceous aggregates, flint gravel granite, etc., are inferior types as far as the resistance to fire is concerned. The cracks generally start from the reinforcement and as such adequate cover should be given to the steel.

Asbestos cement materials althóugh are not combustible crack explosively when they get heated in a building fire, hence such materials have not adequate resistance to fire. Plaster boards and some boards incorporating asbestos fibre can be used in assisting the required degree of fire resistance for steel work or improving the fire resistance of timber floors or other materials. According to the British standard specification materials used for lining of walls and ceilings can be classified by the "surface spread of flame" test. This test measures the rate of spread of flame and classifies the materials into the various classes.

Development of fire : Once some material gets ignited the fire tries to spread and if there are openings in the walls and floors the fire can spread to other parts of the building. Even though there may be no opening the fire can increase the temperature of the structure itself and transmit sufficient heat so as to ignite the material on the other side. A fire in a building creates a strong draught. Staircases and lift shafts try to act as flues which increase the spread of fire. Before the fire gets transmitted to another enclosure poisonous gases may pass ahead of it and thereby endanger the lives of the occupants there.

The more the material present in an enclosure for burning, the longer and hotter will be the fire. The amount of material is called fire-load and is more clearly defined as the number of Kilo-Calories that could be liberated per square metre of floor area by the combustion of any building or its any part. It is determined by multiplying the weights of all combustible materials by their calorific values and dividing by the floor area under consideration. For some of the materials the calorific values are given below :—

Material	*Calorific value Kilo Calories/kg.*
Timber	45500
Paper	38900
Straw	33400
Bitumen	89500
Oil	94500 to 111100
Rubber	94500

Classification of buildings for fire resistance. To classify buildings based on their fire resistance qualities various codes have been developed in foreign countries—standard fire tests are developed for determining the resistance qualities. This test consists of exposing samples of materials to fires of standard intensities and the performance of materials is tested by noting the period of resistance to standard exposures before a critical point in behaviour is observed. This period is expressed in hours.

According to the National Board of Fire Under-writers of the United States, buildings are classified as under :—

(*a*) *Fire-proof Construction* :—This type of building has masonry or reinforced concrete members built in such a manner that a four-hour rating is available for bearing walls, party walls, isolated piers and columns ; a three-hour rating is available for beams, floors, roofs, and a two-hour rating for partitions.

(*b*) *Semi-fire proof Construction* :—This is similar to above type except that bearing walls, isolated piers and main girders which support walls have got a three-hour resistance. The exposed beams, floors, etc., may have two hour rating.

(*c*) *Heavy timber Construction* :—The walls in this case are of masonry or concrete whereas internal structural members consist of heavy timbers and if some structural members of steel or R .C. C. are used, a three-hour resistance is available.

(*d*) *Ordinary Construction* :—In this the exterior walls are of masonry or R. C. C. and the interior structural members are partially or wholly of wood of smaller sections. They may also be of iron or steel which is not specially treated against fire.

(*e*) *Frame Construction* :—In this type of construction the exterior walls consist of timber. They may also partially consist of masonry and timber combined.

Another way of assessing fire-resistance is by comparing the effects under the fires caused by known fire-loads with the effects of various periods of the standard tests. From this the fire-resistance periods required in structural elements for satisfactory elements can be determined. Some values of the period of fire test equivalent with respect to the fire-load are given in the table below :

Fire load Kilo-Calories/sq. m.	*Period of fire test giving equivalent fire (h)*
Upto 271,250	1
271250—542,500	2
542,500—108,500,0	3
more than 108,500,0	more than 4

This means that any structural member having a fire-resistance of one hour will withstand without failure the effect of fire caused by a fire-load of 271,250 K.Cal./sq. metre. The effects of the fire being extinguished earlier before the structure is exposed to the full effects of the fire-load have to be considered while evaluating the fire-resistance of a building. In United Kingdom, the building regulations take into account the effect of fire fighting by allowing a lower fire resistance than that based on the fire-load relation on the assumption that smaller and lower buildings can easily be extinguished when on fire, by fire fighting : The fire-resistance of structural elements, the main function of which is to protect means of escape, is based on considerations of fire-load since the protection is needed for shorter periods. For such cases a fire-resistance of one hour or so may be sufficient, but if in a building a staircase is to be used as a means of access by fire-men, a higher degree of fire-resistance is essential.

Fire-proofing of walls

The fire resistance of solid wall of brickwork or concrete increases with thickness. Walls of light weight concrete have got higher fire resistance than those made of dense concrete. Plastering slightly improves fire resistance provided it has a good bond with the wall backing. Plasters based on vermiculite give considerable resistance.

Fire-Resistive Materials	*Cm. Required for Rating*			
	4 hrs.	*3 hrs.*	*2 hrs.*	*1 hr.*
Brick, burnt clay or shale ...	8½	8½	6	6
Hollow or solid cinder-concrete block and tile having a compressive strength of at least 48 kg./cm.^{2} of gross area ...	6	5	5	4
Solid gypsum block (to obtain 4 hrs. rating must be plastered with 10 mm. of gypsum plaster) ...	5	5	4	2½
Gypsum poured in place and reinforced ...	5	4	4	2½
Hollow or solid burnt clay tile or combinations of tile and concrete ...	6	5	5	4
Metal lath and gypsum plaster ...	6	5	4	2
Cement concrete good quality ...	5	5	4	2½
Cement concrete poor quality ...	10	7	5	4
Cement concrete, poor quality with wire mesh ...	7	5	5	4
Hollow gypsum block (to obtain 4 hr. rating must be plastered with 10 mm. of gypsum plaster) ...	7	7	7	7

Separating walls between buildings protect the adjacent buildings from hazards. A wall 20 cm. thick gives a fire resistance that is normally needed. Separating walls inside the building may not have such a higher fire resistance. Walls enclosing stairs and lift shafts should be suitably constructed so that they can give effective resistance. A load bearing external wall should have a period of sufficient fire resistance to ensure that it will continue to act as a suitable bearing member during fire when the distance between the buildings is insufficient for fire fighting. The openings in the walls should be restricted. They may also be protected by using fire resistant glass or suitable steel shutters. The risk of the spread of fire from one floor to another must be carefully guarded. Whenever the windows are carried down to the floor it is necessary to provide suitable barriers. These may consist of projecting the slab beyond the outer face of the building. The table on next page gives the needed thicknesses of the materials for various degrees of fire resistance.

Fire-proofing of structural steel : For fire proof construction the minimum resistance needed for columns and girders is of four hours' duration whereas for beams it may be about three hours. In semi-fireproof constructions these values are three hours and two hours respectively.

The modern steel frame building is fire-proof with concrete. The exterior columns may be fire-proofed with concrete and then encased in masonry. The columns may be protected by wrapping by a mesh or expanded metal mesh and then covering by two coats of cement plaster. A combination of terra-cotta and concrete for fire proofing the steel columns is quite suitable. The terra-cotta blocks surround the columns whereas the projections, etc., in column section are filled with concrete. It may be preferable to use either terra-cotta or concrete as otherwise the difference in thermal expansion in the two materials may lead to cracking.

The beam haunches may be protected with concrete, clay tile or gypsum tile. Terra-cotta units may completely encase the steel beams or may be used in a jack arch floor construction along with the steel beams. The fire resistance of various coverings on steel work for different thicknesses is given in the table on next page.

Fire-resistance of wooden joist floors :—Under fire, such types of floors should not collapse or deflect more than $\frac{1}{30}$ of the span within thirty minutes. The flames should not penetrate through the upper surface within 15 minutes. The average temperature rise should not increase more than 120°C within 15 minutes. The type of ceiling is very important as it protects the joist and also prevents the penetration of flame in-between the wooden boards if they are butt-jointed as there would be excessive gaps present. The fire resistance of a floor depends much on the detailed design of the various elements.

Construction and materials	*Minimum thickness in Centimetre (excluding plaster) for period of*				
	6 hrs.	*4 hrs.*	*2 hrs.*	*1 hr.*	*½ hr.*
Bricks and Solid Block Construction :					
Bricks of clay, concrete or sand-lime built as a solid wall :					
No plaster ...	20	20	20	10	10
Built as a cavity wall ...	23	—	—	—	—
Concrete Blocks :					
Built as a cavity wall 10 cm. outer leaf : inner leaf of solid or hollow concrete blocks ...	10	7	—	—	—
Reinforced concrete:					
With minimum concrete cover to reinforcement of 2.5 cm. ...	20	17	10	7	7
Hollow Block Construction :					
Clay blocks :					
Plastered at least 1 cm. thick on each side and shells not less than ½ cm. thick :					
1 cell in each block and each block not less than 50 per cent solid ...	—	—	—	10	7
1 cell in each block and each block not less than 30 per cent solid ...	—	—	—	15	—
2 cells in each block and each block not less than 50 per cent solid ...	—	—	20	10	—
2 cells in each block and each block not less than 30 per cent solid ...	—	—	—	15	—
Concrete blocks :					
Plastered at least 1 cm. thick on each side and 1 cell in wall thickness :					
Good aggregates ...	—	21	11	7	6
Poor aggregates ...	—	—	—	21	7

Construction and materials	*Minimum thickness in centimetre for period of*				
	6 hrs.	*4 hrs.*	*2 hrs.*	*1 hr.*	*½ hr.*
Hollow Partitions, steel or timber studding :					
Plaster on metal lathing :					
Portland cement plaster, Portland cement lime plaster or gypsum plaster ...	—	—	—	1.5	1
Plasterboard with or without gypsum plaster :					
1.5 cm. thick plasterboard on each side ...	—	—	—	—	0.4 (neat single coat)
1 cm. thick plasterboard on each side ..	—	—	—	0·9	nil.*
2·5 cm. woodwool slab on each side plastered	—	—	—	—	1

*Thickness of plaster only.

General

A building can never be completely fire-proof. It should have structural elements which can withstand the effects of fire for suitable intervals so that adequate protection to the occupants is afforded. Limitations to the height and the floor areas of buildings which are not fire-proof are imposed by the various Building codes. Adequate means of escape must be provided if a fire breaks out. The location and design of lifts and stairs should be well worked out. All doors leading to them should be fire-proofed.

QUESTIONS

1. What is the object of shoring? Describe in detail the shoring operations of a building wall with the aid of raking shores.

2. A concrete footing of a building wall is to be re-built at a deeper depth. Describe in detail the method during the job.

3. Describe fully the various elements of a bricklayer's scaffold. What is the difference between this type of scaffolding and that used by the masons?

4. How do the earthquakes damage a building? Briefly describe some of the steps which are essential in getting an adequate protection of a building against earthquakes.

5. What is meant by fire-proof construction? What are the steps taken in fire-proofing steel columns?

6. Write short notes on :

   (*i*) Horizontal shores.

   (*ii*) Use of steel centering.

(*iii*) Treatment of foundations against earthquake effects.

(*iv*) Fire-resistance of wooden members.

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