A TEXT BOOK
OF
BUILDING CONSTRUCTION
(Including Questions from Universities of Gujarat, Bombay, Poona, Baroda, Karnatak, Sind, etc.)

By
N. K. R. MOORTHY, B. Sc. (Engg.)
F. R. E. S., A. M. I. S. E., A. M. M. E. A.
Principal, College of Engineering, Madurai.

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PREFACE

The author has written this book mainly for the use of students in India. The author has made an attempt to deal with the various processes in Building Construction, from the foundation to the roof and finishing. Much care has been exercised for the correct presentation of the technical details in simple and plain language. More than 1200 illustrations have been added and most of them have been prepared to a large size. The chapters have been arranged mostly in the order in which the subjects are usually taught in regular colleges and polytechnics. At the end of each chapter a number of questions, selected from various Indian University Examination papers, has been added for revision. The author hopes that this book will fulfill a want of the civil engineering and architecture students and that it will be of use to them in their career. It is hoped that in addition to meeting the requirements of most of the professional examinations in Indian Universities and Government Institutions, it will also be useful as a book of reference to Engineers, Architects, Builders, Contractors, Surveyors and to those engaged on construction works.

The author desires to express his indebtedness to the authors of a number of books on the subject which he has found of immense use in the compilation of this volume. He is also indebted to the Universities of Bombay, Baroda, Poona, Gujarat, Karnataka and Sind and to the Institution of Engineers (India) for questions taken from their examination papers. The author also wishes to express his grateful thanks to his colleagues and friends for their valuable criticisms and suggestions during the preparation of this volume.

The author will be thankful to readers if they bring to his notice any errors of omission or commission, or give valuable suggestions for improvements of the book in order to enhance its usefulness.

Madurai, April, 1957. N. K. R. MOORTHY.
# CONTENTS

## PART I

<table>
<thead>
<tr>
<th>CHAPTERS</th>
<th>PAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Foundations, Excavating and Concreting</td>
<td>1</td>
</tr>
<tr>
<td>II Masonry—Stone Masonry</td>
<td>139</td>
</tr>
<tr>
<td>III Masonry—Brick Masonry</td>
<td>208</td>
</tr>
<tr>
<td>IV Composite Masonry</td>
<td>285</td>
</tr>
<tr>
<td>V Partitions</td>
<td>295</td>
</tr>
<tr>
<td>VI Circular Brickwork, Reinforced Brickwork and Damp-proof Courses</td>
<td>318</td>
</tr>
</tbody>
</table>

## PART II

<table>
<thead>
<tr>
<th>CHAPTERS</th>
<th>PAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>VII Scaffolding, Shoring and Underpinning</td>
<td>1</td>
</tr>
<tr>
<td>VIII Lintels and Arches</td>
<td>14</td>
</tr>
<tr>
<td>IX Joints in Carpentry</td>
<td>50</td>
</tr>
<tr>
<td>X Doors and Windows</td>
<td>82</td>
</tr>
<tr>
<td>XI Stairs and Staircases</td>
<td>128</td>
</tr>
<tr>
<td>XII Roofs</td>
<td>170</td>
</tr>
<tr>
<td>XIII Structural Steelwork</td>
<td>223</td>
</tr>
<tr>
<td>XIV Ground and Upper Floors</td>
<td>259</td>
</tr>
<tr>
<td>XV Plastering, Pointing, White-washing and Colour-washing</td>
<td>349</td>
</tr>
<tr>
<td>XVI Painting, Varnishing and Distempering</td>
<td>384</td>
</tr>
</tbody>
</table>
BUILDING CONSTRUCTION

CHAPTER I

FOUNDATIONS, EXCAVATING AND CONCRETING

As the word implies, building is a house. Construction is the art or act of designing and constructing works. "Building Construction" is therefore the art or act of designing and constructing houses. The art of building construction is not new to this country. At Mohanjodaro, Harappa and a few other places in India there have been buildings constructed with sanitary systems which are stated to date back to about 3000 B.C.

Structure: A structure is a part, generally constructed to support certain definite loads. Wall, pier, stanchion, etc., are examples of structures. Structures are acted upon by external or outer forces and these forces are held in equilibrium by internal or inner forces, called stresses. A structure usually consists of two parts, viz., the foundation and the superstructure. Among these two, the former is generally under the ground surface and the latter above ground level.

Foundation: The foundation, as applied to buildings and bridges, is considered as the lowest artificially built part of a structure, upon which the structure directly rests. It includes both the portion below the ground level and the artificial arrangement, such as concrete or concrete block, piles, grilles, etc., upon which the structure stands. The upper surface of the artificial arrangement is called the foundation bed. Although the foundation supports the weight of a structure, it may be said that foundation is a device provided at the base of a structure to transmit the load to the soil on which it rests. The foundation work generally includes the excavation to, and the preparation of, the subsoil and the placing of concrete, stone, brick or other footings thereon.
Superstructure: The superstructure, as applied to buildings and bridges, is considered as the upper portion of a structure, which is generally above the ground level as already mentioned. It consists of walls at some intervals or piers or columns at some fixed places, supporting the load of the floors, temporary materials such as furniture, etc., and also the persons, animals, etc. living inside.

Importance of good foundations: The foundation is the most critical point of any structure, and more failures are probably due to faulty foundations than to any other cause. Hence, if the greatest importance to secure good foundations, the stability of the structure being in a large measure dependent on the unyielding nature of its foundations. A good foundation must remain in position without sliding, bending, overturning or falling in any other way.

Laying of foundations under the ground level: The foundations of any structure are generally laid below the surface of the ground (1) to secure a good natural bed; (2) to protect the foundation courses from atmospheric influences; and (3) for stability. The bottom of a foundation should be safe against all external influences, such as weather, temperature, etc.

Objects of foundations: It is very often confused by simply presuming or thinking that the weight of a structure is supported by its foundations; but, it is not the purpose of foundations. The objects of foundations of any structure may be listed as heretofore:

1. To distribute the weight of the structure over a vast bearing surface so as to prevent it from any movement.
2. To load the bearing surface at a uniform rate so as to prevent practically any unequal settlement.
3. To prevent the lateral escape or movement of the supporting material. (For this sand may be taken as a good example. The movement of the supporting material may generally leave a room or hollow below the foundation, and consequently this may endanger the structure).
4. To secure a level and firm natural bed, upon which to lay the courses of masonry.
5. To increase the stability of the structure as a whole so as to prevent it from sliding or overturning.

**Loads on Structures and Bearing Capacity of Soils:**
The following particulars are quite essential to design the foundation of a structure:

(a) A detailed analysis of loads acting on various parts of the structure, and the intensity of this load per sq. ft., and
(b) The nature and bearing capacity of the soil on which the structure directly rests.

After obtaining the above particulars, a suitable foundation can be designed and constructed in one of the methods explained later.

**Loads on foundations:** The loads coming on the foundations are generally classified into three types:—

1. **Dead load:** It is the weight of a structure itself plus any permanent loads. The dead load of a building is found by calculating the weights of all walls, floors, ceilings, and roof finishes, stone work, brick work, steel work, partitions, fixed tanks, machinery, and similar other permanent construction comprised in the building. Very often the positions of partitions are not shown in the plan. In such cases, a minimum allowance of 20 lbs. per sq. ft. over the whole floor area should suffice for light partitions such as of timber with glass or wooden panels. Brick and concrete construction have the largest dead load relative to the total load. The weights of various substances and the safe compressive stresses in masonry and concrete are given in Tables 1 and 2 respectively.

2. **Live load:** It is any moving or variable load which may come upon the structure—e.g., for example, the weight of people on a floor, or the weight of materials stored temporarily on the structure. Sometimes the live load is known as "superimposed" or simply "super load." For the purpose of design, its equivalent dead load as shown in Table 3 is usually taken. The table is based on the recommendations of the London County Council (L. C. C.) Building By-Laws and Code of Practice (1948). Some authorities specify that the foundations shall be designed to carry 50% of the assumed live load in addition to the dead load, wind
load and snow load. But in practice, this is very often disregarded to ensure safety.

In design, some reductions are made in live loads in multi-storeyed buildings except those for factories and stores. Such reductions, generally taken for purposes of calculations, are given in Table 4.

(3) Wind load or wind pressure: Tall buildings are subjected to wind pressure on the exposed walls and roof surfaces. It is assumed that wind pressure acts horizontally and exerts a uniform pressure over the entire surface of the windward side of the building. The ill-effects of wind pressure are: (a) a tendency to over-turn the building, and (b) a tendency to collapse the building. The first ill-effect may be resisted by the dead load of the building or by anchorage, and the second by the structural parts of the building, i.e., by a triangular framing having axial stresses (Fig. 1) or by a rectangular or portal framing (Fig. 2) having bending stresses.

\[ P = 0.004 V^2 \]

where

- \( P \) = Pressure in lbs. per square foot, and
- \( V \) = Velocity in miles per hour.

(Continued on Page 13)
### TABLE No. 1.
Weights of various Materials.

(Note:—These weights are for solid materials. Sufficient provision must be made for the weights of broken materials varying with the percentage of voids. Green timbers weigh 1/5 to 2/5 more than seasoned or dry).

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Description of Material</th>
<th>Weight.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Granite</td>
<td>168 lbs. per cu. ft.</td>
</tr>
<tr>
<td>2.</td>
<td>Trap</td>
<td>187</td>
</tr>
<tr>
<td>3.</td>
<td>Basalt</td>
<td>178</td>
</tr>
<tr>
<td>4.</td>
<td>Gneiss</td>
<td>160</td>
</tr>
<tr>
<td>5.</td>
<td>Laterite</td>
<td>140</td>
</tr>
<tr>
<td>6.</td>
<td>Limestone</td>
<td>165</td>
</tr>
<tr>
<td>7.</td>
<td>Sandstone</td>
<td>137</td>
</tr>
<tr>
<td>8.</td>
<td>Slate</td>
<td>170</td>
</tr>
<tr>
<td>9.</td>
<td>Gravel</td>
<td>100</td>
</tr>
<tr>
<td>10.</td>
<td>Kankar</td>
<td>99</td>
</tr>
<tr>
<td>11.</td>
<td>Marble</td>
<td>169</td>
</tr>
<tr>
<td>12.</td>
<td>Brick, ordinary</td>
<td>112</td>
</tr>
<tr>
<td>13.</td>
<td>Brick, soft, inferior</td>
<td>100</td>
</tr>
<tr>
<td>14.</td>
<td>Brick, common hard</td>
<td>125</td>
</tr>
<tr>
<td>15.</td>
<td>Brick, best pressed</td>
<td>130</td>
</tr>
<tr>
<td>16.</td>
<td>Brick, fire</td>
<td>137</td>
</tr>
<tr>
<td>17.</td>
<td>Cement, Portland</td>
<td>92</td>
</tr>
<tr>
<td>18.</td>
<td>Lime (fat, slaked)</td>
<td>36</td>
</tr>
<tr>
<td>19.</td>
<td>Lime (Kankar)</td>
<td>72</td>
</tr>
<tr>
<td>20.</td>
<td>Quicklime, ground, loose, or in small lumps</td>
<td>53</td>
</tr>
<tr>
<td>21.</td>
<td>Quicklime, ground loose or thoroughly shaken</td>
<td>75</td>
</tr>
<tr>
<td>22.</td>
<td>Plaster of Paris, cast</td>
<td>80</td>
</tr>
<tr>
<td>23.</td>
<td>Plaster. Cement</td>
<td>130</td>
</tr>
<tr>
<td>24.</td>
<td>Plaster, Lime</td>
<td>120</td>
</tr>
<tr>
<td>25.</td>
<td>Mortar, Lime</td>
<td>109</td>
</tr>
<tr>
<td>S. No.</td>
<td>Description of Material</td>
<td>Weight.</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>26.</td>
<td>Chalk</td>
<td>112 lbs. per cu. ft.</td>
</tr>
<tr>
<td>27.</td>
<td>Stone Masonry</td>
<td>160</td>
</tr>
<tr>
<td>28.</td>
<td>Dry stone masonry</td>
<td>130</td>
</tr>
<tr>
<td>29.</td>
<td>Brickwork, ordinary</td>
<td>115</td>
</tr>
<tr>
<td>30.</td>
<td>Brickwork, hard burnt brick</td>
<td>120</td>
</tr>
<tr>
<td>31.</td>
<td>Brickwork, Sundried or Kachcha</td>
<td>100</td>
</tr>
<tr>
<td>32.</td>
<td>Brickwork, pressed brick in cement mortar</td>
<td>140</td>
</tr>
<tr>
<td>33.</td>
<td>Concrete, cement, with stone ballast</td>
<td>150</td>
</tr>
<tr>
<td>34.</td>
<td>do Brick do</td>
<td>120</td>
</tr>
<tr>
<td>35.</td>
<td>Concrete, lime, with stone ballast</td>
<td>140</td>
</tr>
<tr>
<td>36.</td>
<td>do brick ballast</td>
<td>115</td>
</tr>
<tr>
<td>37.</td>
<td>Concrete, reinforced, including weight of steel</td>
<td>150</td>
</tr>
<tr>
<td>38.</td>
<td>Teak (Burma or Malabar)</td>
<td>41</td>
</tr>
<tr>
<td>39.</td>
<td>Teak (Central Province)</td>
<td>38</td>
</tr>
<tr>
<td>40.</td>
<td>Sal</td>
<td>54</td>
</tr>
<tr>
<td>41.</td>
<td>Chir</td>
<td>35</td>
</tr>
<tr>
<td>42.</td>
<td>Sain</td>
<td>53</td>
</tr>
<tr>
<td>43.</td>
<td>Deodar</td>
<td>36</td>
</tr>
<tr>
<td>44.</td>
<td>Jarrah</td>
<td>55</td>
</tr>
<tr>
<td>45.</td>
<td>Douglas Fir</td>
<td>31</td>
</tr>
<tr>
<td>46.</td>
<td>Kall</td>
<td>28</td>
</tr>
<tr>
<td>47.</td>
<td>Babul</td>
<td>54</td>
</tr>
<tr>
<td>48.</td>
<td>Bamboo</td>
<td>25</td>
</tr>
<tr>
<td>49.</td>
<td>Mango</td>
<td>42</td>
</tr>
<tr>
<td>50.</td>
<td>Malabar walnut or Karinaradaa</td>
<td>50</td>
</tr>
<tr>
<td>51.</td>
<td>Red wood or Padowk</td>
<td>54</td>
</tr>
<tr>
<td>52.</td>
<td>Vengay or Indian Padowk</td>
<td>36</td>
</tr>
<tr>
<td>53.</td>
<td>Bentak</td>
<td>41</td>
</tr>
<tr>
<td>54.</td>
<td>Peenah</td>
<td>40</td>
</tr>
<tr>
<td>55.</td>
<td>Asjielly</td>
<td>40</td>
</tr>
<tr>
<td>56.</td>
<td>Red cedar or Toon</td>
<td>31</td>
</tr>
<tr>
<td>S. No.</td>
<td>Description of Material.</td>
<td>Weight.</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>57.</td>
<td>White cedar or Chittagong wood</td>
<td>42 lbs. per cu. ft.</td>
</tr>
<tr>
<td>58.</td>
<td>Rose wood or Black wood</td>
<td>50</td>
</tr>
<tr>
<td>59.</td>
<td>Casuarina</td>
<td>55</td>
</tr>
<tr>
<td>60.</td>
<td>Palmyra</td>
<td>65</td>
</tr>
<tr>
<td>61.</td>
<td>Cocoonut</td>
<td>70</td>
</tr>
<tr>
<td>62.</td>
<td>Sisso</td>
<td>70</td>
</tr>
<tr>
<td>63.</td>
<td>Pine, white</td>
<td>25</td>
</tr>
<tr>
<td>64.</td>
<td>Pine, yellow</td>
<td>34 to 45</td>
</tr>
<tr>
<td>65.</td>
<td>Roof, Mangalore tiles and battens</td>
<td>10 lbs. per sq. ft.</td>
</tr>
<tr>
<td>66.</td>
<td>&quot; Allahabad tiles and battens (single)</td>
<td>17</td>
</tr>
<tr>
<td>67.</td>
<td>&quot; Allahabad tiles and battens (double)</td>
<td>33</td>
</tr>
<tr>
<td>68.</td>
<td>&quot; Country tiles and frames (single)</td>
<td>14</td>
</tr>
<tr>
<td>69.</td>
<td>&quot; (double)</td>
<td>24</td>
</tr>
<tr>
<td>70.</td>
<td>&quot; Eternit sheet</td>
<td>5</td>
</tr>
<tr>
<td>71.</td>
<td>&quot; asbestos cement sheet</td>
<td>7</td>
</tr>
<tr>
<td>72.</td>
<td>&quot; 1&quot; cement tiles on mortar bedding</td>
<td>10</td>
</tr>
<tr>
<td>73.</td>
<td>&quot; Corrugated iron sheets (24 gauge)</td>
<td>1½</td>
</tr>
<tr>
<td>74.</td>
<td>&quot; -do- (22 gauge)</td>
<td>2</td>
</tr>
<tr>
<td>75.</td>
<td>&quot; Galvanised iron (24 gauge on 1&quot; boarding)</td>
<td>5</td>
</tr>
<tr>
<td>76.</td>
<td>&quot; 6&quot; thatch and frames</td>
<td>6½</td>
</tr>
<tr>
<td>77.</td>
<td>&quot; 9&quot; -do-</td>
<td>10</td>
</tr>
<tr>
<td>78.</td>
<td>&quot; Slates on 1&quot; boarding</td>
<td>12</td>
</tr>
<tr>
<td>79.</td>
<td>Timber trussed and purlins</td>
<td>24</td>
</tr>
<tr>
<td>80.</td>
<td>Rafters</td>
<td>1</td>
</tr>
<tr>
<td>81.</td>
<td>Battens</td>
<td>½</td>
</tr>
<tr>
<td>82.</td>
<td>Paving flagstone 1½ to 2&quot;</td>
<td>12 to 18</td>
</tr>
<tr>
<td>83.</td>
<td>Time plaster ceiling on 2½ wire netting</td>
<td>7</td>
</tr>
<tr>
<td>S. No.</td>
<td>Description of Material</td>
<td>Weight</td>
</tr>
<tr>
<td>-------</td>
<td>-------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>84.</td>
<td>Eternit or Polite or Asbestos sheets or tiles 5/32&quot; thick</td>
<td>2\frac{1}{2} lbs. per sq. ft.</td>
</tr>
<tr>
<td>85.</td>
<td>Venesta or Pine ceiling</td>
<td>2</td>
</tr>
<tr>
<td>86.</td>
<td>1/8&quot; Metal Tin Toilet Ceiling</td>
<td>2\frac{1}{2}</td>
</tr>
<tr>
<td>87.</td>
<td>Doors with frames</td>
<td>8</td>
</tr>
<tr>
<td>88.</td>
<td>Hay</td>
<td>5 lbs. per cu. ft.</td>
</tr>
<tr>
<td>89.</td>
<td>Hay, pressed</td>
<td>8</td>
</tr>
<tr>
<td>90.</td>
<td>Water, ordinary</td>
<td>62\frac{1}{2}</td>
</tr>
<tr>
<td>91.</td>
<td>Water, sea</td>
<td>64</td>
</tr>
<tr>
<td>92.</td>
<td>Ice</td>
<td>57\frac{1}{2}</td>
</tr>
<tr>
<td>93.</td>
<td>Snow, freshly fallen</td>
<td>5 to 12</td>
</tr>
<tr>
<td>94.</td>
<td>Snow, moistened and compacted by rain</td>
<td>15 to 50</td>
</tr>
<tr>
<td>95.</td>
<td>River sand</td>
<td>117</td>
</tr>
<tr>
<td>96.</td>
<td>Sand, dry</td>
<td>100</td>
</tr>
<tr>
<td>97.</td>
<td>Sand, moist</td>
<td>110</td>
</tr>
<tr>
<td>98.</td>
<td>Sand, saturated</td>
<td>120</td>
</tr>
<tr>
<td>99.</td>
<td>Clay, ordinary, dry</td>
<td>110</td>
</tr>
<tr>
<td>100.</td>
<td>Clay, damp</td>
<td>120</td>
</tr>
<tr>
<td>101.</td>
<td>Clay, wet</td>
<td>130</td>
</tr>
<tr>
<td>102.</td>
<td>Earth, common, dry</td>
<td>75</td>
</tr>
<tr>
<td>103.</td>
<td>Earth, common, dry, moderately rammed</td>
<td>95</td>
</tr>
<tr>
<td>104.</td>
<td>Earth, compacted</td>
<td>135</td>
</tr>
<tr>
<td>105.</td>
<td>Earth, as a soft, flowing mud</td>
<td>108</td>
</tr>
<tr>
<td>106.</td>
<td>Alluvial deposits</td>
<td>90</td>
</tr>
<tr>
<td>107.</td>
<td>Loam</td>
<td>80 to 110</td>
</tr>
<tr>
<td>108.</td>
<td>Shingle</td>
<td>90</td>
</tr>
<tr>
<td>109.</td>
<td>Mud, dry, close</td>
<td>80 to 110</td>
</tr>
<tr>
<td>110.</td>
<td>Mud, wet, fluid, maximum</td>
<td>120</td>
</tr>
<tr>
<td>111.</td>
<td>Coal</td>
<td>2\frac{1}{2}</td>
</tr>
<tr>
<td>112.</td>
<td>Coal, broken, loose</td>
<td>52</td>
</tr>
<tr>
<td>113.</td>
<td>Ballast and sand, damp, loose</td>
<td>90 to 106</td>
</tr>
<tr>
<td>114.</td>
<td>-do-, well shaken</td>
<td>59 to 117</td>
</tr>
<tr>
<td>115.</td>
<td>-do-, thoroughly wet</td>
<td>120 to 140</td>
</tr>
<tr>
<td>S. No.</td>
<td>Description of Material</td>
<td>Weight</td>
</tr>
<tr>
<td>-------</td>
<td>------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>116.</td>
<td>Iron, cast</td>
<td>454 lbs. per cu. ft.</td>
</tr>
<tr>
<td>117.</td>
<td>Iron, wrought</td>
<td>484</td>
</tr>
<tr>
<td>118.</td>
<td>Steel</td>
<td>490</td>
</tr>
<tr>
<td>119.</td>
<td>Lead</td>
<td>710</td>
</tr>
<tr>
<td>120.</td>
<td>Aluminium</td>
<td>162</td>
</tr>
<tr>
<td>121.</td>
<td>Zinc sheet</td>
<td>444</td>
</tr>
<tr>
<td>122.</td>
<td>Gun-metal</td>
<td>528</td>
</tr>
<tr>
<td>123.</td>
<td>Brass, rolled</td>
<td>525</td>
</tr>
<tr>
<td>124.</td>
<td>Bronze</td>
<td>513</td>
</tr>
<tr>
<td>125.</td>
<td>Gold</td>
<td>1151</td>
</tr>
<tr>
<td>126.</td>
<td>Copper, sheet</td>
<td>555</td>
</tr>
<tr>
<td>127.</td>
<td>Platinum</td>
<td>1340</td>
</tr>
<tr>
<td>128.</td>
<td>Silver</td>
<td>625</td>
</tr>
<tr>
<td>129.</td>
<td>Tin</td>
<td>455</td>
</tr>
<tr>
<td>130.</td>
<td>Red lead</td>
<td>557</td>
</tr>
<tr>
<td>131.</td>
<td>Asphalt</td>
<td>88</td>
</tr>
<tr>
<td>132.</td>
<td>Ashes, loose</td>
<td>40</td>
</tr>
<tr>
<td>133.</td>
<td>Petrol</td>
<td>42</td>
</tr>
<tr>
<td>134.</td>
<td>Petroleum</td>
<td>54</td>
</tr>
<tr>
<td>135.</td>
<td>Tar</td>
<td>63</td>
</tr>
<tr>
<td>136.</td>
<td>Mercury</td>
<td>850</td>
</tr>
<tr>
<td>137.</td>
<td>Glass, plate</td>
<td>170</td>
</tr>
<tr>
<td>138.</td>
<td>Glass, common window</td>
<td>165</td>
</tr>
<tr>
<td>139.</td>
<td>India-rubber</td>
<td>60</td>
</tr>
<tr>
<td>140.</td>
<td>Iron ore</td>
<td>230</td>
</tr>
<tr>
<td>141.</td>
<td>Pumice stone</td>
<td>57</td>
</tr>
<tr>
<td>142.</td>
<td>Salt, loose</td>
<td>50 to 70</td>
</tr>
<tr>
<td>143.</td>
<td>Salt, solid</td>
<td>131</td>
</tr>
<tr>
<td>144.</td>
<td>Salt, dry, loose</td>
<td>89 to 106</td>
</tr>
<tr>
<td>145.</td>
<td>Terra-cotta</td>
<td>112</td>
</tr>
<tr>
<td>146.</td>
<td>Tile</td>
<td>113</td>
</tr>
<tr>
<td>147.</td>
<td>Coke, loose</td>
<td>30</td>
</tr>
<tr>
<td>S. No.</td>
<td>Kind of Masonry or Concrete</td>
<td>Safe bearing loads in tons per sq. ft.</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td>Masonry, Random rubble, in lime mortar.</td>
<td>3</td>
</tr>
<tr>
<td>2.</td>
<td>Do., in cement mortar.</td>
<td>8</td>
</tr>
<tr>
<td>3.</td>
<td>Masonry, Coursed rubble, in lime mortar.</td>
<td>5</td>
</tr>
<tr>
<td>4.</td>
<td>Do., in cement mortar.</td>
<td>12</td>
</tr>
<tr>
<td>5.</td>
<td>Masonry, ashlar, in lime mortar (granite.)</td>
<td>15</td>
</tr>
<tr>
<td>6.</td>
<td>Do., in cement do.</td>
<td>18</td>
</tr>
<tr>
<td>7.</td>
<td>Masonry, ashlar, in lime mortar (Trap).</td>
<td>15</td>
</tr>
<tr>
<td>8.</td>
<td>Do., in cement mortar (Trap).</td>
<td>20</td>
</tr>
<tr>
<td>9.</td>
<td>Brickwork, ordinary, in mud</td>
<td>14</td>
</tr>
<tr>
<td>10.</td>
<td>Brickwork, country brick, in lime mortar.</td>
<td>3</td>
</tr>
<tr>
<td>11.</td>
<td>Do., in cement mortar</td>
<td>6</td>
</tr>
<tr>
<td>12.</td>
<td>Brickwork, hard burnt brick, in lime mortar.</td>
<td>4 to 5</td>
</tr>
<tr>
<td>13.</td>
<td>Do., in cement mortar</td>
<td>7</td>
</tr>
<tr>
<td>14.</td>
<td>Cement concrete, 1:1:2</td>
<td>40</td>
</tr>
<tr>
<td>15.</td>
<td>Do., 1:1.5:3</td>
<td>35</td>
</tr>
<tr>
<td>16.</td>
<td>Do., 1:2:4</td>
<td>30</td>
</tr>
<tr>
<td>17.</td>
<td>Do., 1:3:6</td>
<td>20</td>
</tr>
<tr>
<td>18.</td>
<td>Do., 1:4:8</td>
<td>12</td>
</tr>
<tr>
<td>19.</td>
<td>Lime concrete</td>
<td>7</td>
</tr>
<tr>
<td>S. No.</td>
<td>Description of building</td>
<td>Equivalent dead load in lbs per sq. ft.</td>
</tr>
<tr>
<td>-------</td>
<td>------------------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>1.</td>
<td>Domestic Rooms</td>
<td>50</td>
</tr>
<tr>
<td>2.</td>
<td>Hotel bed-rooms, Hospital Wards and Rooms</td>
<td>50</td>
</tr>
<tr>
<td>3.</td>
<td>Public spaces in above</td>
<td>100</td>
</tr>
<tr>
<td>4.</td>
<td>Office Rooms</td>
<td>80</td>
</tr>
<tr>
<td>5.</td>
<td>Entrance floor, and below Above entrance floors</td>
<td>80</td>
</tr>
<tr>
<td>6.</td>
<td>Churches, Schools, Reading Rooms, Art Galleries, Retail Shops, Garages of Cars, less than 2 tons weight</td>
<td>80</td>
</tr>
<tr>
<td>7.</td>
<td>Assembly Halls, Drill Halls, Dance Halls, Gymnasia, Light Workshops, Theatres, Cinema Houses, Restaurants, Cafes and Grand stands</td>
<td>100</td>
</tr>
<tr>
<td>8.</td>
<td>Printing Presses, Large Workshops and Factories</td>
<td>150</td>
</tr>
<tr>
<td>9.</td>
<td>Warehouses, Book-shops, Stationery Stores, Garages for Cars more than 2 tons weight</td>
<td>200</td>
</tr>
<tr>
<td>10.</td>
<td>Staircases, Landings, and Corridors, Overhanging Balconies in Buildings other than Domestic Buildings</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Domestic Buildings</td>
<td>80</td>
</tr>
</tbody>
</table>
1. Description of building.

11. Roofs

- Roofs inclined at not greater than 20 degrees to horizontal
- Roofs inclined at greater than 20 degrees to horizontal.

Equivalent dead load in lbs per sq. ft.

50 lbs./ft² normal to the sloping surface on the windward side. 10 lbs./ft² normal to leeward slope (not simultaneously)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Description of building</th>
<th>Equivalent dead load in lbs per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.</td>
<td>Roofs</td>
<td>50 lbs./ft² normal to the sloping surface on the windward side. 10 lbs./ft² normal to leeward slope (not simultaneously)</td>
</tr>
<tr>
<td>12.</td>
<td>Roofs</td>
<td>15 lbs./ft² normal to the sloping surface on the windward side. 10 lbs./ft² normal to leeward slope (not simultaneously)</td>
</tr>
</tbody>
</table>

TABLE NO. 4
Reduction of superimposed loads on columns on multi-storeyed buildings.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Position of column in the building</th>
<th>Percentage of reduction in live load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Topmost storey below the roof</td>
<td>No. reduction</td>
</tr>
<tr>
<td>2.</td>
<td>Second storey from the top</td>
<td>10%</td>
</tr>
<tr>
<td>3.</td>
<td>Tiled</td>
<td>20%</td>
</tr>
<tr>
<td>4.</td>
<td>Fourth</td>
<td>30%</td>
</tr>
<tr>
<td>5.</td>
<td>Fifth</td>
<td>40%</td>
</tr>
<tr>
<td>Note:</td>
<td>After this no further reduction is allowed.</td>
<td></td>
</tr>
</tbody>
</table>

Reduction of superimposed loads on columns on multi-storeyed buildings.
For 50 miles per hour, the above formula gives a pressure of 10 lbs. per square foot. This formula is of little practical use because of the uncertainty of the velocity to be provided for. According to the London County Council Building Bylaws and Code of Practice the wind pressure may be neglected if the height of a building is less than twice its width, provided that the building is stiffened by cross-walls, partitions, floors, etc. In other cases, a wind pressure of 15 lbs. per sq. ft. upon the upper two-thirds of the vertical projection of the surface of such buildings, with an additional pressure of 10 lbs. per sq. ft. upon all projections such as chimneys, etc. above the general roof level should be taken.

4. Snow Load: The snow load to be carried by a roof truss is a variable quantity, depending upon the slope of the roof, the latitude, and the humidity. Usually an allowance of 5 lbs. per sq. ft. for every foot depth of snow is made for the purpose of design, but nothing is allowed for roofs sloping at 1 to 1 (45°) or steeper. So far concerned with South India, no provision is made for this purpose except those for hilly areas like Kodikanal, Nilgiris, etc.

Classification of bearing soils: The soils on which a structure rests may be classified into three classes:

(a) Hard soils: These are incompressible soils which are capable of bearing loads usually put on and fairly heavy without yielding. Solid rock, morum and stony soils are examples of hard soils.

(b) Soft soils: These are compressible soils which do not take loads and yield in every direction. Ordinary clay, loam and common earths are examples of soft soils.

1. In American practice, a wind pressure of 20 lbs. per sq. ft. of the projected area is most commonly used. The formula $P=0.004 V^2$ is also used by American Engineers. The City of New York Building Code of 1917 prescribes a pressure of 30 lbs. per sq. ft.

2. This is rock weathered in place. The upper surface of it is usually softer than the lower and the total thickness is generally within 3 feet.
(c) Spreading Soils: These are incompressible soils, but spread out laterally. Sand and gravel are examples of spreading soils.

Bearing Power of Soils: The bearing power or bearing capacity of a soil is the maximum load per unit of area (usually in terms of tons per square foot) which the ground will support without yielding or displacement. Experience shows that very often a structure fails by unequal settlement, i.e., when the intensity of load is varying and is more than the bearing power of the soil. Unequal settlement is the usual cause of cracks and similar defects occurring in walls, floors, etc. Hence it is evident that if a structure is to be stable, it should not give more load on the soil than its bearing capacity, and it should be much less, to ensure safety.

Safe bearing power of soils: So far we have been considering the ultimate bearing capacity of soils. The allowable bearing capacity or the safe bearing capacity of a soil is, however, the value required for design. The safe bearing capacity of a soil may be defined as the ultimate bearing capacity of the soil divided by a certain factor of safety. This is not a factor of ignorance but a factor used to keep the loading well below the ultimate, and thus to keep the settlements within reasonable limits. To keep the settlements small, an adequate factor of safety must be applied to the ultimate bearing capacity, and the value of the factor depends to some extent on the type of building. As a rough guide it may be said that a factor of safety of 2 is suitable for most buildings, and a factor of safety of 2.5 to 3 for very heavy buildings. Thus, if the bearing power of the soil was found to be 6 tons per sq. ft., the safe or allowable bearing capacity of the soil should be between 3 and 2 tons per sq. ft., depending on the type of structure.

The average values of the safe load bearing capacity of each type of soil are given in Table No. 5 for ready reference and use. A factor of safety of 2 is employed in determining the safe bearing capacity of each type of soil.
# TABLE NO. 5.
Safe permissible loads on various kinds of soils.
(A factor of safety of 2 is employed)

<table>
<thead>
<tr>
<th>S No.</th>
<th>Kind of soil</th>
<th>Safe load in tons per sq. feet.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Soft, wet, muddy clay, and marshy clay</td>
<td>0.25 to 0.33</td>
</tr>
<tr>
<td>2.</td>
<td>Moist clay</td>
<td>1.00 to 1.75</td>
</tr>
<tr>
<td>3.</td>
<td>Ordinary compact clay, nearly dry</td>
<td>2.00 to 2.50</td>
</tr>
<tr>
<td>4.</td>
<td>Solid clay mixed with very fine sand</td>
<td>3.50 to 4.00</td>
</tr>
<tr>
<td>5.</td>
<td>Dry compact clay of considerable thickness</td>
<td>3.00 to 5.00</td>
</tr>
<tr>
<td>6.</td>
<td>Alluvial deposits in river-beds</td>
<td>0.20 to 0.35</td>
</tr>
<tr>
<td>7.</td>
<td>Diluvial clay in beds of rivers</td>
<td>0.35 to 1.00</td>
</tr>
<tr>
<td>8.</td>
<td>Alluvial earth, loams, sandy loams (clay and 40 to 70 per cent of sand), and clay loams (clay and about 30 per cent of sand)</td>
<td>0.75 to 1.50</td>
</tr>
<tr>
<td>9.</td>
<td>Black cotton soil</td>
<td>0.50 to 0.75</td>
</tr>
<tr>
<td>10.</td>
<td>Loose surface soil</td>
<td>0.20 to 0.25</td>
</tr>
<tr>
<td>11.</td>
<td>Loose sand in shifting river-beds, the safe load increasing with depth</td>
<td>1.50 to 2.50</td>
</tr>
<tr>
<td>12.</td>
<td>Silted sand of uniform and firm character in a river-bed, secure from scour and at depths below 25 feet</td>
<td>3.50 to 4.00</td>
</tr>
<tr>
<td>13.</td>
<td>Compact sand</td>
<td>2.00 to 3.00</td>
</tr>
<tr>
<td>14.</td>
<td>Compact sand, prevented from spreading</td>
<td>5.00 to 7.50</td>
</tr>
<tr>
<td>15.</td>
<td>Made up or reclaimed soil</td>
<td>0.75 to 1.50</td>
</tr>
<tr>
<td>16.</td>
<td>Sandy gravel or Kankar</td>
<td>2.00 to 3.00</td>
</tr>
<tr>
<td>17.</td>
<td>Sandy gravel, but compact, dry and prevented from spreading</td>
<td>4.00 to 6.00</td>
</tr>
<tr>
<td>S. No.</td>
<td>Kind of soil</td>
<td>Safe load in tons per sq. feet</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>18</td>
<td>Compact gravel</td>
<td>7.00 to 9.00</td>
</tr>
<tr>
<td>19</td>
<td>Very firm, compact sand at a depth not less than 20 feet, and compact sandy gravel</td>
<td>6.00 to 7.00</td>
</tr>
<tr>
<td>20</td>
<td>Firm shale, protected from weather, and clean gravel</td>
<td>6.00 to 8.00</td>
</tr>
<tr>
<td>21</td>
<td>Red earth</td>
<td>3.00</td>
</tr>
<tr>
<td>22</td>
<td>Hard morum</td>
<td>4.00 to 6.00</td>
</tr>
<tr>
<td>23</td>
<td>Soft morum</td>
<td>2.00 to 3.00</td>
</tr>
<tr>
<td>24</td>
<td>Soft rock</td>
<td>5.00 to 8.00</td>
</tr>
<tr>
<td>25</td>
<td>Laterite</td>
<td>6.00 to 10.00</td>
</tr>
<tr>
<td>26</td>
<td>Limestone</td>
<td>12.00 to 16.00</td>
</tr>
<tr>
<td>27</td>
<td>Sandstone</td>
<td>16.00 to 20.00</td>
</tr>
<tr>
<td>28</td>
<td>Granite and trap</td>
<td>20.00 to 30.00</td>
</tr>
<tr>
<td>29</td>
<td>Very hard solid rock</td>
<td>40.00 and upwards</td>
</tr>
</tbody>
</table>

Test for the bearing capacity of soils: Experiments have shown that different kinds of soils have relatively different limits of the bearing capacities, and hence it is very necessary to make test to find out the bearing power of the soil where the local conditions are not well understood. The soil is usually tested by putting a platform on the ground and loading it gradually. The larger the area covered by the testing platform the more reliable the results. The method of test is as follows:

1. Dig a pit of 6' x 6' size at the ground to be subjected to test.
2. Make the bottom of the pit truly level by simply spreading by hands. The surface should not be rammed under any circumstances.
3. Put a steel plate of 2' x 2' and 3" thickness in the centre of the pit.
4. Erect a wall of 18" thick either with bricks or concrete blocks over it. Drive two pegs at the bed of the pit as shown in Figure 3. The exact level difference will be taken between the top of the two pegs and (the top of the wall, say "H"). Now gently place the loads one by one at the top of the wall, which may consist of sand bags, iron bars, rolled steel sections, etc. An
Interval of time must be allowed after placing one load for change of level, and a constant watch must be made by a levelling instrument (usually by a Dumpy Level) for the difference of level "H".

METHOD OF LOADING A SOIL FOR ASCERTAINING ITS BEARING CAPACITY

Note down the reading at which the ground yields. Within the limits of bearing power, the level difference "H" will remain unchanged.

Then the ultimate bearing power or simply bearing power of the soil per square foot—

\[
\text{Weight of steel plate plus weight of wall plus weight of loads added} = \frac{\text{Area of the steel plate, } 2' \times 2'}{13.6.2} 
\]

If, weight of plate = \(\frac{1}{2}\) ton; weight of wall = 1 ton; and weight of loads added = 3\(\frac{3}{4}\) tons,

then bearing power of the soil

B. C. 2
\[
\frac{1}{4} \text{ ton plus } 1 \text{ ton plus } 2\frac{1}{2} \text{ tons} \\
\text{sq. ft.} \\
= 1 \text{ ton per sq. ft.}
\]

If a factor of safety of 2 is taken, then the safe bearing capacity of the soil

\[
= \frac{\text{Bearing capacity of the soil}}{\text{factor of safety}}
\]

\[
= \frac{1}{2} \text{ ton per sq. ft.}
\]

The following points should be remembered regarding the test for bearing power of soil:

(i) The area under test should be as large as possible.

(ii) A small area will bear a larger load per unit of area for a short time than what a larger area can sustain permanently.

(iii) The loading should be done gradually without giving shocks to the loading platform.

(iv) The tests should be continued for as long a time as possible. Generally it takes 3 to 5 days for a soil to adjust itself to the load placed upon it.

Increasing bearing power of soils: The bearing power of a soil largely depends on the closeness of its constituents or particles. The bearing power of a soil may be increased by any one of the following methods:

(1) By increasing the depth of foundations. Ordinary soils bear a greater load at depths, being more compact therein.

(2) By draining the soil by means of pipes laid with butt joints in trenches over a bed of sand and filling the trenches above the pipes with loose boulders (big gravels).

(3) By compacting the soil. This is effected (a) by hand-packing rubble boulders or spreading broken stone, gravel, or sand, and ramming well in the bed of trenches; and (b) by using sufficient number of sand piles or wooden piles.

(4) By confining the soil in an enclosed area with the aid of sheet-piles. The same soil if confined well will bear a greater weight.

(5) By increasing the width of foundations by some convenient means.
(6) By hardening the soil by grouting process: In this method a grout of cement is pumped under pressure into the pores of the soil, and the pores are thus sealed up. To ensure a proper distribution of the cement grout, the ground is bored and perforated pipes are introduced to force the grout.

(7) By solidifying the soil by chemicals: Diluted solutions of soda and calcium chloride are generally used for this purpose. They fill the voids of the loose sand and bind the grains together in a solid mass.

Preliminary Investigations and Examination of the Ground:

The foundations of a structure are generally laid below the ground level and hence, it is necessary to test the soil below the ground (or subsoil as it is often called) to determine the nature of foundations required.

Before making any plans a personal inspection of the site is very necessary, for every site has its own peculiar environments which largely affect its adoptability for foundations.

For instance, a site in a large vacant block requires very different treatment than a site in the bank of a river, nalla or stream, which requires more than ordinary consideration.

From a careful examination of the site and the immediate vicinity, some useful information may be gathered regarding the nature of subsoil, but this information is often insufficient to come to a decision. To ascertain exactly, the quality and thickness of soil and laminations under the ground, the following methods are usually employed:

(1) Probing.
(2) Auger boring.
(3) Wash boring.
(4) Drilling.
(5) Test pits.

(1) Probing: This method is adopted where the ground is more or less soft like clay, sand, gravel, etc. A steel rod (figure 4) or crow-bar (figure 5) of about 14" diameter, pointed at one end, and of suitable length is driven into the ground and worked until a hard substratum is obtained. An iron hammer (Fig. 6) may be used for driving it into the ground, if necessary. If it penetrates
only a few feet, more definite means should be taken to ascertain
the nature of the material under the surface. In some cases, the

Fig. 4
STEEL OR IRON ROD

Fig. 5
CROW BAR

Fig. 6
IRON HAMMER

rod or crowbar may be driven 10 feet or more, but at the best, this
method simply indicates that an incompressible foundation cannot
be secured at a reasonable depth. This method of testing is also
known as rod driving or rod test.

(2) Auger boring: The driving of a steel rod or crowbar
stops on the first obstruction and would not indicate that below
this obstruction there is not another soft stratum. To get more
definite and reliable information, an ordinary wood auger (Fig. 7 to
9) or a posthole auger (Figs. 10 to 12) is often used.

Wood auger: This is a very simple and effective tool for
use in exploring shallow foundations in sand and clay. This
consists of an ordinary wooden pipe (or wood auger as it is often
called), 2" in diameter, fitted into a section of 1¾" pipe. During
operation, care should be taken to keep the auger vertical. The
auger is withdrawn to the surface after 5 or 6 turns and cleaned
after examining the samples contained in it.

Posthole auger: It is a very handy and useful instrument
for foundations of ordinary buildings. The auger is held vertically by hands and is rotated by applying leverage while being pressed down at the same time. At every foot of the depth it is withdrawn and the samples, caught in it, are examined. The auger will often conveniently penetrate a depth of 40 to 50 feet and bring up fairly reliable samples. It can be lengthened to any length by using lengthening pieces and casing pipes. The auger is chiefly of use in sand or clay. In ordinary soils two persons can easily bore a depth of 10 to 15 feet in a day.

3. Wash boring: This method can be used for almost all soils except hard pan or where boulders are present. If the depth to be bored is more than the working limits of an auger, this method is advantageously adopted. For this purpose, a water jet pipe (ordinary gas pipe through which water is forced under pressure) of about 1½" diameter, a hollow steel pipe of about 4" diameter and a tub are generally required along with sufficient quantity of pure
water. At first, the hollow steel pipe is driven a short distance into the ground, and then the water jet pipe is put inside of the hollow steel pipe. The pressure of water from the jet pipe displaces the subsoil and forces it to the top through the annular space between the two pipes, and the slurry thus formed is collected at the surface in a bucket, which is generally of ten gallons of capacity. This operation is continued until a hard stratum is met with. If a hard boulder is met with, the casing is raised up and a charge of dynamite is inserted and blasted and then the work re-started. A small quantity of hydrochloric acid is then added to the samples, and the turbid water is decanted and the samples taken out from the precipitation for examination. The
Equipment for wash boring is illustrated in Fig. 13.

In washing up the materials, the finer materials such as loam, clay, etc. are apt to disappear and the coarse materials to be separated from the finer so it is rather difficult to be sure that the samples obtained really show the nature of subsoil. Wash boring, however, is in many cases sufficiently reliable for the purpose, and may be used to a depth of 100 feet or more.
(4) Diamond drill or core boring: In examining the ground, when rock is reached, this method is used to drill some distance into the same in order to eliminate any possibility of mistaking a boulder (big gravel) or thin layer of rock for bed rock and the nature of it. This kind of boring is secured by having a cutter which is hard enough to cut out a core of even the hardest marl or rock and bring it to the surface. The cutting tool is made of diamond, chilled-steel shot, or fragments of chilled cast iron. The diamond drill boring is naturally much more expensive than the other methods described.

The boring or drilling machines driven by power are of two kinds. They are:

(1) Churn or Percussion Drill: This machine is very useful in stony ground. It will drill through rock and, of course, through soil, but only in the softer rocks can cores be obtained. The operation consists of dropping the heavy cutting tools into the ground, so that the material is broken up and pulverised. Water is poured into the bore and the slurry formed is pumped out from time to time. The slurry thus obtained is then dried and examined.

(2) Core Drill or Rotary Auger: This is a very useful machine, which can be used both for soft material or hard material. The machine consists of a hollow steel tube, about $\frac{2}{10}$ in diameter, and about 20 feet long. The tube is rotated round and ample water is poured in to help the cutting and leaving the tube free to rotate. In soft or loose material like clay, sand, etc., the slurry of displaced soil and water is obtained by means of a sand pump, which consists of a section of iron or steel pipe with a valve near the bottom. In hard material like marl or rock, the central core is cut solid, broken and brought to the surface for examination.

(5) Test pits or Trial pits: Digging a small test or trial pit will very often take the place of boring or supplement the information obtained thereby. This is the most common and easy method which usually gives a correct information regarding the nature of the strata. But test pit is not usually made under the ground water level nor to more than a few feet, say, 10 feet in depth. The length and breadth of the trial pit largely
depend upon the depth to which the excavation is to be carried. The sides of the pit should be made vertical so that the thickness of the different layers of subsoil may be measured correctly. If the excavation is deep, the sides of the pit must be protected by timber planks. Figure 14 shows a test pit.

The various methods of soil investigation described above should be carried out in a reasonable number of places over the entire area. The results of all tests should be properly noted in log-books and carefully studied to specify the particular type of foundation for a structure.

Types of foundations: Foundations are of different types. The principal types are:

1. Spread footing, shallow, or open trench foundation.
2. Grillage foundation.
3. Raft or Mat foundation
4. Inverted arch foundation
5. Pile foundation
6. Stepped, benched, or slotted foundation
7. Well foundation
(8) Foundation under water by means of cofferdams and caissons.

(1) Spread footing, shallow, or open trench foundation: This is the most common and simplest type of foundation, which is obtained by simply widening the area of the base of a wall or pier so as to distribute the load or weight over sufficient area on the foundation bed to bring the intensity of load within the safe bearing capacity of the soil. The base of the wall or pier is usually widened by means of footings and offsets, and cement concrete or masonry or a combination of both is used for this work. This is the cheapest type of foundation and is largely used for ordinary buildings.

(2) Grillage foundation: The object of this foundation is to spread the load over a large horizontal area near the surface. This type is very suitable for heavy buildings such as factories, town halls, theatres and tall towers. In this type the area of the base of a wall or pier is enlarged by inserting two or more tiers of steel I-beams in cement concrete. The method of construction of a steel grillage foundation for a wall is described below, (Figure 13).

The width of the foundation is first calculated by dividing the load per running foot by the unit safe bearing power of the soil. A trench is excavated to this width and about 3 to 5 ft. deep. The bottom surface of the trench is slightly rammed and levelled. Then a layer of cement concrete (1:2:4 or 1:1:3) or 9" to 12" thickness is spread and compacted well. Over the concrete bed, steel I-beams of the designed section and of the length equal to the width of foundation are placed at a suitable distance apart (usually of 12" to 3") with their upper surface brought in a horizontal plane. The spaces between the steel beams are then filled in with cement concrete in order to give them a solid bearing and also to protect them from atmospheric action. On the lower beams, a second layer of steel I-beams in two or more rows are placed parallel to the axis of the wall and centrally under it. The exact number of rows placed depends on the width of the wall and its individual requirements. The entire space between the beams is now filled with cement concrete. The wall is then built directly on the grillage bed thus prepared. Sometimes timber or R. C. C.
piles are first driven into the ground at suitable intervals and over them grillage foundation is laid as described.

Fig. 15

**Steel Grillage Foundation for a Wall**

In designing steel grillage foundations the following assumptions are made: (a) the pressure from the footing is uniformly distributed over the bed, (b) the pressure of one tier of beams is uniformly distributed on the tier below, (c) each tier acts independently of all other tiers, and (d) the concrete filling and
covering carry no stress, acting merely as a protection against corrosion.

In steel grillage foundation for columns, the space between the I-beams should not exceed one and a-half times the width of the flange. Figures 16 and 17 show a steel grillage for a single column and Fig. 18 shows that of a timber grillage for...
a single column. Another effective method of grillage foundation for a steel stanchion is illustrated in Figure 19.

**Fig. 19**

**AN EFFECTIVE METHOD OF GRILLAGE FOUNDATION FOR A STEEL STANCHION**

**Raft foundation:** Generally speaking a raft or a mat foundation is used when the ground condition is very poor and when it is required to distribute heavy concentrated loads over a large area. The raft foundation is very useful where there is a possibility of unequal settlement to happen. Usually a raft foundation is in the form of a slab covering the whole area of the bottom of the building, like a mat or a raft. Thus a raft foundation spreads the load of a building over the whole plan area, and reduces the foundation pressure to a minimum. The raft is particularly effective if combined with a deep excavation. Each raft must be designed to suit the individual needs of the structure. The method of construction of a raft foundation is described below.

The entire area bounded by the outer wall line of the building, generally 1 foot more on all outer side of the walls, is first excavated to the required depth. The excavation is then well watered, consolidated by heavy rammerms and made the surface level. Upon the bed thus prepared, reinforced cement concrete is laid to the required thickness and with necessary steel reinforcement. The R.C.C. is rammed well and an even bed is obtained.

1. The steel reinforcement is quite essential in a raft foundation in order to prevent the shearing and punching action of the walls in buildings, and to increase the stability of the building as a whole.
The walls are then lined out and built on the R.C.C. slab as plinth masonry up to the floor level. The inside spaces are then filled with hard, dry sand and gravel. Concrete may also be used for this purpose if the building is very heavy, but it is very costly and cannot ordinarily be used. A raft foundation is shown in Figs. 20 and 21.

Raft foundation is employed for the construction of schools, hospitals, offices, public buildings and other important buildings.
Inverted arch foundation (Fig. 22). This is not a general type of foundation for buildings. It is very suitable for underground construction of bridges, tanks, reservoirs, and drainage lines. This type is frequently used for distributing pressure, where the weight is concentrated over the pier and it is necessary to distribute it over a large area to keep the load within the bearing power of the soil, and to reduce the depth of the foundation. The rise of the arch is generally from 1/5 to 1/3 of the span. Nowadays this type is rarely used in India.

Pile foundation. A pile is an element of construction placed vertically or nearly so in the ground, to increase its power to bear the weight of a structure or to resist a lateral load. A pile foundation (Fig. 23) usually consists of a base of concrete or of wooden or steel grillage, supported by piles which distribute the load to the earth through a considerable depth either by friction alone or by friction combined with bearing on the ends of the piles. A pile foundation is used—

(1) When the soil is very soft and there is no solid substratum for the foundation at a reasonable depth to keep the bearing capacity of the soil within safe limits.
(ii) When the grillage or raft foundation is very expensive or practically impossible.
(iii) When the building is very heavy or carrying heavy concentrated loads.
(iv) When deep sewers or irrigation canals are likely to be constructed in the area in near future, and
(v) When it is necessary to construct a building along the sea-shore or river bed and to control scour.

Fig. 23

PILE FOUNDATION

General classification of piles: Piles are designated
(1) by their uses, as bearing piles, friction piles, batter piles, guide piles and sheet piles;
by the material of which they are composed, as timber or wooden piles, concrete piles, sand piles and metal piles.

(1) Classification of piles by their uses.

(a) Bearing or sustaining piles: These piles are used to bear vertical loads. They are driven into the ground until a hard bed is met with, so as to transfer the weight of the structure to the hard bed below. They act merely as columns carrying the structural load down to the firm stratum. Even if the soil is soft it gives some frictional resistance and the soil becomes hard after driving piles.

Friction piles: When the soil is very loose or soft to a considerable depth, friction piles are used in order to balance the weight of the structure by the friction offered by the surrounding soil on the sides of the piles. They are short in length and are not driven to hard bed below. The frictional resistance is increased by making the surface of the pile rough, or by increasing the area of the surface of the pile in contact with the soil.

The problem of friction pile foundations is a controversial one, at least in clays and silts. If a soil is a rather loose sand there is much to be gained by piling, since the vibrations tend to compact the sand and increase its bearing capacity. In clay soils, however, the pile driving tends to break down their delicate microstructure and makes them softer. For this reason, among others, some engineers (including the author) view the whole question of friction piles with disfavour. Generally the friction piles should be used only in exceptional cases.

(b) Batter piles: The batter or spar piles are those that are driven at an inclination to resist forces that are not vertical. Experience shows that batter piles resist lateral forces better rather than other piles, and they are used for retaining wall, piers, abutments, etc.

(d) Guide piles: These are chiefly used in the construction of cofferdams. They are also used in ferry slips and to help in locating and sinking open and pneumatic caissons. The various types of cofferdams and caissons are described later in this chapter.
Sheet piles: These are used
(i) To enclose soils and to prevent their lateral pressure,
(ii) to prevent the slip sides of excavations made for foundations, etc.
(iii) to prevent the leakage of water and soft materials,
(iv) to protect structures from shocks, vibrations and similar other bad external influences, and
(v) to construct cofferdams in order to build foundations under water and in similar situations.
Sheet piles are not intended to carry any load, but are required to be strong enough against back pressure and overturning. They are made of wood, of steel, and of R. C. C.

Timber or wooden sheet piles: (Figures 24 and 25) are usually 3" to 6" thick, 5" to 10" wide and 8 ft. to 12 ft. long. The

![Timber Sheet Pile](image)

Fig. 24 and 25

Timber Sheet Pile

bottom of the piles is chamfered so as to present an edge rather than a point. The feet and heads of piles are protected by iron fittings. The joints generally used in timber sheet piling are illustrated in figures 26 to 29. These are of less water tight and hence used only for temporary work.
In cases where more water-tightness and strength are required, what is known as the Wakefield pile is used. The pile consists

Fig. 26
**BUTT JOINT**

Fig. 27
**DOVETAIL JOINT**

Fig. 28
**GROOVED AND TONGUED JOINT**

Fig. 29
**PLoughED AND TONGUED JOINT**

Figs. 30 and 31
**Wakefield Pile**
of three planks bolted together to form a tongue on one side and
a groove on the other (see Figures 30 and 31). This gives practi-
cally watertight construction, but as the planks are driven as a
unit, the resistance to driving is considerable. By careful selec-
tion and grading of the centre plank, a good joint can be secured.
Three advantages may be claimed for this type of pile, namely,
(1) knots, cross grains, and other defects can be seen, though it is
unlikely that these defects would come at the same point of the
pile; (2) there is no waste in forming the tongue and groove,
and there is less tendency to buckle or warp before driving; and
(3) Only one side of each pile is sharpened, the long edge being
placed next to the last pile driven, which crowds the new pile
against the old one and helps to make a tight joint.

Steel sheet piles are generally 9" to 20" wide and 10 ft.
to 40 ft. long. The thickness depends on the depth and the pres-
sure behind the sheet piles. The piles have good interlocking
arrangements, so as to form close joints. Various types of steel
sheet piles are manufactured now and a few of them are illustrated
in Figures 32 to 39. Steel sheet piles give satisfactory interlock-
ing for watertightness and hence largely used in cofferdam
construction.
Corrugated-steel sheet piles are made of thin plates and they are used only for light work, such as trench bracing for sewer and pipe-line construction. The maximum thickness of metal used is 1/4 inch.

Reinforced cement concrete sheet piles are of very many designs, and the simplest of design is the best. They are generally precast and their feet are bevelled like wooden sheet piles. They are generally used for permanent works, such as wharves, piers, retaining walls, docks, etc. The thickness of the piles is usually 8" or more and they are mostly tongueed and grooved for sheet piling work.

Where the sheeting is to be withdrawn, steel sections would be more economical than wood or R.C.C. Where the ground is not too hard and the sheeting is to be left in place, timber sheeting is probably still the cheapest. In all cases, the depth that the sheeting is to be driven should be determined in advance by borings.

(2) Classification of piles by the material of which they are composed.

(a) Timber or Wooden piles: These are made from trees like Teak, Sal, Deodar, Babul, Jamba, Khair and Sissoo. Khair is best suited for use under sea-water as it resists the action of sea water and marine borers. Good timber piles shall be free from any defects such as decay, splits, twists, knots, etc. which may impair their strength or durability. Timber piles are circular or square in cross-section. The size of the pile if circular is generally from 8" to 20" in diameter and if square, the side is 6" to 20". The length of the pile is about 20 times its breadth or diameter. The top of the pile is provided with an iron ring or band (say, 3" x 3") to prevent the same from bending and splitting under the blows of a hammer, and the bottom is sharpened and fitted with an iron shoe (Vide Figures 40 to 43). They are generally spaced at 2½ to 3 ft. centre to centre. The interval should not be less than 2½ ft., as driving of piles would disturb the adjoining ones already driven. Wooden piles are generally driven by blows delivered by a drop hammer. The tops of timber piles are cut off a little below the ground-water level, otherwise, if they are exposed alternatively to wet and dry, they will soon be destroyed. On the top of the piles, a framework is provided to
lay concrete bed and footings of walls or piers. The maximum load allowed on a wooden pile is 20 tons. Timber piles are largely used for buildings, bridges, docks, wharves and cofferdams. They cannot be used in sea-water. Generally, timber piles should be impregnated with solignum or painted by some kind of preservatives.

(b) Concrete piles: These piles were first used in 1901 in
a building foundation in Chicago, U.S.A. They are very strong and durable and they bear more weight than timber piles. They are free from danger of deterioration if wholly in the ground and cannot be attacked by termites, marine borers, etc. They are of two classes, pre-cast and cast in-situ,\(^1\) and they may be either plain or reinforced with steel (in combination with lateral reinforcement in the form of wire hoops or spiral wrapping), though pre-cast piles always should be reinforced and probably always are.

\(^1\)Cast-in-situ=built-in-place, or made-in-place.

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**Fig. 44**

**METHOD OF ABUTTING TOGETHER FOUR PILES BY MEANS OF IRON CRAMPS**

**Fig. 45**

**METHOD OF LENGTHENING WOODEN PILES BY MEANS OF FISH-PLATES**

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\(\text{(F)}\) Pre-cast piles: These are reinforced cement concrete piles which are moulded to a regular form and, after curing and seasoning, they are handled and driven like wooden piles. They are square, circular or octagonal in cross-section. The corners of square piles are generally chambered or bevelled to a width of 2\(\) or 3\(\). The stresses are more on top due to direct strikes of
hammer and at the foot in overcoming the resistance to penetration, and hence additional reinforcement is used at both ends for about 3 ft. and an iron shoe is fitted at bottom. They are generally cast in a horizontal position and cured on ground. Most of the Building Laws stipulate that “piles of constant cross-section shall have a least diameter or dimension of 14” for piles up to 35 ft. in length and not less than 16” for lengths over 35 ft. and not over 50 ft.; piles with a uniform taper shall have a minimum lateral dimension of not less than 8” at the point and an average diameter of not less than 12” for lengths not over 40 ft. Piles over 40 ft. shall have a minimum taper of 1” to 8 ft. and a lateral dimension at the point of not less than 10”. Piles shall not contain more than 4 per cent of steel reinforcement. Generally precast piles are constructed without taper. The length varies from 8 to over 100 ft. and the longest on record is 115 ft. To increase the length of the pile, small pieces to the required lengths are cast and connected at top by fish plates and bolts. Tongued and grooved joints may also be used to connect each other.

The steel reinforcement of a concrete pile is intended to resist the stresses due to handling the pile, driving the pile, and the load which may come on its final position, and it usually consists of four or more vertical rods from 2” to 2 1/2” in diameter, tied in place with lateral reinforcement in the form of horizontal rings made of steel wires or rods up to 3/8” in diameter. The thickness of concrete beyond the reinforcement is from 2” to 3”. Precast piles are largely used for docks, wharves, dams, bridges and similar structures.

Method of casting pre-cast piles: The casting of pre-cast piles is done in forms placed either horizontally or vertically. The former practice is more common. In horizontal casting, the form is first cleaned well, and then a layer of rich cement concrete of 2” to 3” thickness is laid at

Generally 1: 1 ½: 3 concrete (1 part of cement, 1 ½ parts of sand and 3 parts of coarse aggregate by volume) should be used. The size of the coarse aggregate should be between 3/8” and 1”. For one bag of cement five gallons of water should be added, and the cement should give a compressive strength of 3,000 to 3,500 lbs. per sq. inch.
bottom and well consolidated. Upon this, the steel reinforce-
ment, made as a single unit, is placed centrally with great
care, and the shoe also adjusted in position. The entire
form and the reinforcement are then filled with concrete in
layers continuously, and in each layer the concrete is tamped
and pressed well into all corners and angles to eliminate all
voids. In vertical casting, the form is set upright and the
reinforcement is placed in it accurately with its shoe down-
wards. The form and the reinforcement are then filled with
concrete in layers of 3" to 4" thickness and each layer rammed
well with care. Good results may be obtained by using
vibrators.

The form is removed after 3 or 4 days, but the pile is
allowed to rest on the base for about 7 days and during this
period it is kept wet for the setting of the cement. The pile
is then taken to a safe place and cured there for at least
3 weeks. Special devices are usually used for handling of
piles conveniently. Figures 46 to 49 show two shapes of
pre-cast piles.

—(6) **Cast-in-situ piles:** A cast-in-situ or cast-in-place
pile is a concrete pile, which is constructed in its permanent
location in a hole prepared for that purpose. The operations
consist of boring a hole, usually by driving a casing, and filling
it with concrete or concrete and steel reinforcement. These piles
may be tapered piles in metal cases, cylindrical piles in metal
cases, or uncased cylindrical piles. Most of the types of cast-in-
situ piles are patented according to the method of construction and
the appliances used for that purpose. A few of them are briefly
described hereunder.

**Raymond Concrete Pile:** This is an example of tapered
Cast-in-situ pile and is largely used for foundations. It is made
by driving a tapered sheet-steel shell of 0.036" to 0.023" into the
ground by means of a collapsible mandrel. When the required
depth is reached, the mandrel is withdrawn and the hole is filled
with concrete-reinforced, or not, as desired. The permanent steel
shell used outside of the mandrel has the great advantage of pre-
venting any sand or water flowing in as the mandrel is withdrawn.

1 *Curing* is the process of hardening of concrete with water.
The shell is reinforced with $\frac{1}{2}$" or $\frac{3}{8}$" wire spiral, spaced about 3".
and it is generally 8 ft. in length, but the same may be lengthened by overlapping the sections each other. Figure 50 shows a completed Raymond concrete pile.

Simplex pile: This is an example of uncased cylindrical cast-in-situ pile and is very simple in construction. A hollow cylindrical steel pipe of about 16" diameter, fitted with a detachable metal base, is driven into the ground to the required depth, and the hole is then filled with concrete as the pipe is gradually withdrawn. A pistonlike plunger, of slightly smaller diameter than the hollow pipe, is employed for ramming the concrete well. The detachable metal base remains in place, and hence a new one is needed for each pile. Figure 51 shows a simplex pile.

Pedestal or Bulb Pile: This pile may be regarded as a modification of the simplex pile by the addition of a bulb shaped base or pedestal at the foot. This is formed just like a simplex pile, but usually a spread footing is obtained by driving the first batch of concrete out at the bottom of the shaft much. This type of pile is used to increase the bearing capacity at the lower stratum.
McArthur Pedestal Pile: A hollow cylindrical steel pipe of 
\( \frac{3}{4}'' \) thickness is driven into the ground with a solid steel core in it. The core is removed and a charge of concrete is poured to the bottom of the pipe. The core is employed again and the pipe is pulled up 1 to 3 ft, by pushing the concrete down with the core at the same time. The concrete is rammed well with the core, so that it will form like a pedestal. This operation is repeated each time for a height of about 3 ft, until the pipe is withdrawn. A completed McArthur pedestal pile is shown in Figure 52.

Vibro Pile: This is an uncased cylindrical cast-in-situ pile, which is formed thus: A steel tube attached with a conical cast-iron shoe is driven into the ground until the required depth is reached. The tube is then filled with concrete. The extracting of the tube and compacting of the concrete is effected by upward and downward blows of the hammer. The tube is from 13'' to 18'' diameter, \( \frac{3}{4}'' \) thick widened to \( \frac{3}{4}'' \) thickness at the rim. A 2-ton
steam hammer is generally used for driving, and a pile of dense concrete is made at the rate of about 4 ft. per minute. Figure 53 shows a completed vibro pile.

The bearing resistance of the vibro pile can still further be increased by adopting the following method: The tube fitted with the cast iron shoe is driven at the site as usual. Then a portion of the pipe, say, about 10 ft., is filled with concrete and the tube is withdrawn. The concrete is expanded (nearly double its original area) by driving down the tube either by itself or fitted with a special flat shoe. If, however, the bearing capacity is still too small, a further quantity of concrete is deposited and expanded. A cylindrical cage of steel reinforcement may also be inserted vertically and it can be carried well into the enlargement at the bottom. Now this pile is known as vibro expanded pile. (Vide Fig. 54).

Franki Pile: It has a pedestal or bulb base and corrugated stem. The method of formation of this type differs in many respects from the other types, and hence more attention should be paid in it. A steel pipe casing of 15" to 18" diameter is placed vertically with its lower end resting on the site at the point where the pile has to be driven. A charge of thick and rich concrete is poured to the bottom of the casing and a suitable drop-hammer of 2 to 4 tons weight, is allowed to deliver blows on the concrete through a fall of several feet. Now the concrete forms as a plug at the bottom of the tube, and the strokes of the hammer force the concrete plug into underground, the side friction of the concrete on the pipe pulling the casing down with the concrete. When the pipe is reached to a sufficient depth, it is raised slightly and held in place by cables. The drop-hammer is again allowed to deliver blows on the concrete plug. When the plug has been forced sufficiently out of the pipe, another charge of concrete is poured into the pipe and rammed so much as to separate the pipe from the plug. At this stage a cylindrical cage of reinforcement is inserted vertically, if needed. The pile is completed by pouring charges of concrete, each charge being rammed well while the pipe is withdrawn a short distance. Vide Figure 55 for a completed Franki pile with reinforcement.

Composite Pile: This is constructed with timber and concrete piles by adopting a suitable method. For example, a timber pile
is driven into the ground to a depth such that the top of the pile will be a little below the permanent ground-water level, and then a concrete pile is placed on its top. To get a satisfactory composite pile care must be taken (a) to maintain perfect alignment between the timber and concrete sections, and (b) to provide enough reinforcement and anchorage to lock the timber and concrete sections together.

R. C. C. piles can safely bear a load of 20 to 35 tons per sq. ft.

(iii) Sand Piles: These are formed by simply digging holes by means of a wooden pile or some other method, and then filling and ramming sand into the holes. The tops of the piles are covered with concrete to prevent the sand from squeezing upwards by lateral pressure. As a rule, the length of the pile should not be more than 12 diameters. Sand piles are employed occasionally for supporting light loads where the soil is soft, without being damp or fluid. They are hardly to be recommended, as a more reliable type can always be obtained.

Compressol Pile: The compressol pile may be said as a modification of the sand pile. It is built by making a hole in the ground with a pear shaped weight operated by a pile driver, and then filling and ramming concrete in the hole. This type of pile was first used in France and is seldom used in India. It is more economical to use concrete in the form of concrete piles.

(iv) Steel Piles: These are very useful where the driving conditions are difficult and where other types are difficult to penetrate. They are used for bridge and building foundations. Steel piles may consist of any convenient structural form. They were originally made in the form of I-beams, and recently H-section beams (first manufactured and used in 1901) are used extensively. The common sizes of H-section piles vary from 8" to 14" depth, inclusive, and from 33 to 117 lbs. per foot of length. The thickness of metal is usually 7/16" or more. Steel pipes, fitted with a conical cast iron shoe are driven into the ground and the hollow space is filled with plain or reinforced concrete. These are known as tubular piles. The American Railway Engineering Association specifies that "pipes shall have an inside diameter of 10" or more and a thickness of not less than 3/8" except that
A thickness of 5/16" may be used on 10" and 12" pipe. The steel piles are also available in the form of sheet (vide 'sheet piles'). The screw or disc piles may also be taken as steel piles.

A screw pile consists of a hollow steel or cast-iron pipe of 3' to 10' diameter with a cast-iron broad-bladed screw attached to its foot. The diameter of the screw varies from 1 1/4' to 5', and the pitch from one-third to one-sixth of its diameter. The points of the screws are also varied, the blunt point (Figure 56) being suitable for sand, the hollow conical point (Figure 57) for sand and gravel, the gimlet point (Figure 58) for gravel, and the serrated point (Figure 59) for soft rock or coral.

A disc pile consists of a hollow steel or cast-iron pipe of 3" to 10" diameter with a cast-iron disc attached to its foot (Vide Figures 60 and 61). The disc is a casting which consists of a horizontal circular plate, stiffened by a number of radial ribs.

The diameter of disc varies from 1 1/2 ft. to 4 ft.

Screw and disc piles are very useful where shocks of driving other types of piles are injurious to neighboring structures. They are generally driven into the ground by manual labour with big levers. Sometimes a water jet is used to facilitate the driving.
They are unsuitable for deep foundations.
Steel piles can safely bear a load of 8,000 to 10,000 lbs. per sq. in.

**Advantages and disadvantages of various types of piles:**

1. **Timber Piles**:
   - **Advantages**: (i) They are cheaper.
   - (ii) They can be easily handled without damage.
   - (iii) They can be easily driven into the ground and within a short period.
   - **Disadvantages**: (i) They are weak in strength as well as in load-bearing capacity.
   - (ii) They may be deteriorated by decay, insects or marine borers.
   - (iii) Generally, they require some preservation, which is a costly one.
   - (iv) Very often, long timber piles are not available and hence they require joints, which are a source of weakness.

2. **Concrete Piles**:
   - **Advantages**: (1) They are strong and durable than timber piles.
   - (2) They are not attacked by decay, insects or marine borers.
   - (3) They are fairly fire-proof and water-proof, and become stronger with age.
   - (4) They have more bearing capacity than timber piles.
   - (5) They can be manufactured to any length and size and they are cheaper in the long run, as a good deal of saving can be effected by reduction in excavation and masonry.
   - (6) The materials required for the manufacture of concrete piles can easily be obtained anywhere, and this saves time and cost.
   - **Disadvantages**: (1) They require more technical supervision than timber piles and this involves extra cost.
   - (2) When precast piles are employed, they require more time and care in handling than do timber piles, on account of their greater weight and less flexural strength.
   - (3) Generally, concrete piles cannot be driven so rapidly as timber piles.
   - (4) They are costly than timber piles.

B. C. 4
Precast Piles:
Advantages: (1) They can be manufactured conveniently at a place away from the site of works and conveyed to the place where they are to be driven.
(2) They are cheaper, as they can be cast on a large scale in an open yard.
(3) The reinforcement remains in a central position without displacement.
(4) Any defects such as hollows or honey-combing can be detected before use.
(5) They are ready to receive loads as soon as they are driven into the ground.

Disadvantages: (1) They are very heavy and hence difficult to transport and handle.
(2) They require much time for driving, and heavy machinery is required for the purpose.
(3) They are subjected to vibrations under a hammer, and consequently the construction may not be sound.
(4) They are generally cast of a length as determined from the results of borings, and hence, sometimes they may be required to lengthen or shorten due to local circumstances. This item of work gives much trouble and involves more time, expense, and labour.

Cast-in-situ Piles:
Advantages: (1) They are formed by merely making holes in the ground by means of a steel pipe or some other method, and then filling them with concrete. Thus they may be made easily and in comparatively short time.
(2) There is no waste of material as the correct depth is known and used.
(3) There is no need of driving them into the ground by a hammer, and hence they are sound in construction.
(4) The strength of the piles may be increased by adopting some suitable methods to bear more loads (e.g., Bulb Piles).
(5) There is no necessity of lengthening or shortening the piles as in the case of precast piles and consequently considerable time, labour and money are saved.

Disadvantages: (1) The reinforcements, if any, may go out of place during concreting.
The concrete may not be rammed well, and the work may not be properly supervised.

(3) Voids may be left between the reinforcement and concrete, particularly if the former is displaced.

(4) The adjacent dry soil will absorb the moisture from the green concrete and thus make it weak.

(5) They cannot be used in or under water.

(6) In general, their composition and design cannot be supervised well.

(4) Steel Piles:

Advantages: (1) They are very useful where the driving conditions are difficult and where other types are difficult to penetrate.

(2) They bear more loads;

(3) They permit close spacing of piles;

(4) Any length of piles may be obtained;

(5) They present a large surface area to develop skin friction;

(6) They are immune from the attack of marine borers, and have sufficient resistance to flotation.

(7) Generally they last long.

Disadvantages: (1) They are very costly and extra cost is also involved owing to the labour in cutting the head of the piles to a level.

(2) They are subject to corrosion, particularly when they are above ground-water level.

(3) They (except screw and disc piles) cannot be used where they are subject to shock.

(4) They are not fire-proof.

(5) Sometimes they bend and buckle under heavy loads.

(1) Sand Piles:

Advantages: (1) The method of construction is very easy, and can be constructed in comparatively short time.

(2) They are very cheap, if compared with other types of piles.

(3) They transmit the load to the sides as well as to the bearing area.

Disadvantages: (1) They are weak in bearing capacity.
(2) They cannot be used in or under water.
(3) They are unsuitable for deep foundations.

Group or cluster of Piles: Sometimes the piles are placed in groups or clusters and lashed together to act as fenders; in this case they are called "Dolphins".

After the piles are driven into the ground to the required depth, their tops are cut off to a uniform level, and a framework is provided to lay the footings of walls or columns. The concrete footings or R.C.C. columns are supported directly over the piles (see Figure 62). The arrangement of piles and shapes of footings illustrated in Figures 63 to 84 will be found convenient. The spacing of piles is not given, as the designer must comply with the local ordinances in this matter (refer "Protection of piles, spacing of piles etc." page 57).

-Pile driving: Pile-driving is the act of forcing any pile into the ground without previous excavation by means of a machine, called "pile driver". A pile driver usually works by raising a
hammer known as ram or rammer (but not monkey!) through a certain height and by allowing it to fall on the head of the pile or

![Diagram of piles and footings](image)

**Arrangement of Piles and Shapes of Footings**

on the pile cap (see page 57) directly. A pile driver essentially consists of a bed, two upright members, called leads or leaders and a hammer. The bed is composed of timber sills and supports the operating machinery. The bed is generally mounted on rollers for lateral movement from place to place for pile driving. The leads are rigidly connected to the sills and framed with back-stays

1 The "monkey" is the clip-book that runs up and down the pile driver (and hence the name) to catch hold of the ram, lift it and then drop it. (See figure 53) Many a person wrongly call the ram by this name; the ram is the hammer or top.
to form a tower. The leads support the pulleys used to raise the hammer or piles and guide the hammer during its movement. The leads may be made of wood, steel, or a combination of wood and steel. Leads are generally made of wood. Steel leads are more subject to deformation, caused by a pile striking the leads, than are those made of wood. Steel leads are also liable to shake loose at the joints. The leads may be tipped a little for driving piles with a small batter or inclination, or false leads may be employed for driving piles with a large batter. The total weight of a pile-driver depends on the size of the pile to be driven and the weight of hammer used. A pile driver may be operated either by hand power or by steam power.

Fig. 65

MONKEY OF A PILE DRIVER

The piles are commonly driven into the ground by any one of the following:

(1) Drop-hammer type
(2) Steam-hammer type.
(3) Boring
(4) Screwing
(5) Water jets.

(1) Drop hammer type: A drop-hammer is one which is raised in the leads by means of a pulley and rope and then allowed to drop with the force of gravity. It consists of a solid casting with jaws on each side which fit into the guides of the pile driver leads, with a pin near the top for the attachment of the rope, and with a broad base on which it strikes the pile. The light hammers are made of hard wood and the heavier of cast iron or steel. The weight of the drop-hammer ranges from 500 lbs. to
2000 lbs. for short concrete or timber piles, and from 2000 lbs. of 5,200 lbs. for long and heavy piles. Drop-hammer is generally dropped from a height of 3 to 15 ft. and the height is limited to 20 ft. The weight of the hammer necessary depends on the length of the piles and the character of soil. But under any circumstances the weight of the hammer should not be less than the weight of the pile to secure good results. A typical pile driving machine is shown in Figs. 86 and 87.

PILE DRIVING MACHINE—DROP-HAMMER TYPE

(2) Steam-hammer type: A steam-hammer is one that is automatically raised and dropped through a height of about 3 feet by the action of a steam cylinder and piston supported in a frame which follows the pile. During working, the hammer and its frame rest upon the pile, the head of which is trimmed to fit into the recessed base of the frame. The frame has channel guides on the sides which engage the leads of the driver. The frame in turn guides the hammer in its movement. Steam-
hammers are specially used for driving sheet piles, and where small vibrations are required to be set up in the piles.

There are two types of steam-hammers, the single-acting and the double-acting. The weight of the single-acting hammer varies from 550 lbs. for sheet piles to 7500 lbs. for heavy concrete piles. The number of blows varies from 50 to 60 per minute depending on the steam pressure. The weight of the double-acting hammer ranges from 21 lbs. to 1250 lbs., and it strikes from 100 to 120 blows per minute. The force of the blow depends on the weight of the hammer, the nature of the soil, and the distance through which the hammer is dropped. The following advantages may be claimed for the single-acting and double-acting steam hammers over the drop hammer:

(a) Serious damage to the piles, such as brooming, splitting, etc., is avoided (especially in using the double-acting steam hammer).
(b) More piles may be driven in a given time.
(c) Less injury is caused to adjacent buildings due to vibrations (the double-acting hammer being more efficient in this regard).
(d) The life of the loads is increased three to four times.
(e) The speed of driving is greater as the pile is kept in motion (this being more especially true of the double-acting hammer).

3. Boring: Sometimes piling is done by boring holes of the required depth and diameter by means of drilling or some other method, and then laying piles in them. Generally cast-in-situ piles are laid in them.

4. Screwing: Screw piles and disc piles are driven into the ground with big levers by turning round and round in one direction.

5. Water jets: Pile driving may also be done by displacing the material at or near the foot of the pile by means of one or more water jets, which discharge water under pressure. In some cases the hammer is simply put on top of the pile to increase the pressure, while in other cases the hammer is allowed to fall on the head of the pile from a small height in order to force it rapidly into the ground. In soft ground, one jet may serve the purpose, but in most cases two jets, used on opposite sides of the
pile, give better results. In soft soils like sand, silt, etc., the pile driving is greatly facilitated, and the disturbance to the surrounding soils much reduced. While the pile is forced down into the ground, the material flows back and binds to the pile, increasing the frictional resistance greatly. In soils where the water jet would simply make a hole which would not fill itself up again, this method would not be suitable.

The jet pipes should be 2½" to 3" double-strength pipe, with a ¾" or 1" nozzle at the lower end. The form of nozzle is of importance and should be adapted to the materials to be penetrated. The quantity of water in a jet is more important than the velocity of water. The quantity of water to be pumped into the jet is usually from 50 to 250 gallons per minute, and this quantity should be fixed by trial and experience. The water pressure should be from 100 lbs. to 250 lbs. per sq. in., and the pipe and the hose should be designed to withstand a pressure of 250 lbs. per sq. in. The water jet method minimizes injury to the piles and saves a lot of time and energy. The use of jet pipes is extremely advantageous when piles are to be driven in pure sand.

Protection of piles, spacing of piles, etc.: While driving, the head of the pile may be damaged by the impacts of the blows and hence it is necessary to protect the same by some kind of cap putting on its top. Fig. 88 shows a pile cap generally used for timber piles, and Fig. 89 for pre-cast piles. Over-driving of the piles should be guarded against, as it causes the piles to shatter beneath the ground. Such a pile is almost useless. When the hammer bounces or the pile kicks back, it is an indication that the latter has struck something it is unable to penetrate, and at this stage the driving should be stopped. When a pile is to be driven below the leads, or below the ground or water surface, a follower is generally employed in between the hammer and the pile to transmit blows to the latter when below the foot of the leads. The follower is only a small pile manufactured of the requisite length and diameter. Nowadays, these followers have been superseded by extension or telescopic leads. The pile driving should always progress towards the line of least resistance, i.e., going away from an existing building and not
towards it. Although the number of piles required depends upon the designed load to be carried by them, it is generally determined by dividing the load by safe bearing capacity of the pile. In good practice, piles are never spaced closer than 2 ft. between centres and preferably not closer than 3 ft.

Pulling Piles: Sheet piles are usually removed when that part of the work for which they have been necessary has been completed. Sheet piles are generally removed by special pullers such as Lackawanna pile puller, Vulcan sheet piling extractor, etc. Special pullers consist of special pulling nippers into which the pile line is hooked.

Sometimes piles are found necessary to be removed when they are out of plumb or when they get damaged in driving, and also when changes and alterations are made in the designs. In some cases experimental piles are driven in and are to be pulled out. In all such cases the piles are pulled out by taking several turns.

![Diagram of Cap for Driving Timber Piles](image1)

![Diagram of Cap for Driving Concrete Piles](image2)
around the head of the pile with a heavy chain, or with a wire-rope sling, and attaching to a long lever, this lever being operated by derricks, jacks, or some other convenient means with the new hitches taken as the pile moves upward. Often it may be necessary to keep hold of the pile for some time to overcome suction before it begins, but if it does not begin readily, a few blows from the pile hammer may loosen it. Jetting around the pile is also of assistance in loosening it as it is being pulled upon.

Pile-driving formulae: There are many formulae in use, and most of them have a somewhat rational basis, with co-efficients developed from tests. But, as a rule, pile-driving formula should always be used with caution. Some of the pile-driving formulae, generally used in this country, are given below:

(1) Hiley's Formula:

$$ R = \frac{4 e \cdot W \cdot H \cdot r + n^2}{s + \frac{C}{2}} $$

where

- $R =$ allowable or safe load on pile in pounds
- $e =$ efficiency of hammer blow. The average values of $e$ are given in Table No. 6.
- $W =$ Weight of hammer in pounds.
- $H =$ effective fall of hammer in feet.
- $s =$ average penetration per blow in inches under last few blows (say, 3 to 10 blows).
- $C =$ $C_1 + C_2 + C_3$, where
  - $C_1 =$ elastic compression of pile.
  - $C_2 =$ rebound of pile due to elasticity of soil, and
  - $C_3 =$ elastic compression of pile cap. The average values of $C = C_1 + C_2 + C_3$ are given in Table No. 7.
- $r =$ $\frac{W}{P}$, where $W$ has the same above value, and
- $P =$ weight of pile and cap in pounds,
- $n =$ coefficient of restitution. The average values of $n$ are given in Table No. 7 A.
### Table No. 6
Average values of Efficiency of Hammer Blow "e".

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Type of Hammer</th>
<th>Value of 'e'</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Drop-hammer, free fall</td>
<td>1.00</td>
</tr>
<tr>
<td>2.</td>
<td>—do—, line attached</td>
<td>0.75</td>
</tr>
<tr>
<td>3.</td>
<td>Single-acting steam-hammer</td>
<td>0.50</td>
</tr>
<tr>
<td>4.</td>
<td>Double-acting steam-hammer</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Table No. 7
Average values of \[ C = C_1 + C_2 + C_3 \]

<table>
<thead>
<tr>
<th>Length of pile in feet</th>
<th>Rd = 500 lbs. per sq. in.</th>
<th>Rd = 1000 lbs. per sq. in.</th>
<th>Rd = 1500 lbs. per sq. in.</th>
<th>Rd = 2000 lbs. per sq. in.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rd = 500 lbs. per sq. in.</td>
<td>Rd = 1000 lbs. per sq. in.</td>
<td>Rd = 1500 lbs. per sq. in.</td>
<td>Rd = 2000 lbs. per sq. in.</td>
</tr>
<tr>
<td></td>
<td>Easy driving</td>
<td>Medium Driving</td>
<td>Hard driving</td>
<td>Very hard driving</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>10</td>
<td>0.19</td>
<td>0.25</td>
<td>0.28</td>
<td>0.41</td>
</tr>
<tr>
<td>20</td>
<td>0.23</td>
<td>0.28</td>
<td>0.36</td>
<td>0.47</td>
</tr>
<tr>
<td>30</td>
<td>0.27</td>
<td>0.31</td>
<td>0.44</td>
<td>0.53</td>
</tr>
<tr>
<td>40</td>
<td>0.31</td>
<td>0.34</td>
<td>0.52</td>
<td>0.59</td>
</tr>
<tr>
<td>50</td>
<td>0.35</td>
<td>0.37</td>
<td>0.60</td>
<td>0.65</td>
</tr>
<tr>
<td>60</td>
<td>0.42</td>
<td>0.40</td>
<td>0.68</td>
<td>0.71</td>
</tr>
</tbody>
</table>

(1) For timber piles  
(2) For R. C. C. piles  

Rd = ultimate resistance of the pile; A = mean cross-sectional area of pile in sq. inches.
(2) **Boston Code Formula:**

\[ R = \frac{mWH}{s + K} \times \frac{r}{r+1} \] ................................ (2)

Where \( R, W, H, s, \) and \( r \) have the above values.

- \( m = 3 \) for drop-hammer, 3.6 for single-acting steam-hammer, and 4 for double-acting steam-hammer.
- \( K = 1.5L + 0.05 \) for a wooden pile or a wooden driving cap.
- \( L \) = length of pile in inches.
- \( A \) = mean cross-sectional area of pile in square inches.
- \( E \) = Young's modulus of elasticity of pile in pounds per sq. inch (1500,000 for timber)

(3) **Wellington or Engineering News Formula:**

\[ R = \frac{2WH}{s + C} \] ................................ (3)

Where \( R, W, H, \) and \( s \) have the above values.

- \( C = 1 \) for drop-hammer, 0.1 for single-acting steam-hammer, and 0.3 for double-acting steam-hammer.

(4) **Modified Engineering News Formula:**

\[ R = \frac{2WH}{s + C} \times \frac{r}{r} \] ................................ (4)

Where \( R, W, H, C, \) and \( r \) have the same above values.

(5) **Major Saunders's Formula:**

\[ R = \frac{WH}{8s} \] ................................ (5)

Where \( R \) = allowable or safe load on pile in cwt. (one cwt. = 112 pounds)

- \( W \) = weight of hammer in cwt.
- \( H \) = effective fall of hammer in inches
- \( s \) = average penetration per blow in inches under last few blows (say, 5 to 10 blows).
There is no provision made in the above pile-driving formulae for the vibrations set up in the pile. Pile-driving formulae are generally applicable to materials possessing high internal friction without cohesion (e.g. sand, gravel, etc.), but they are not applicable to materials having high cohesion (e.g. clay, loam, silt, etc.).

Professor Rankine has given the following thumb rules for the weight that piles can take:

1. For bearing piles 1000 pounds per square inch of the area of the head of the pile.
2. For friction piles 200 lbs. per square inch.

The coefficient of restitution, \( m \), may theoretically vary from 0 to 1. The following values are widely used:

<table>
<thead>
<tr>
<th>Material</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron on steel</td>
<td>0.55 to 0.60</td>
</tr>
<tr>
<td>Cast iron on concrete</td>
<td>0.40</td>
</tr>
<tr>
<td>Cast iron on wood</td>
<td>0.20 to 0.25</td>
</tr>
</tbody>
</table>

(6) Stepped, or benched, or slipped foundation: When the ground is sloping considerably, the bottom of the excavation is formed into steps, cut in accordance with the slope of the ground and this is known as stepped foundation. The steps should be of short lengths and preferably of uniform height not exceeding 3 ft., the shorter the better. This type prevents an unnecessary depth of foundation at the upper end, and consequently a waste of labour and of material. This also helps to keep the walls to a uniform height. (Vide Figure 90) If, however, the soil consists of beds of clay, there will be a possibility of the whole structure slipping bodily with the foundations along a line parallel with the slope and below the benching as at AB (See Fig. 90), and in such a case the front wall should have R. C. C. piles that driven along its base, particularly where any cross-walls meet it, to prevent the slipping, as in Fig. 91, or the concrete may be carried deeper to form a toe in front for the same purpose.

(7) Well foundations: Wells are a convenient method of securing a trustworthy foundation in deep sand or soft soil. This
method is also useful in moderate depth of water when the foundation is to be taken in soft sandy soil. Wells are generally made of masonry or of concrete, and in masonry walls vertical holding down bolts and iron plates or hoop irons (Vide Figures 92 and 93)

Fig. 90
**Stepped Foundation on Sloping Ground**

Fig. 91
**Piling in front of Foundation to Prevent Slipping**
are provided to secure good bond, in order to prevent formation of cracks during sinking operations. At the bottom of the well, a curb made of wood or of concrete, having a steel or cast-iron.
For larger wells, iron curbs of the form shown in Figure 94 are sometimes used. The position of the well to be sunk is first correctly marked on the ground, and the curb is placed upon it. On the curb the masonry ring or the steining of the well is built to a height of about 4 feet and allowed to dry. The material within the masonry ring is scooped out or dredged, so that the curb and masonry descend. Another height of 4 feet is then built, and again the same process is resorted to, and the curb and masonry again descend, and so on until the required depth is attained. The outer surface of steining is, as a rule, plastered smooth to minimize frictional resistance in sinking. The well is then filled with concrete or masonry and the superstructure built upon it. Sometimes to save concrete the bottom and top of the well are filled with concrete and the centre with only sand.

Great care should be taken during the sinking operation to maintain the perpendicularity of the well, particularly in the initial stage of about 20 ft. of sinking. Sometimes the well is loaded with artificial weights to facilitate sinking. The steining of the well may be constructed by laying upon the ground surface if possible, and the same may then be used in the work.

When one well is insufficient to fulfill the requirement, a combination of two or more wells may be constructed as described.
above, and they may be connected at top by an R. C. C. cap and the superstructure built on it (see Figs. 58 and 59). Wells are usually circular in section. The thickness of the steinling is generally taken as a quarter of the internal diameter; and to use a dredger, the internal diameter should be at least 8 feet. For all wells purpose-made or special bricks should be used. The width of the wells from outside to outside should be at least 9" greater than that of the base of the wall they are intended to carry. The space usually allowed between the walls is about 6" to 48". It will generally be found more easy and economical to sink two or more rows of wells of small diameter than one row of large diameter.

In some cases, and especially where foundations have to be carried down to great depths, iron wells are used instead of masonry ones. These iron wells are cylinders, generally of steel or cast iron, their dimensions depending upon the nature of the soil, the load to be carried, and on the height above the river bed. They are sunk in the same manner as masonry wells and afterwards filled with concrete.

8) Foundations under water: The foundations of bridges, piers, sea-walls, quays, etc. are usually constructed in or under water. The construction of foundations under water, either still or running, is always a difficult job. There is not only the initial difficulty in excluding the water temporarily from the site of construction and leaving the foundations, but also there is the necessity of protecting them from the scouring action due to running water and waves. The following methods are generally used in connection with foundations under water:—

(a) Cofferdams,
(b) Caissons.

(a) Cofferdams: Cofferdam is a temporary water-tight structure generally used for excluding the water from a given area for the construction of a permanent structure within it in the open air. Cofferdams are usually constructed in place. They may be built of earth, timber, steel or concrete. They may be divided into the following classes:—

(1) Earth Cofferdam: (Figure 95): The earth cofferdam is the simplest type in construction. It is generally used where
the depth of water is below 6 ft. Having decided upon the area to be enclosed, an earth bank is built around it. The material for making the bank should consist of clay and sand or gravel in equal proportions. The top level of the bank should be about 2 to 3 ft. above the water level, and its width should be at least 3 ft. at top, with side slopes of 1:1 to 3:1. If the velocity of the current is heavy, the face of the bund may be protected by a cover of rubble stones, called stone pitching. This type usually fails by seepage, and hence care should be taken to avoid it. When the cofferdam is thus completed, the water inside is pumped out, and then the work of excavations, filling of foundations and construction of superstructure are carried on as in open air.

(2) Single-wall or single sheet pile cofferdam: This type is used where the area to be enclosed is small and that the depth of water is about 10 ft. to 20 ft. It may advantageously be used where the space for putting the cofferdam is restricted. This type of cofferdam is constructed by first driving ordinary timber piles about 10 feet to 12 feet centre to centre, bolting longitudinal timbers, called wales, to these piles on both the sides, and then driving a single row of steel or timber sheet piles in the line demarcated. Internal bracing may be used to increase the stability of the cofferdam. Sometimes an earth bank is formed against the sheet piles on the inside to support the same against water pressure and also to reduce percolation. If the velocity of current is too much, the sheet piling may be protected from sliding or overturning by providing sand bags against them on both sides. The water is pumped out from the area thus enclosed to expose the bottom surface, and then other works are carried on as in open air. Figures 96 and 97 show a single-wall cofferdam.
(3) Double-wall or Double sheet pile cofferdam: A double-wall type cofferdam is used where the depth of water is about 20 ft.
to 40 ft. This type consists of ordinary vertical piles, horizontal wales, sheet piles, and a puddle filling. Two rows of ordinary piles, called guide piles, are driven into the earth about 6 to 15 ft. apart. Wales are bolted to these piles a short distance above the water level on the outside of the rows, and these are connected by frequent cross-timbers. Sometimes the guide piles opposite each other in the two rows are tied together by means of tie-rods of steel or iron. To the guide piles, on the inside of each row, wales of smaller size are fixed, and then sheet piles are driven closely together, near the smaller wales, as shown in figure, 98. The sheet piles should be driven to an impervious stratum to prevent leakage into the cofferdam from below. The space between the two rows of sheet-piling is filled with a puddle composed of sand and clay, or clay and gravel in equal proportions, to make the cofferdam water-tight and stable. The water is

As far as water-tightness is concerned, a thickness of cofferdam equal to the depth of water will be sufficient up to depths of 10 ft., and for greater depths this thickness should be increased about 1 foot for each additional 3 feet of depth.
elOcluded from the enclosed area and other works are carried out as usual.

For small or medium-sized cofferdams wooden sheet piles are satisfactory, but for large or deep cofferdams, steel piles with bracings are generally employed.

(4) Rockfill cofferdam: This type is suitable for small depths up to 10 feet, and can be advantageously used where rock is available abundantly and cheaply. A bank is made by merely throwing rubble stones around the area to be enclosed, and its outside is covered with a layer of earth in order to make the cofferdam fairly water-tight. To prevent scour, the face of the cofferdam is protected by some kind of matting, either timber or stone pitching. When the cofferdam is completed, water is pumped or baled out from the enclosed area, and the bed for the foundations prepared as on dry land. This type can be used even in swift water. A rock-fill cofferdam is shown in Figure 99.

![Fig. 99: Rockfill Cofferdam](image)

(5) Crib cofferdam: Instead of supporting the sheet-piling by means of guide piles, a series of cribs, laid up log-house fashion, are used for this purpose. Rough logs are usually tied although in some cases they may be squared. The bottom courses of the crib are generally constructed on land, and floated to place where it is to be fixed and completed. The crib is built to a height, to permit the top part being well out of water when it is first launched. The bottom of each crib should be shaped to fit the impervious stratum below, and if a layer of sand, silt, mud or other loose material overlies the hard substratum, the same should be dredged out before placing the cribs. After all the cribs are sunk, the space inside of them is filled with stones or earth.
When the cribs are fixed in place, sheet-piling is driven around the outside and banked with earth. This type of cofferdam is very suitable where the depth of water is about 30 ft. to 50 ft. and the velocity is also high. A crib cofferdam is shown in Figure 100.

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5 Cellular cofferdam: The cellular steel sheet-pile cofferdam consists of a series of cells connected to each other, and filled with earth to prevent the cofferdam from sliding or overturning and also to make the same stable. This type of cofferdam is very widely used for dewatering large areas and is very suitable where the depth of water is about 50 ft. to 60 ft. It may be classed as diaphragm type cellular cofferdam and circular type cellular cofferdam.

The diaphragm type cellular cofferdam consists of a series of arcs connected to straight diaphragm walls. The radius of arcs is usually made equal to the distance between diaphragms.
(72)

In which case the tensions in the arcs and cross walls are equal. See Fig. 101.

[Diagram of a cofferdam with labels D and R]

D = distance between the diaphragm; 
R = radius of the arc, R = D.

Fig. 101

Diaphragm type cellular cofferdam

The circular type cellular cofferdam (Figure 102) consists of a series of complete circles connected by short arcs, the radius of the latter generally being about 8 ft. This type requires more quantity of material than the first type but has the advantage that each cell may be filled independently of other cells without distortion of the shell. In the first type the height of...
fill must be kept nearly uniform, otherwise the cross walls will be distorted. The second type is usually employed as the work of this type is easier and quicker than the first type. Both types of cellular cofferdams may fail due to (i) over driving; (ii) pressure of earth fill in the cell; (iii) sliding or overturning of the cell; and (iv) unsuitable interlocking arrangement. These failures may be safeguarded against by a little effort.

(b) Caissons: When the depth of water is great or when it is difficult to prevent leakage, a cofferdam may be useless. Further, the construction of a cofferdam may involve much trouble, expense and delay to the work under certain conditions. In such cases the use of caissons may prove better.

A caisson is a water-tight box which is used for placing the foundation of a structure safely, in correct position. It is constructed partly or wholly on land, floated to the place, moored, and sunk by loading with steel rails and stones and by hanging chains over the walls to the required level under water. Before placing the caisson, the site is dredged to rock or to any hard stratum. Caissons may be largely divided into three classes: box caissons, open caissons, and pneumatic caissons. They are made of timber, metal, or concrete. In all cases the caisson is merely a shell, which must be filled with concrete or other masonry.

(1) Box caissons: The box caisson is used where no excavating is required after placing it, and consists of a box, open at the top and closed at the bottom, which is filled with concrete or stone masonry to serve as a foundation for the pier or other structure to be built on the same. This type is suitable where the depth of water is below 25 ft. The box caisson is made of concrete and of timber, the latter material being largely used than the former. It is formed on land, floated to place and sunk by loading it with iron or steel rails, and widely used for breakwaters, jetties, piers and wharves. A box caisson is also termed as a "Floating Caisson." A box caisson, made of R. C. C., is shown in Figs. 103 and 104.

(2) Open caissons: An open caisson or a dredging caisson

1 The word 'caisson' is derived from the French word 'caissie', meaning a box.
Is a box like water-tight structure either partly or wholly open at both top and bottom, and it forms an integral and permanent
part of the foundation. This type is suitable for deepest foundations and is widely used for piers in water. The open caisson may be subdivided into rectangular single-wall caisson, cylinder caisson, and rectangular caisson with dredging wells.

A rectangular single-wall caisson consists of a timber frame with solid walls and without top, bottom, interior chambers, or cutting edges, and is used where little or no sinking is required. The site to be occupied by the caisson is dredged to a hard ground prior to its placing. It is made at the site, floated to place and sunk by weighting it with steel or iron rails. The sinking is facilitated by removing the material inside the caisson and also by using the water-jet along the sides. On reaching its final position concrete is poured through the water to a depth of several feet and allowed to harden. The water inside it is then pumped out and filled with concrete. A typical rectangular single-wall caisson is illustrated in Figs. 105 and 106.

A cylinder caisson consists of a cylindrical shell of concrete (plain or reinforced), masonry, wood, iron, attached with a cutting edge at the bottom. Where the cylinder is of large diameter, there may be two shells, an outer and an inner one, the space between the two being filled with concrete as the caisson sinks. It is usually sunk by loading it, and at the same time excavating the material inside it. The sinking may further be facilitated by using the water-jet around the sides. Sometimes the caisson may sink out of plumb due to its artificial weight at top, and hence guide piles are driven to maintain the verticality. This type of foundation is largely employed (1) where sheet piles cannot be driven easily (2) where the depth of water is more than 40 ft., and (3) where it is necessary to go down a considerable depth to avoid scouring action. The cylinder caisson can be used to a depth of 100 feet or more.

A rectangular open caisson with dredging wells is a type of construction which is employed for the deepest foundations of bridge piers. It consists of a box-like structure of concrete (plain or reinforced), wood or iron, partly closed both at the top and at the bottom, with open wells running vertically through it. The caisson is sunk by excavating the material from the bottom of the wells by means of dredges and at the same time filling the wells
with concrete. After the caisson is sunk to a proper bearing, the wells are filled with concrete. A typical rectangular open caisson with dredging wells is shown in Figs. 107 and 108.

(3) Pneumatic caissons: A pneumatic caisson (Fig. 109) is a box-like water-tight and air-tight structure, closed at the top and open at the bottom in which pressure is used to force out the
water below in order that workmen may enter to remove the material by hand, and which forms an integral part of the foundation. The caisson has a steel cutting edge at the bottom and its

Fig. 109

PNEUMATIC CAISSON

roof has one or more holes for vertical wells, called shafts, usually of a circular or oval section and about 3 ft. to 4 ft. in diameter, for the passage of men or material from the outer air into the working chamber. At the top of the shafts air locks are placed and they prevent the air pressure in the working chamber from being seriously reduced while men or material are passing in or out. The air pressure in the working chamber is kept just high enough to balance the water pressure, otherwise difficulties may arise under certain conditions. A cubic foot of water weighs about 62.5 lbs., giving a pressure on its base of 0.434 lbs. per square inch. If the depth of water is 100 feet, the air pressure

1 An air lock is an air-tight cast iron chamber, often merely a part of the shaft itself, fitted with two doors, one of which leads to the working chamber and the other to the open air.
required will be 43.3 lbs. per sq. in., which is nearly the limit of human endurance. Sometimes this limit is increased to 51 lbs. per sq. inch. The caisson is generally constructed on the shore on launching ways; after launching it is towed into its final position. Special sea anchors are very often used in landing and holding caissons in place. Compressed air is admitted into the working chamber to force the water out, and the excavation started. After cutting about 2 or 3 feet deep, the loosened material is removed by means of buckets or blow out pipes, and the caisson sinks gradually. This process is continued until it is reached to rock or to any impervious ground. The working chamber is then filled with concrete. Sometimes the caisson is surmounted by a crib cofferdam and a certain height of crib is constructed as an integral part of the caisson to facilitate the sinking of the caisson.

The sides of the caisson should be made rigid and strong enough, and they should be vertical on the outside. The working chamber must be practically watertight and airtight. The thickness of the walls largely depends on the height of the working chamber and the nature of the soil through which the caisson is to be sunk. The height of the working chamber is usually about 6 ft. The cutting edge should be hard enough to withstand the strains and abrasive action of sinking. A thin knife-edge gives better results. Concrete is much the cheapest material for caisson construction. It is economical, however, to use a certain amount of wood or steel as the occasion requires. Steel caissons are rarely used on account of heavy cost. The pneumatic caissons are suitable where the soil is treacherous, and are usually employed for depths from about 40 ft. to 100 ft.

General: The size and type of foundation depend upon the nature of the subsoil and the weight which is transmitted to it. As the nature of the soil varies from place to place it follows that the bearing capacity of the soil to support loads is also variable. This difference in the bearing capacity of soils may be experienced on a single building site, as very often its nature is not exactly the same throughout. Hence it is not always possible to adopt a uniform size of foundation for the entire building, even if the walls and piers may support equal loads.
Footings: For first class and for buildings of greater height and weight, footings are used. Each wall, pier and column have independent footings. Footings are courses of brickwork or stonework, which are usually stepped inwards by suitable offsets on each side until the thickness of the wall or pier is reached. The width of the bottom course of footings must be at least 12" or twice the thickness of the wall (whichever is the greater), and the footings must be of uniform thickness throughout as far as possible. The brick footings are generally constructed in heading bond in order to secure adequate entry of the bricks into the body of the wall, thereby obtaining a more reliable distribution of the load. Where unequal settlements are anticipated, several strips of hoop-iron bond, properly tarred and sanded should be laid through the footings. The masonry footings must be in rich cement mortar and not lime mortar. A concrete bed must be provided at the lowest course of the foundation. The width of the concrete bed must be at least twice the thickness of the wall plus 12 inches. In some cases it will be found necessary to spread the offsets or set-backs are narrow horizontal surfaces which are formed by reducing the thickness of walls (see Fig. 110.)

Brick footings should have an offset of 2½ inches which is the standard size of a quarter brick and those of stone masonry 3 to 6 inches. The offsets of concrete should not be less than 6 inches beyond the edges of the lowest masonry footing on either side.

Sometimes the lowest brick footing is constructed in two courses to increase rigidity at the base. The footings may be built of concrete also, similar to masonry ones.

Some engineers use the following formula to determine the thickness of the footings:—

\[ t = 0.64 \sqrt{\frac{p}{s}} \]

where:
- \( t \) = thickness of course in inches,
- \( p \) = offset of the course in inches,
- \( p \) = pressure in pounds per sq. ft. on the base of the course in question,
- \( s \) = permissible bending stress in pounds per sq. inch.
Foundation concrete beyond a width of $2W$ plus 12", where $W$ is the thickness of the wall in inches at the base. The thickness of the concrete is generally determined by the formula, $D_c = \frac{5}{6} W$, where $W$ is the thickness of the wall. This proportion is usually employed for walls up to 2' 3" thick; the concrete then requires to be $\frac{5}{6} \times 27$ or 222" deep. Beyond this dimension, roughly 2 feet, the thickness is kept constant. Figure 110 shows a typical footing of a brick wall. The stone footings of a wall are given in Figure 133. Figures 111 and 112 show a typical footing of a reinforced cement concrete column. An R. C. C. footing of a brick wall is given in Figure 113. Figure 114 shows a typical footing of a steel stanchion, and Figure 115 that of an isolated brick masonry pillar. The footings of an 18" pier is illustrated in Figs. 116 to 120.

**Objects of footings:** The principal objects are:

1. To spread the weight over a sufficiently wide surface.
2. To transmit the load more uniformly over the foundation area by providing a gradual increase of base.
3. To reduce the projection of the lowest course of foundation,
which it directly supports the structure.

(4) To increase the stability of the structure and to prevent the possibility of its being thrown out of the plumb.

Usually a concrete bed is adopted below the footings. The objects of concrete bed are:

(1) To fill the inequalities of excavation and thus to facilitate even bearing on the soil.
(2) To cover small defects in the sub-soil by acting as a beam.
(3) To provide an even bed to lay the masonry footings upon.
(4) To give more stability to the foundation.

Figs. 111 and 112
FOOTINGS OF AN R. C. C. COLUMN

The projection would, in many cases, become excessive if the footings were omitted and would only be capable of resisting the B.C. 6
Fig. 114
FOOTINGS OF A STEEL STANCHION

Fig. 115
FOOTINGS OF A MASONRY PILLAR

Figs. 116 to 120
FOOTINGS OF AN 18" PIER
bending tendency illustrated in Figure 121, if made of considerable thickness. The insertion of footings (Figure 122) reduces the bending tendency on the concrete bed by curtailing the projection, and also ensures a more uniform distribution of the load over the concrete, and consequently upon the earth. Footings are usually found to fail by shearing (Figure 123), rupture in bending (Figures 124 and 125), crushing or spreading. If they are designed to resist rupture by bending, they will be safe against other manners of failure.

Combined footings: When two or more columns are supported by a single base area, they are called combined footings. These are very often used to establish exterior columns along the boundary lines of the property. As it is not possible to construct a symmetrical footing without encroachment upon the adjoining property, one or more interior columns are designed to have a common footing base with the exterior column to form a combined footing. The following points should be kept in view when designing combined footings:
The base area should be so shaped as to be symmetrical about the central line of weights. Usually the base area is rectangular or trapezoidal in shape, as shown in Figures 126 and 127.

If the exterior column load is less than the interior column load, a rectangular footing is used. If it is not possible, a trapezoidal footing may be used. In case the exterior column load is greater than the interior, a trapezoidal footing must be used.

The base area of the combined footings should be equal to or more than that secured by dividing the combined total load of the columns and the footings, by the bearing capacity of the soil.

The centre of gravity of the combined total load of the columns should coincide with the centre of the base area in the same vertical line.

If the distance between the columns is great, each should be given an independent or isolated base, and these bases should be connected by a beam to increase stability.

If the combined footing is extended longitudinally beyond the columns, the bending moment in the section between the columns should be reduced.
Eccentric loading of footings: According to the fundamental principle, the centre of gravity (C.G.) of the load must pass through the centre of the foundation base area, and usually the load is arranged so that the footings extend symmetrically on all the sides. But this is not possible when the building area is restricted. For instance, when a wall (see Figs. 126 and 129) or a column or a pier is placed close to the boundary line of a property, as in the case of buildings lining city streets, the footings cannot be extended symmetrically on either side due to the boundary line, i.e., the load cannot be made concentric with respect to the base area. Hence the footing of the wall or column or pier is constructed by spreading the base on the inside of the building only, thus having a much greater load on the outside of the building.

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1. Eccentric = not having the same centre.
2. Symmetry = similarity in size.
3. Concentric = having the same point as centre.
the base than on the inside. The only defence for such designs is that it has been much used. It would be better to limit the eccentricity within $\frac{1}{3}$ of the base width, and carry the foundations deeper and use high unit loads, or to use piles or caissons.

The intensity of pressures can be found by taking moments:

At the heavier end = \[ \frac{W}{l} \left( \frac{6e}{l} + 1 \right) \]

At the lighter end = \[ \frac{W}{l} \left( \frac{6e}{l} - 1 \right) \]
where \( W \) = total load,
\( I \) = width of base, and
\( e \) = eccentricity from center.

Cantilever footings: Eccentric or wide footings with the walls carried on one side making the pressure so much greater on the outside of the footing, are obviously incorrect in principle and very dangerous on soft soils. A very safe and better arrangement is a system of cantilever beams. In this method, two columns, exterior and interior \((P_t\) and \(P_i\)), provided with independent footings, are simply connected by a cantilever beam so that the cantilever beam will have a bearing on the centre of both bases. The cantilever thus supports the

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**Fig. 130 and 131**

**CANTILEVER FOUNDATION**
outer column with a short leverage arm, usually not over a few feet. A cantilever spread footing is shown in Figs. 130 and 131. Cantilever footings may be constructed either of RCC, beam and footings, or of steel beam grillage.

If it is not possible, due to some reasons, to provide an interior column, a suitable anchorage in the form of mass concrete or tension piles may be provided as shown in Fig. 132.

The counterbalancing load $W_1$ must be $W'$ and the reaction at $R=W (\frac{I_0}{I_1} + 1)$

Cantilever footings are adopted where it is not possible to extend the footing symmetrically on either side of the wall.

![Cantilever Footing Diagram]

**Fig. 132**

*The load $W$ on the column on boundary line is balanced by anchoring the footing beam in mass concrete at the end of cantilever.*

**Founding on different kinds of soil:** The general methods of founding on different kinds of soil are briefly given below:

1. **Rock:** Though rock is good for foundation, the nature
of the rock should be ascertained with respect to its strength to bear the weight. A good rock when lying in its original bed will support any load which is liable to be placed upon it. The surface for laying foundations should then be prepared by cutting away all loose and decayed stuff at the surface. If the surface is sloping, it should be stepped to prevent any tendency to slip and also to avoid unnecessary excavation (see "stepped foundation," page 62).

All the fissures and cavities should be carefully filled with concrete and rammed well; if they are too large, they may be arched over. If any springs exist their source should be ascertained and their course diverted, and catch-water drains should be formed on the upperside of the site to divert the surface-water. This method may be successfully adopted to lay foundations on hillside also.

(2) Hard pan: This is usually a thoroughly compact mixture of sand, clay and gravel and this usually lies directly on the rock, and can be removed by pick and shovel. Most hard pan is much harder when dried out than when in its original bed, under water, but any good hard pan will support in its natural bed more than 15 tons per sq. ft. Some hard pans water-tight, others water-bearing. The bed is prepared by digging a trench wide and deep enough to lay the foundations. A depth of 3 to 6 ft. is sufficient for foundations of ordinary buildings.

(3) Gravel or stony earth: This is fairly good for foundation of ordinary buildings. If it is too loose, it may be improved by grouting with thin cement mortar. The stability of the foundation may further be increased by driving piles about 3 ft. centre to centre.

(4) Clay: This is a fine-grained, inorganic soil possessing sufficient cohesion when dry to form hard lumps which cannot readily be pulverized by the fingers. Clay is of many kinds—hard clay, medium clay and soft clay. It is very absorbent and its cohesion decreases with moisture. On drying, it cracks by contraction and form fissures; water may find its way through the fissures and damage the foundation. Hence the quality of clay should be improved by adding sufficient quantity of coarse sand, and the foundation should be taken below the influence of alternate wetness and dryness or changes in temperature. A layer
of sand or some loose material should be interposed between the concrete or masonry in the foundation and the clay, so as to prevent contact between the two. Figure 133 shows a wall foundation on clay.

Fig. 133

METHOD OF FOUNDATION IN CLAYY SOIL

Shrinkage of clay soil can, however, also result from the drying action caused by roots of fast-growing trees. It is, therefore, care should be taken to avoid the planting of fast-growing trees within 60 feet of the building. A further point must be considered for laying foundations on sloping ground in clay soil. For it is an unfortunate fact that clay tends to creep down-hill, and footings, must therefore be deep enough to be below the zone of this movement. A possible remedy is to provide R. C. C. foundations, supported at intervals by piles about 12 ft. long. These could be bored piles, the boring being made with a hand
post-hole auger (see page 20 for a description on posthole auger).

(5) Sand: This kind of soil varies from pure silica in very fine particles, to gravel, or it may be mixed in various proportions with many different materials, as clay, loam, decayed vegetable matter, minerals, etc., and, most important of all, water. If the sand is confined so that it cannot escape, it will safely bear great weights whether it be dry or wet. The strength of the foundation may also be increased by driving friction or bearing piles about 2' to 3' centre to centre. (see Figure 23).

Figures 134 and 135 show a better and more permanent method of foundation, called Pier Foundation, which is very suitable for heavy buildings. In this type mass concrete or masonry piers of 4 feet to 6 feet thick are constructed to the required depth, and then the tops of these piers are connected by mass concrete arches or arches of masonry, below the footing level. Both these methods have been used successfully. The pier foundation method may also be adopted to lay foundations on partly hard and partly soft ground, i.e., the soft portions may be arched over, using the adjacent hard parts as abutments, taking care to see, however, that the latter will sustain the pressure and are not liable to slide. Sometimes the area of foundation is enclosed with sheet piles to resist lateral pressure of earth. As a bed for foundation the partly hard and partly soft ground is
very dangerous on account of its unequal yielding, and hence special care must be taken in determining the safe bearing capacity of the soil.

(6) Soft soil: Any one of the following methods may be adopted to secure safe foundations in soft soil:

(i) By increasing the area of the base of foundations by means of (a) Grillage (see page 26), (b) Reinforced concrete raft (see page 29), or (c) Inverted arches (see page 31).

(ii) By driving piles about 2½ to 3' centre to centre.

(iii) By building piers, or sinking wells underground and filling them with concrete (see "well foundation," page 62).

(7) Foundation partly on rock: Sometimes it is necessary but never desirable to have part of the foundation on bed rock and part on sand, clay, or on a combination of sand and clay. Whenever this is the case, the building should be so designed that settlement in the softer material will not crack walls, plaster, etc. In many cases the bulk of the settlement will occur during construction, and the remainder can be taken up by the blind joints in the walls, etc. If the building is subject to vibration from machinery, etc., serious trouble will result, unless separate foundations either entirely on or entirely off the rock can be secured for the machinery.

(8) Black cotton soil: The black cotton soil is a very treacherous soil. It is very good for agriculture, but as a bed for foundation very unreliable. It occurs mostly in the table lands south of the Vindhyas Hills, in the whole of the Deccan Plateau, and over a considerable portion of South India. It may be generally classified under two categories: (a) Formed by the decomposition of rocks like granite, trap and gneiss or limestone, which by continued weathering action had been converted into black cotton soil; and (b) Formed by similar decomposition and later transported by wind and water and deposited in low lying and flat areas and subjected to continual weathering action.

The main feature of black cotton soil is the quality of organic particles content which varies between 4 and 8 per cent. This humus forms a coating round the colloidal clay particles. The
soil has an inclination to considerable swelling and shrinking with change in moisture content which fluctuates a lot due to the high capillarity of the colloidal clay particles. The soil in its natural dry state can stand high bearing pressures, but after rains it is so soft that even a man cannot walk on it without sinking. The soil also swells very greatly when confined between walls or under a rigid floor or foundations, and exerts a very great upward and sideward pressure. In dry weather, the water evaporates comparatively fast and the soil shrinks considerably forming wide fissures which extend to very great depths. When the rains start, the fissures favour the percolation of water and accelerate the swelling process up to considerable depths. Building on black cotton soil is proverbially risky. The following precautions have been proved useful in securing safe foundations in black cotton soil:

(1) The load should be limited to \( \frac{1}{2} \) ton per sq. ft. to reduce the intensity of pressure on the soil.

(2) The foundation should be taken to such a depth to which cracks do not extend, preferably one foot below the depth at which cracks cease.

(3) The concrete should be reinforced, so as to enable it to withstand any tensile stress which may come on it.

(4) A layer of sand or some other loose material should be interposed between the concrete or masonry in the foundation and the black cotton soil, so as to prevent contact between the two.

Any one of the following methods may be adopted for laying foundations in black cotton soil:

(1) Excavation of the black cotton soil and foundation on the stratum below:

If the layer of black cotton soil extends to a depth of less than 5 feet it may be economical to excavate the trench to the stratum of marum below and provide a sand cushioning to take care of the horizontal pressures as shown in Figure 136. The impervious lining on top of the sand prevents it from becoming wet by percolating surface water or by absorbing moisture and keeps the sand pillow clean.

(2) Pile foundations: If foundations are to be made for important buildings where the soil thickness extends to more than
10 feet a pile foundation will have to be resorted to. The piles should be of R. C. C., and a sand pillow will also be useful for the taking up of the horizontal force. (Vide Fig. 137).

Fig. 136

FOUNDATION IN BLACK COTTON SOIL

(3) Foundations with piers and transverse arches: Foundations on piers, made of concrete or masonry, with transverse arches have been carried out with success. (Vide Figs. 134 and 135). For economic reasons, this type can be justified only for heavy buildings. In this case, the sand pillow will not be necessary, as the stiffness of the walls strengthened by the arches will be sufficient.

(4) Shallow foundation on sand pillow: The bottom of the trench is well watered and rammed with heavy rammers. Upon the bed thus prepared a 12" layer of hard gravel is spread, in two layers, each layer being well watered and rammed. On this layer, an 18" layer of moist sand is spread and rammed well. The sand should be prevented from running into the cracks of the adjacent black cotton soil by constructing a retaining wall, as shown in Figure 138. Over the top of the sand bed, concrete is laid and carried up to within 6" of ground level, from where masonry is commenced.
Small buildings have been founded on sand pillows, as shown in Figure 139. Sometimes the whole building has been set in a sand bed, as shown in Figure 140. This method has not been very widely tried, and definite results are not available. However, it is a very cheap method, but it also requires bigger expenses for excavation and considerable sand masses.

![Fig. 137 Foundation in Black Cotton Soil](Image)

(5) Steel grillage foundation.
A description of this type of foundation is given on page 26.

(6) Reinforced concrete foundations: This is the same as for I-beams, only less steel will be required, that shown in Figure 141 is normally sufficient. No calculations are possible as the acting forces cannot be comprehended.

(7) Raft foundation: This is described on page 29. This is a very expensive method and should only be used in cases where the bearing capacity of the soil is very disproportionate. (See Fig. 142).

Building on old foundations: When it is desired to add
Fig. 138

Fig. 139

Fig. 140

FOUNDATION IN BLACK COTTON SOIL
3 or 4 stories to an old building, it will often be found that building which has been in existence for many years; resting

![Fig. 141](image1)

**Fig. 141**

**FOUNDATION IN BLACK COTTON SOIL**

on sand, clay, etc., has so compressed its foundation that the additional weight will not cause any settlement or cracks in the building at all. This can be determined by a careful investigation of the site, making borings and some other convenient observations.

![Fig. 142](image2)

**Fig. 142**

**FOUNDATION IN BLACK COTTON SOIL**

*Effect of climate on foundations*: Foundations are not usually exposed to the weather and are not therefore as much affected by the climate as the rest of the buildings, but the results of expansion and contraction must always be carefully considered. Some reinforced cement concrete buildings have been constructed from 100 ft. to 300 ft. (or even more) long without any expansion joints, but if the foundations had been continuous for that length, the upper part of the structure would have expanded more than the base with disastrous results.

**Causes of failure of foundations and precautions to prevent such failures**: The important causes are:

1. **Unequal settlement of the subsoil**: This is the B.C. 7
commonest cause, and it is very dangerous to foundations. All soils, except rock and hard morain, are liable to yield under pressure when the latter increases beyond certain limits, and thus unequal settlement of the subsoil arises. It causes cracks in the buildings and moisture gains access into the walls, sets up decay and in the long run deteriorates the whole building. The following precautions should be taken to prevent this:

(a) A right type of foundation design based upon the knowledge of the type of soil existing to an appreciable depth below the proposed foundation level should be adopted in each case. The chief cause of trouble from faulty foundation design is relative settlement. Every endeavour must be made to keep this to a minimum and uniform and where necessary, provision should be made in the superstructure to allow for some relative settlement. Otherwise one part of the building will settle more than the other parts of the building. A low or light building attached to a high or heavy or old building should have an open joint, not necessarily exposed to view, so that if the heavier building settles it would not make an unsightly crack between it and its addition.

(b) Greatest care should be exercised to see that the load of the structure is within the safe bearing capacity of the soil, and that the load is even all over the area.

(c) The foundation of a structure should be deep enough to reach a soil which is compact and possesses the required bearing capacity.

(d) The axis of the load of the structure should coincide with the centre of the area of the foundation base.

(e) Only good and durable materials should be used for the foundation work.

(f) The foundation bed should not be disturbed under any circumstances, by adjoining excavations or drains.

(g) The ground round about a structure should be kept free from underground water troubles. A good method of subsoil drainage is shown in Figure 143.

(h) The sides of the foundation should be protected by proper drainage, preventing the water from entering into the ground. (see Figure 144).

(i) The nature of the soil as well as its bearing capacity
should not be affected either by the weather or by the sub-soil

Fig. 143
SUB-SOIL DRAINAGE FOR FOUNDATION

water. Black cotton soil is generally affected by the changing

Fig. 144
DRAINAGE FOR FOUNDATION

weathering conditions. The soil becomes very soft when wet and
loses its bearing capacity considerably. When dry it shrinks and splits, forming large cracks. This introduces tensile stresses in foundations and causes lateral movement in the various parts of the base of the structure. R. C. C. foundations or the driving of R. C. C. piles up to rock or hard pan are strongly recommended. The precautions to be taken regarding black cotton soil and the various methods of foundations on black cotton soil are described on page 92.

2. Unequal settlement of the masonry: This usually occurs due to the shrinkage and compressibility of mortar joints. The following precautions should be taken against this:

(a) The mortar used in the masonry should be as stiff as possible, consistent with workability.

(b) The height of the masonry should be carried up at an even level throughout.

(c) The wall should not be constructed more than 5 feet in height in a day.

(d) The whole masonry should be kept damp by frequently sprinkling water at least for two weeks.

(1) Withdrawal of moisture from the sub-soil below the foundations: This is liable to occur in foundations in damp soils overlying a layer of sand or gravel. In dry weather the seepage water level sinks too low, and the soil below the foundation loses its cohesion and shrinks, causing cracks in the building by uneven settlement. Either such positions should be avoided or the foundation should be strengthened by driving piles up to hard pan or rock.

(4) Lateral pressure on the superstructure: This is particularly likely to happen due to the thrust of a sloped roof, an arch at the end of a wall, or wind, tending to cause the wall to overturn. When the area of base is too small, the wall tilts and causes unequal settlement in the foundation. The precautionary measures are:

(a) A sufficient base area should be provided below the walls and columns.

(b) The thrust should be reduced by suitable means.
(101)

(5) Lateral escape of soft soil from underneath the foundations. This is liable to occur when the soil is very soft, and particularly in river banks. As a precautionary, the soil should be well confined by driving sheet piles, or such positions should be avoided if possible.

Design of foundations: The design of foundations consists of determining three items. They are:
1. The width of foundations.
2. The depth of foundations below the ground level.
3. The depth of concrete block below the masonry footings to act as a beam.

1. Width of foundations: This should be sufficient enough to bear the superincumbent load per running foot. To determine the width, the total load, which is the sum of the dead load, live load and wind load, is divided by the safe bearing capacity of the soil. This may be briefly noted as hereunder:

\[
\text{width of foundation} = \frac{L}{P} \quad \ldots \ldots \ldots \ldots \ldots \quad (1)
\]

where \( L \) = total load per running foot, and
\( P \) = safe bearing capacity of the soil.

The width of foundations may also be determined by adopting the following formula (see Figure 110):

\[
\text{Width of foundation} = 2W + 2J \quad \ldots \ldots \ldots \ldots \ldots \quad (2)
\]

where \( W \) = thickness of wall above the plinth level, and
\( J \) = projection of concrete block on each side which should be at least 6".

Out of the two formulae mentioned above, the one which gives greater result should be adopted. The increase in thickness from \( W \) at the plinth level to \( 2W \) at the bottom should be effected by suitable footings and offsets as already explained on page 79 (see Figure 110).

2. Depth of foundations below the ground surface:
This is generally determined by Rankine's formula, which gives the minimum depth. The formula is given below:

\[
\text{Depth of foundation below the ground level} = \frac{L}{P} \left( \frac{1 - \sin \theta}{1 + \sin \theta} \right)^4 \quad \ldots \ldots \ldots \ldots \ldots \quad (3)
\]
where \( P \) = maximum load in lbs. per square foot on foundations.
\( W \) = weight of the soil below the foundations in pounds per cubic foot (see Table No. 1), and
\( \theta \) = angle of repose\(^1\) of the soil (see Table Nos. 8 and 9).

In order that the foundations should not be affected by atmospheric action, etc., a minimum depth of 3 feet should be adopted for all types of foundations in soil irrespective of the result of the Rankine’s formula.

(3) Depth of concrete block below the masonry footings:
For this, one of the two following formulae may be used:
\[
d = \sqrt{\frac{46.7 \cdot \rho^2}{m}} \quad \text{..........................(4)}
\]
where \( d \) = depth of the concrete block in inches,
\( \rho \) = load on foundation in tons per square foot which is also the reaction of the bearing soil,
\( j \) = projection of the concrete on each side which should be at least 6", and
\( m \) = safe modulus of rupture\(^2\) of the concrete block in pounds per square inch (see Table No. 10).

The other formula is as follows:
\[
d = \frac{5}{6} W \quad \text{......................(5)}
\]
where \( d \) = depth of the concrete block in inches, and
\( w \) = thickness of wall above the plinth level.

Out of the above two equations the one which gives greater result should be adopted.

---

\(^1\)Angle of repose is the natural slope which a soil makes with the horizontal. The angles of repose of various soils are given in Table No. 8.

\(^2\)Modulus of rupture is the maximum bending stress computed on the assumption that elastic conditions exist until failure. Bending stress is the stress induced by loads perpendicular to the member.
**TABLE No. 8.**

Angles of repose of various soils.¹

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Kind of soil</th>
<th>Angle of repose in degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Loose earth</td>
<td>30 to 45</td>
</tr>
<tr>
<td>2</td>
<td>Dry sand</td>
<td>25 to 35</td>
</tr>
<tr>
<td>3</td>
<td>Moist sand</td>
<td>30 to 45</td>
</tr>
<tr>
<td>4</td>
<td>Wet sand</td>
<td>15 to 30</td>
</tr>
<tr>
<td>5</td>
<td>Dry clay</td>
<td>25 to 30</td>
</tr>
<tr>
<td>6</td>
<td>Damp or well drained clay</td>
<td>30 to 45</td>
</tr>
<tr>
<td>7</td>
<td>Wet clay</td>
<td>15 to 20</td>
</tr>
<tr>
<td>8</td>
<td>Gravel and sand</td>
<td>25 to 40</td>
</tr>
</tbody>
</table>

**TABLE No. 9.**

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Angle of repose in degrees or Slope</th>
<th>Value of ( \left( \frac{1 - \sin \theta}{1 + \sin \theta} \right)^3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14° 23' (4 to 1)</td>
<td>0.3707</td>
</tr>
<tr>
<td>2</td>
<td>15° 0' (3.2 to 1)</td>
<td>0.346</td>
</tr>
<tr>
<td>3</td>
<td>18° 26' (3 to 1)</td>
<td>0.2894</td>
</tr>
<tr>
<td>4</td>
<td>20° 0' (2.7 to 1)</td>
<td>0.245</td>
</tr>
<tr>
<td>5</td>
<td>25° 34' (2 to 1)</td>
<td>0.1444</td>
</tr>
<tr>
<td>6</td>
<td>30° 0' (1.7 to 1)</td>
<td>0.111</td>
</tr>
<tr>
<td>7</td>
<td>33° 41' (1.3 to 1)</td>
<td>0.0894</td>
</tr>
<tr>
<td>8</td>
<td>45° 0' (1 to 1)</td>
<td>0.095</td>
</tr>
</tbody>
</table>

¹Given in Military Engineers' Services Hand book, Vol. III.
TABLE No. 10.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Description of material</th>
<th>Modulus of rupture (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lime concrete (1 mortar to 3 stone metal)</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>Cement concrete (1 : 2 : 4)</td>
<td>75</td>
</tr>
<tr>
<td>3</td>
<td>Do. (1 : 3 : 6)</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>Do. (1 : 4 : 8)</td>
<td>35</td>
</tr>
</tbody>
</table>

**Illustrative examples in design of foundations.**

**Example 1:** A 2' - 0" thick brick wall carries a load of 10 tons per foot run at ground level. The angle of repose of the soil is 33° 41' (18 : 3) and the weight of soil is 100 lbs. per cubic foot. If the safe load on the soil be taken as 2 tons per square foot, design the foundation which you consider will be suitable.

The design of foundations consists of determining:

(a) The depth of foundation below the ground level
(b) The depth of concrete block the masonry footings, and
(c) The width of foundation.

(a) Depth of foundation $= \frac{P}{W} \left( 1 - \sin \theta \right) \frac{\gamma}{g}$

where $P = 2$ tons or $2 \times 2240$ lbs. per square foot, $W = 100$ lbs. per cubic foot, and

$\left[ \frac{1 - \sin \theta}{1 + \sin \theta} \right] = 0.0804$

Depth $= \frac{2 \times 2240 \times 0.0804}{100} = 18.0096$

$= 3.602$ ft. or 3'-7" nearly.
(b) Depth of concrete block = $\sqrt{\frac{46.7p^3}{m}}$

where $p = 2$ tons per sq. ft.,

$j = 6$ inches, and

$m = 50$, if cement concrete 1 : 3 : 5 is used (see Table No. 10).

Depth = $\sqrt{\frac{46.7 \times 2 \times 6 \times 6}{50}}$

= $\sqrt{\frac{1681.2}{25}}$

= $\sqrt{67.25}$

= 8.2 inches nearly.

The depth of concrete block may also be determined by the following formula:

Depth = $\frac{2}{3} W$, where $W =$ thickness of the wall in inches.

= $\frac{5/6 \times 24}{5/6 \times 24}$

= 20" or 1' - 8".

Note: A depth of 1' - 8" may be provided as it is safe rather than a depth of 8.2".

(c) Width of foundation = $L/P$

where $L =$ total load per running foot, and

$P =$ safe bearing capacity of the soil.

Load at ground level = 10 tons per foot run

Weight of footings = Length $\times$ Breadth $\times$ Depth $\times$ weight of masonry per cu. ft.

= $1 \times 2W \times (3'-7" - 1'-8") \times 120$

= $1 \times 2 \times 1' \times 11" \times 120$

= 920 lbs. .......

(2)

Weight of concrete block = Length $\times$ Breadth $\times$ Depth $\times$ weight of concrete per cu. ft.

= $1 \times (2W + 2) \times 1' - 8" \times 150$

= $1 \times (2 \times 2 + 2 \times 6/12) \times \frac{3}{12} \times 150$

= 1250 lbs. .........

(3)
Total load per ft. run = (1) + (2) + (3)
= 10 tons 2170 lbs. or 11 tons nearly.

Width = L/P = 11/2 = 5.5 feet or 5’-6”.
The width of the foundation may also be determined by the formula given below:

\[ \text{Width} = 2W + 2J, \text{where } W = 2'-0", \text{and } J = 6". \]

Thus,

\[ \text{Depth of foundation} = 5'-7". \]
\[ \text{Depth of concrete block} = 1'-8". \]
\[ \text{Width of foundation} = 5'-6". \]

**Example 2.** Design the foundation of a residential building, four storeys high, with a roof of Allahabad tiles (2 to 1 slope), on 2" Moulmein teak ceiling. The height of the wall from ground level is 50 feet. The angle of repose of the soil is 30° (1.7 to 1 slope). The soil weighs 100 lbs. per cubic foot and it has a safe bearing capacity of 2 tons per square foot. The walls are 1'-6" thick in lime mortar plastered on both sides. The maximum span of the reinforced cement concrete slab between two walls and of roof is 20 feet. The floors are of R. C. C. 6" thick with terrazzo topping.

(a) Depth of foundation =

\[ \frac{P}{W} \left( \frac{1 - \sin \theta}{1 + \sin \theta} \right) \]

where

\[ P = 2 \text{ tons or } 2 \times 2240 \text{ lbs. per square foot.} \]
\[ W = 100 \text{ lbs. per cubic foot, and} \]
\[ \left( \frac{1 - \sin \theta}{1 + \sin \theta} \right)^2 = 0.111 \]

Depth =

\[ \frac{2 \times 2240}{100} \times 0.111, \]
\[ = 24.864 \times 0.111, \]
\[ = 2.75 \times 5 \]
\[ = 4.973 \text{ ft. or } 5 \text{ feet nearly.} \]
(b) Depth of concrete block = \( \sqrt[3]{\frac{46.7 b^3}{m}} \)

where \( p = 2 \) tons per square foot, 

\( i = 6 \) inches, and 

\( m = 50 \), if cement concrete 1:3:6 is used (See Table No. 10.)

Depth = \( \sqrt[3]{\frac{46.7 \times 2 \times 6 \times 6}{50}} \)

= \( \sqrt[3]{\frac{1681.2}{25}} \)

= \( \sqrt[3]{67.25} \)

= 8.2 inches nearly.

The depth of concrete block may also be determined by using the following formula:

Depth = \( \frac{5}{6} W \), where \( W = \) thickness of the wall in inches.

\( \frac{5}{6} \times 18 \)

= 15" or 1'-3"

Note:—The result obtained by the latter formula is very safe rather than obtained by the former. Hence a depth of 1'-3" may be adopted.

(c) Width of foundation = \( L/P \),

where \( L = \) total load per running foot, and 

\( P = \) safe bearing capacity of the soil per sq. ft.

First calculate the loads (dead load, live load and wind load).

Wall load per running foot = Length \times Breadth \times Depth \times Weight of masonry per cu. foot.

\( = 1 \times 1.5 \times 50 \times 120 \)

\( = 9000 \) lbs.....................(1)

Weight of masonry footings = Length \times Breadth \times Depth \times Weight of masonry per cubic foot.
\begin{align*}
\text{Weight of concrete block} &= \text{Length} \times \text{Breadth} \times \text{Depth} \\
&= 1 \times 2W \times (5' - 1\frac{1}{2} \text{ ft.}) \times 120 \\
&= 1 \times 2 \times 1\frac{1}{2} \times 3\frac{1}{2} \times 120 \\
&= 1350 \text{ lbs.}
\end{align*}

\text{Weight of concrete per cubic ft.} \\
\begin{align*}
&= 1 \times (2W + 2) \times 1\frac{1}{2} \times 150 \\
&= 1 \times (2 \times 1\frac{1}{2} + 2 \times \frac{6}{12}) \times 1\frac{1}{2} \times 150 \\
&= 750 \text{ lbs.}
\end{align*}

\text{Load of R. C. C. floors:} \\
\text{Maximum span is 20 feet; thickness of floor 6".} \\
\therefore \text{Weight of R. C. C. slab per foot run} \\
\begin{align*}
&= \text{Length} \times \text{Breadth} \times \text{Depth} \times \text{Weight of R.C.C. per cubic foot}. \\
&= 1 \times 20 \times 6 \times 150 \\
&= 1500 \text{ lbs.}
\end{align*}

\text{Load of terrazzo topping 1" thick} \\
\begin{align*}
&= \text{length} \times \text{Breadth} \times \text{Weight per sq. ft.} \\
&= 1 \times 20 \times 10 \\
&= 200 \text{ lbs.}
\end{align*}

\text{Total floor load} = 1500 + 200 = 1700 \text{ lbs.}

\text{There are three floors to the building is four-storied, but half of the load would come on each wall. Hence} \\
\text{Total floor load} = \frac{3 \times 1700}{2} = 2550 \text{ lbs.} \quad \text{iv}

\text{Roof and wind load:} \\
\text{Maximum span is 20 feet; slope of roof 2 to 1 or 26.34'} \\
\text{Horizontal width of roof} \\
\begin{align*}
&= 20 + 2W + 2 \times 1.5 \text{ (projection of caves).} \\
&= 20 + 2 \times 1.5 + 3 \times 1.5 \text{ (see Fig. 145)} \\
&= 25 \text{ feet.}
\end{align*}
Sloping length \( = 2s = 14.534 + 14.534 = 29.068 \text{ ft.} \)

(See Fig. 145)

\[ x = \sqrt{(\frac{s}{2})^2 + (4.5)^2} \]

\[ = 14.934 \text{ feet.} \]

**Fig. 145**

**METHOD OF DETERMINING THE HORIZONTAL WIDTH OF ROOF**

<table>
<thead>
<tr>
<th>Description</th>
<th>Load (lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allahabad tiles and battens (see Table No. 1.)</td>
<td>17 lbs.</td>
</tr>
<tr>
<td>Timber trusses and parlins</td>
<td>24 lbs.</td>
</tr>
<tr>
<td>3&quot; thick Moulmein teak ceiling</td>
<td>28 lbs.</td>
</tr>
<tr>
<td>Wind load (1 lb. per degree of slope)</td>
<td>20 lbs.</td>
</tr>
<tr>
<td>Total roof and wind load on one wall</td>
<td>42 lbs.</td>
</tr>
</tbody>
</table>

Total dead load = \( (i) + (ii) + (iii) + (iv) + (v) \)

\[ = 9000 + 1350 + 750 + 2550 + 611 \]

\[ = 14261 \text{ lbs.} \]

---

*Note:* All loads are for one wall. Total for both walls would double the values listed. The given calculations assume a standard roof structure and are based on the principles of statics for structural design.
Total live load = span × equivalent dead load
= 20 ft. × 50 lbs. (see Table No. 3.)
= 1000 lbs.

∴ Live load on each floor = \( \frac{1000}{3} \) = 333 1/3 lbs.

As the building is four-storied, 30% reduction is necessary according to Table No. 4.....i.e.,

\[
3 \times 333 \frac{1}{3} \times \frac{70}{100} = 700 \text{ lbs. ....(B)}
\]

Total dead load and live load = (A) + (B)
= 14261 + 700 lbs.
= 14961 lbs.
= 6.68 Tons.

\[
\text{Width of foundation } = \frac{L}{P} = \frac{6.68}{3.34} = 2 \text{ tons per sq. ft.}
\]

This figure coincides with the safe bearing capacity of the soil given in the problem. Though a width of 3’-4” is sufficient for the foundation in question, it should not be less than double the thickness of the wall + 12 inches in order to meet the requirements of stability or safety against the tendency to tilt. Hence the width should be increased to 2W + 21 or 4 feet.

Thus,
Width of foundation = 4’-0”
Depth of foundation = 3’-0”
Depth of concrete foundation = 1’-3”.

**Example 3:** Design and sketch the footings of a rolled steel stanchion with a base steel plate 2’-0” X 2’-0” X 2” fixed by anchor bolts on the top of a stone block. The stanchion carries an axial load of 50 tons. The soil under the footing can safely bear a maximum pressure of 2 tons per sq. ft.
The base area of the concrete block

\[
\text{Total load} = \frac{50}{2} = 25 \text{ sq. ft.}
\]

\[\therefore \text{side of the square block } = \sqrt{25} = 5 \text{ feet.}\]

Thus, the block will be 2'-0" x 2'-0" at top and 5'-0" x 5'-0" at bottom.

Depth of concrete block = \(\frac{46.7 \times 75}{\sqrt{m}}\)

where \(\phi\) = Safe bearing capacity of the soil = 2 tons per sq. ft.

\[
f = \frac{\text{Width of concrete block} - \text{width of base plate}}{2}
\]

\[= \frac{5'-0" - 2'-0"}{2} = \frac{3'}{2} = 1'6" \text{ or 18".}\]

\[m = 75, \text{ if cement concrete 1: 2: 4 is used (see table No. 10).}\]

\[\therefore \text{Depth} = \sqrt{\frac{46.7 \times 2 \times 18 \times 18}{75}}\]

\[= \sqrt{10087.2} = 100.9\]

\[\approx 20.09\text{" or } 20" \text{ nearly.}\]

This depth may be divided into three steps, each 6" or 7" as shown in Figure 114.
Setting out or ground tracing: Prior to the commencement of building operations, the site must be surveyed and any differences of the surface obtained by means of a dumpy level. The position of the building should carefully be fixed on the ground, and the whole area cleared of any grass, shrubs, trees, etc. If the site is sloping, it should be levelled by excavating the higher parts and removing the soil to the lower portions as required. Boning rods (Fig. 146) are generally used for levelling trenches, ground work, etc. They are made of wood, and are similar to a draftsman’s T-square in shape, and consist of an upright about 3” x 3” x 1” and the tee or sighting rail about 1’-3” x 3” x 1”. They are painted white. There are three boning rods in a set. Two of the rods are held vertical on the tops of wooden stakes (say, A and B), driven to the predetermined levels at a suitable distance, and the third rod held upright at some intervening point (say, C), which is to be fixed. The position of the point C is then established by sighting or boning over their top surfaces along the line. Then the point C will be at the same level as

1 Setting out or ground tracing is the operation of laying down of certain lines and marks on the surface of the ground prior to the excavation of trenches for foundations. Lines and marks are required for (1) immediate use in making excavations for foundations, and (2) guidance in construction, at any rate until the work has risen sufficiently high above the ground level. The plans of most buildings must be approved by the local authority before the building operations are commenced. A plan submitted for approval will include the block plan of the building on which is shown the site, drainage, relative position to adjacent streets, etc. If the site adjoins existing buildings, or a highway, or a land, the exact position of the same as outlined on the deed must be confirmed with great care, to avoid subsequent disputes with adjoining owners. After the plans are approved by the local authority, contract drawings are prepared for the proposed works. If the work is to be competed for, a bill of quantities (estimates) should be prepared, copies of which are supplied to the various contractors as a basis for tendering; all other conditions being equal, the lowest tender should obtain the contract for construction.
A and B. This process is repeated to establish the other points. The method of using boning rods is illustrated in Fig. 147.

Fig. 146
BONING ROD

Fig. 147
METHOD OF USING THE
BONING RODS

After the foundation designs are ready for any building, foundation plans are prepared to any convenient scale showing all measurements. The trenches to receive the foundations are then set out on the surface of the ground before their excavation is started. The equipment required for the work consists of (1) a 100 ft. steel tape, (2) a 100 ft. metallic tape, (3) a hammer, (4) a pick-axe, (5) a plumb-bob, (6) stakes or pegs, (7) iron and wire nails, and (8) a long string. The usual method of setting out foundation lines of a building is described below.

The centre line of one of the longest outer walls is first marked out by stretching a string between two wooden pegs driven at ends, and set out all the centre lines of the walls with reference to it, either perpendicular, parallel, or at any other angle to it, as shown on the foundation plan. If the pegs are set out at the exact position of each of the corners formed by the centre lines of the walls (see Fig. 148, A, B, C, G)
A, B, C, and D), they would be dug out as the work of excavating the foundations proceeds. Hence they should be set out sufficiently outside the limits of excavation, say about 3 feet from the work as shown in Figure 148. While driving the pegs, care should be taken to see that their tops are in one horizontal level, even if the ground is sloping. All the lines at right angles to any vertical line should be fixed by using the "3 : 4 : 5" method, as shown in Figure 149. The large wood square shown in Figure 150 is also used for setting out and checking right angles. Or a

![Diagram](image)

**Fig. 148**

**MARKING OUT THE CENTRE OF A BUILDING BY MEANS OF WOODEN PEGS AND STRING**

**Diagram Illustrating the "3 : 4 : 5" Method for Setting Out Lines at Right Angles**

cross-staff, or an optical square, may be used. In important work a theodolite is used, as this instrument will give any required angle absolutely correct; but it is an expensive instrument, and for its use requires considerable skill. All measurements must be taken
by steel tapes. If the ground is uneven, the required points may be fixed on the ground by means of a plumb bob. Accuracy of

**Fig. 150**

*LARGE SQUARE OR MASON'S SQUARE*

the rectangle should be checked by carefully measuring the two diagonals from opposite corners, which should be equal to each other. If there be any differences, either in the sides or diagonals, the positions of the strings on the pegs are adjusted to neutralise the errors. Then these positions of strings are finalised by driving small wire nails at the exact string points on the pegs. The foundation trench lines are not carefully marked on either side of the centre line with a pickaxe, and all pegs and strings not required for future reference are removed to carry out the excavation work without any obstruction.

For all important and large works, instead of the pegs being driven into the ground, masonry piers, about 6" wider than the proposed foundation trenches and about 3 feet clear of their outer edges, are built as shown in Figure 151. When the lines are finally set out and checked, the strings stretched on the centre
points are pressed by means of a mason's trowel on the top of the piers to leave their marks on the wet plastered surface as shown in Fig. 152. The outer lines of the foundation trenches also may be marked on the top of the piers. These remain intact for a reasonable period, and they are very useful for checking the measurements at any time. The excavation work is then carried out as usual after laying down the trench lines on either side of the centre line by a pick.

The excavation should be commenced over the entire foundation lining and the work carried on layer by layer. The excavated earth should be dumped away from the edge of the trench (say, 5 feet from the outer edge of the trench), both for facility of work and to avoid slipping or falling in of the earth into the trench. Proper protection should be afforded against damage from surface water flowing into the excavation from neighbouring sides or streets.

Timbering for trenches: After completing the work of setting out foundation lines, trenches are made to the exact width, length and depth. The excavated trenches must retain their shape till the foundations are filled up. This is only possible if the soil excavated through is hard and the depth small. But when the trenches are deep, or the sides are not of hard soil, they must be supported by some arrangement of boarding, which is called timbering or...
The various members generally used in timbering are: (1) Poling Boards—Members placed vertically next to the sides of the excavation or sheeting; sizes vary from 7" x 14" to 9" x 18"; (2) Walings, Wales, Waling Pieces or Planks—Members placed horizontally next to the earth or poling boards; various sizes in use, are 4" x 3", 4" x 4", 6" x 6", 7" x 2", 9" x 3", and 9" x 3" and from 8 to 14 feet lengths; (3) Sheeting—Members placed horizontally; of similar scallings to poling boards and from 8 to 14 feet long; (4) Runners—Members placed vertically behind the walings instead of the poling boards; they are long planks and are about 3" thick and 7" to 9" wide. They are pointed at their lower end and sometimes are provided with an iron shoe and an iron cap; and (5) Struts—Short lengths of
timber driven down between poling boards or waisting places at a minimum distance of 6 feet centres; they are either circular 3" to 5" diameter, or square 3" x 3" to 4" x 4" in section. The various members which are used in timbering are illustrated in Figures 153 to 160.

The sizes and arrangement of the various timbers depend upon the nature of the soil and the depth of the cutting. There are various kinds of soil, but for convenience, they may be divided into: (1) Hard soil (including rock), (2) Firm soil (including dense gravel), (3) Moderately firm soil (including hard clay and loose gravel), (4) Loose soil (including dry sand, soft clay, and made-up ground), and (5) very loose soil. The general methods of timbering in different kinds of soil are described below:

(1) **Hard soil**: No timbering would be required (unless there were pockets of loose soil) for the sides of the trench would be self-supporting.

(2) **Firm soil**: Very often a light support in the form of a pair of poling boards strutted apart at a minimum distance of 6 ft. centres is sufficient to protect the sides of a trench in firm soil. A minimum distance of 6 ft. is necessary to allow sufficient working space for the men engaged in constructing the foundation. Usually

![Fig. 153](image-url)

**Figure 153**

**Timbering for a Trench in Firm Soil**
It is sufficient to use one central strut to each pair of poling boards as shown in Figure 153, but sometimes it is necessary to use two struts as shown in Figure 154. The struts are generally little longer than the horizontal distance between the poling boards, and they are driven down until they are tight and horizontal. But, care should be exercised not to overdrive the struts and disturb the earth behind the poling boards.

**Fig. 154**
Timbering for a Trench in Firm Soil.

**Fig. 155**
Timbering for a Trench in Moderately Firm Soil.
(120)

(3) *Moderately firm soil*: In this case the vertical pole boards are placed closer together perpendicularly with walling held horizontally against them on the inner sides and strutted at intervals of about 6 feet. Two methods of timbering are illustrated in Figures 155 and 157. The timbering shown in Fig. 156 is also sometimes used. Usually the pole boards are placed at a distance of 1 to 3 feet centres.

![Fig. 156](image)

*Timbering for a Trench in Moderately Firm Soil*

(4) *Loose soil*: Horizontal sheeting is quite essential, for unlike the soils referred to in the first three kinds, it is not possible to excavate in loose soil for several feet in depth before resorting to timbering. The sides of the trenches dug in this soil cannot stand unsupported for a height greater than a few inches, and hence horizontal boards or sheets are required to protect them from falling in. The usual procedure is as follows: The excavation is made to a depth of 9" and is immediately supported by boards placed horizontally against the opposite sides and two or more temporary struts are driven between to hold them in position. Then the excavation is continued for a depth of 9" or so and a second pair of boards is placed against the bottom edge of the first pair of boards and strutted as before. This operation is repeated until
four or five pairs of boards have been temporarily strutted or the required depth is reached. Finally, piling boards are placed at a

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**Fig. 157**

**Timbering for a Trench in Moderately Firm Soil**

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**Fig. 158**

**Timbering for a Trench in Loose Soil**
minimum distance apart of 6 feet centres and strutted as shown in Figure 158, and the temporary struts removed. Sometimes the sheets are placed vertically instead of horizontally, and they are supported by wallings and struts at suitable intervals as usual (see Fig. 159).

TIMBERING FOR A TRENCH IN LOOSE SOIL.

(5) Very loose soil: In very loose soil, like running sand, long planks, called runners, pointed at their lower end, are driven in along with the excavation of the trench—the driving being a foot or so in advance of the progress of excavation. Wallings and struts are then inserted to support the runners as usual. The runners are generally driven into the ground by a drop-hammer, but for speedy work steam hammers, single or double-acting, are employed. In Figure 160 a typical timbering for a trench in very loose soil is illustrated.

For deep excavation the timbering is carried out in different stages. For each stage the width is increased at the top by about 6" to 24" on either side. In Fig. 160 is illustrated a method of timbering in two stages, in the case of a trench for deep excavation for a wall foundation. Sometimes vertical props are used under the wallings as shown in Figure 160. Platforms are formed at convenient levels by nailing planks on the top of some of the struts to facilitate the work of lifting and removing the excavated earth from the bottom of the deep trench.
Steel sheet piles, with round or square struts tightened by screw arrangement are also used in very loose soil nowadays.

**Fig. 160**

**TIMBERING FOR A TRENCH IN VERY LOOSE SOIL**

The timbering is usually removed, when the foundations are completed and the walls constructed to a height of three or four
courses above the ground level: the trenches on both sides of the wall are then filled with earth and rammed well. In some cases, the poling boards or sheets or runners are left in the trenches for security.

Water in foundation trenches: When the excavation depth is carried below the underground water level, underground water is generally met with in the foundation trenches. Underground water has always been a nuisance, and sometimes an insuperable barrier to making proper foundations. The following methods are generally used to deal with water in foundation trenches:

1) By simple drains and sump wells: In this method, drains are first excavated by the side of the trench, and a shallow sump well is formed at one end at the lowest point to collect water from them. The water is then bailed out from the sump well by means of buckets or hand pumps. This method is generally employed to dispose off moderate amounts of water.

2) By cofferdams: To control and dispose off large quantities of water, cofferdams are largely employed. The site required for excavation is first enclosed by constructing a cofferdam, and the water inside it is then pumped out by some convenient means to expose the bed of soil and to create dry conditions for laying foundations. It should, however, be remembered that the purpose of a cofferdam is not to completely exclude the water, but to minimise it considerably. The various types of cofferdams are fully described with sketches on pages 66 to 73.

3) By caissons: For deep excavations as in the case of foundations for piers, sea-walls, etc., caissons are used to keep away water during excavation of foundation. Caissons are described in detail on pages 73 to 78.

4) By well point-system. This method is adopted for predating any area before the excavation is actually commenced, and is very suitable for water-logged areas. In this method, the area to be excavated is first surrounded by a number of pipes sunk vertically to the required depth (generally 2 to 5 feet below the foundation level). At the bottom of each pipe a perforated metal tube fitting, called "well point", is provided. The tops of the vertical pipes are connected by a common horizontal
suction pipe, and the underground water is pumped out through this piping system. Thus the underground water level is lowered to the required depth (thereby making the different strata of the soil all free from water content) to do the excavation work as in ordinary dry soil. Sometimes this method is assisted by a barrier of sheet piles.

(5) By chemical process. Soft and permeable soils can be made hard and water-tight by adopting this process. In this process the soils are impregnated by diluted silicate of soda and calcium chloride in suitable proportions. The chemicals fill the interstices of the soils and bind the grains together in a solid mass. This method is suitable only for small areas. In some cases, cement grouting through perforated pipes is also employed. But as it is very costly, it is rarely used for foundations of ordinary buildings.

(6) Freezing method. This method is employed in waterlogged areas containing fine sand. In this method, the water in the soil is made to freeze, so that it is changed or transformed into a solid mass. A freezing mixture is circulated through a number of vertical pipes, called freezing pipes, which are driven into the soil at distances of 3 to 5 feet as required by local conditions, all around the site to be excavated. After a number of days, the soil round about the pipes gets frozen and forms into an impervious solid wall. Within the area thus enclosed, excavation for foundation is carried out easily. As the excavation proceeds the sides are protected, if found necessary, by timbering. The freezing method is found very efficient, but it is very costly, and hence it is rarely used.

General. On all foundation work, pumping equipment of some kind should be provided to remove water from the trenches or pits. Various kinds of pumps such as hand pumps, diaphragm pumps, syphons, etc., are now available for building excavation work. The size and type of pump to be provided on a particular job will depend upon the relative positions of the suction and discharge, upon the amount of water, and upon the amount of sediment carried by the water. The hand pump will be useful to remove moderate amounts of water. The diaphragm pump, driven by gasoline, will find its use on any foundation
work. For deeper trenches, the steam syphon or the pulometer type of pump will probably give the best results.

Foundation concrete. A concrete bed is generally laid in the foundation trench to lay the masonry footings upon (see Figs. 110 and 113). Concrete possess both the essential properties of strength and durability and is suitable to almost any condition in foundation. It is made from cement or lime, water, sand and rough hard material broken to pass through a circular ring 1½" to 2" diameter or through 1½" square mesh, and prepared by mixing the materials in a dry state, then wetting and further mixing until a composition is obtained which is plastic enough to place in position and ram solid. For lime concrete only good lime, preferably hydraulic lime, should be used. Suitable proportions of lime concrete are: 1 part lime, 2 parts sand, 4 or 5 parts coarse aggregate measured by volume; or 1 part lime, 1 part surkhi, 1 part sand, 4 or 5 parts coarse aggregate measured by volume.

In damp foundations only cement concrete should be used. Plain concrete has great compressive strength but has less strength in shear and tension. Hence it is used in combination with steel to resist great shear and tensile stresses (see Fig. 113). The combination is then called Reinforced Cement Concrete (R. C. C.). Suitable proportions of cement concrete are: 1 part cement, 2 parts sand, 4 parts coarse aggregate measured by volume; or 1 part cement, 3 parts sand, 6 parts coarse aggregate measured by volume.

The cement concrete is mixed either in machines or by hand. In present day practice, mechanical concrete mixers are universally used for mixing. They are available in so many sizes and types that one will be found to meet any given condition of foundation work. Only pure water—suitable for drinking—should be used for concrete work.

After mixing, the concrete should be immediately conveyed to the required place and gently tipped into position so that the ingredients are not separated or disturbed and honeycomb texture is eliminated. It should not be thrown from a height. It should be laid in horizontal layers of thickness not exceeding 6" to 9" and rammed hard with heavy rammer. The surface should then be
well watered. Electrical or pneumatic vibrators may be used to produce dense concrete. Expansion joints and construction joints should be carefully provided wherever necessary. The concrete should never be placed when the temperature is below the freezing. Wherever required form work should be provided to support the concrete until it hardens and gains strength to support its own weight. A good form work should be rigid and be capable of being removed easily and quickly after use.

The concrete should be kept thoroughly wet for at least 14 days for curing. During this period, certain chemical changes take place in concrete and the whole mass hardens and gains strength.

**Implements for excavation:** Ordinarily the common implements used for excavation are pick-axes, shovels, spades and mammites or hoes. Crow-bars, chisels and hammers are used for removing boulders. The full-revolving power shovel is employed when the volume exceeds about 1000 cubic feet. It is very effective up to a depth of about 20 feet. Rock excavation is carried on by the aid of explosives. On small work, hand drills are successfully used, but for large work steam or air drills should be provided. The use of explosive is to lift the rock slightly and break it up into sizes convenient for disposal.
CHAPTER I. 
QUESTIONS FOR REVISION 

1. What do you understand by "Foundation"? What are its objects? Why is it laid below the ground level? 

2. (i) Detail and describe the various loads we take into consideration in the design of foundations.
   (ii) Indicate on a sketch cross section of a tall building, why and where we allow, decreasing loads per floor. Indicate the decrease.
   (iii) In the case of large warehouses the live load incidence is not constant over the columns and walls. How do we adjust the changing ratio of dead load to live load in the design of foundation? (University of Poona, 1951). 

3. What live loads would you adopt for (i) residential buildings, (ii) office buildings, (iii) a cinema hall, (iv) balconies in a public place, (v) godowns. (Gujarat University 1954). 

4. Describe the various methods of improving the bearing capacity of soils. (Karnatak University, 1952 and Bombay, University 1946). 

5. Give the bearing power of—
   (a) Soft wet clay
   (b) Coarse sand
   (c) Black cotton soil
   (d) Laterite rock. (Karnatak University, 1954). 

6. (a) Describe a method of testing the bearing capacity of a soil.
   (b) What are the minimum and maximum bearing powers of the following soils:—
   (i) Black cotton soil
   (ii) Hard marum
   (iii) Compact gravel
   (iv) Soft rock. (Gujarat University, 1954). 

7. What do you understand by the bearing capacity of soil? What are the safe permissible loads on the following
(129)

soils:—
(a) Moist clay
(b) Compact sand
(c) Murum.

Draw the section of foundation-wall on Black cotton soil, showing the precautions you will take, in founding on such soil.

(Gujarat University, 1953).

8. State the different methods of exploration of sub-soil conditions and describe in detail any ONE of these, listing the equipment you used.

(University of Sind, 1950)

9. What are the allowable bearing pressures in the case of the following soils:
   (i) Quick sand
   (ii) Wet sand
   (iii) Clay
   (iv) Black cotton soil.

What are the shortcomings of such numerical values and how would you determine the exact index?

(University of Sind, 1950)

10. (a) Discuss the various investigations you would make for the examination of soils for the design of the foundations.
    (b) Explain the meaning of the term bearing power of the soil.

(University of Baroda, 1953).

11. What are exploratory borings? When are they necessary?

What are the different methods of making them?

Explain any ONE method in detail along with the type of apparatus used for the purpose.

(Karnatak University, 1955).

12. Describe with the aid of sketches the following construction:
    Boring operations for soil explorations.

(Bombay University, 1952).

13. State the various investigations you would make and the

A. C. 9
different methods you would adopt for the examination of soils to obtain data for the design of foundations.

What values of safe bearing pressure would you adopt in the following cases?—
(i) Compact clay nearly dry
(ii) Compact sand prevented from spreading
(iii) Hard rock.

(University of Poona, 1950).

14. What are the characteristics of a black cotton soil?
   What are the remedies adopted to meet these characteristics?
   Sketch the foundation of the main wall of a building in black cotton soil.

(University of Bombay 1946).

15. (i) Describe fully a method to test the bearing capacity of soil.
   What effect has time factor on the results?
   (ii) What bearing capacities will you allow for:
       (a) Hard murrum
       (b) Black cotton soil
       (c) Trap rock
       (d) Gravel.
   (iii) What are the methods normally used to increase the bearing power of foundation soils?

(University of Poona, 1951).

16. Describe the process of sinking:
   (a) Cast-in-situ pile in restricted position.
   (b) The Fraski pile.

(Karnatak University, 1955).

17. What are the advantages and disadvantages of (i) precast
   and (ii) Cast-in-situ, concrete piles?

(Karnatak University, 1955, 1952, and Bombay University, 1950).

18. What is a pile foundation? Describe the different types
    of piles used for foundations, and indicate in what situation each
type is most commonly used.

(Karnatak University, 1954 and University of Poona, 1954).
19. Write short notes on the following bringing out clearly the importance and the special features involved.
(a) Core drilling
(b) Raft foundation
(c) Inverted arches
(d) Steel sheet piles
(e) Black cotton soil
(Karnatak University, 1954)
20. Describe the process of sinking
(a) a Vibro pile
(b) a Mac Arthur pedestal pile
(Karnatak University, 1954)
21. Compare precast R.C.C. piles with cast-in-situ piles
(Karnatak University, 1954).
22. Write short notes on any three of the following, bringing out clearly the importance and peculiarity of each:
(I) Steel grillage foundation
(ii) Black cotton soil foundation
(iii) Shoring of trenches for pipe lines
(iv) Spread footings.
(Gujarat University, 1954).
23. (a) Differentiate between open foundations, pile foundations and raft foundations. State under what conditions, each type is preferably adopted?
(b) Give sketches of different types of piles.
(Gujarat University, 1953).
24. (a) List the different types of foundations.
(b) Compare raft and footing foundations.
(University of Sind, 1950).
25. Write short notes on any four of the following:
(i) Permeability of soils
(ii) Shearing resistance of soils
(iii) Raft foundation
(iv) Friction pile
(v) Spread footing.
(University of Sind, 1950)
26. What is core drilling and where is it useful?
What is the usual method of determining the subsoil strata for laying of foundations?
(Bombay University, 1946.)
27. (a) Distinguish between bearing piles and friction piles, and state the various factors on which their bearing capacity depends.
(b) Explain with sketches any one method of driving a cast-in-situ concrete pile in a made-up soil.

(University of Poona, 1950, and University of Bombay, 1952.)

28. (i) What is a spread foundation and its footings?
(ii) Give a formula connecting the offset with the height of footing courses.
(iii) Show by sketches the footings for brick masonry, cement concrete, and R.C.C giving reasons for the dimensions.

(University of Poona, 1951.)

29. Draw neat sketches to explain the following types of foundations:
   (i) A grillage foundation to carry a heavy concentrated stanchion load of 60 tons on a soil of 1.75 tons per sq. ft. bearing power.
   (ii) A combined foundation for two columns carrying unequal loads.

(University of Poona, 1950.)

30. What is a steel grillage foundation? Under what circumstances is such a foundation resorted to? Give sketches illustrating such a grillage foundation.

(University of Bombay, 1948.)

31. (a) Write short notes on any four of the following bringing out clearly the importance and peculiarity in each:
   (i) Black cotton soil
   (ii) Boundary footings
   (iii) Raft foundations
   (iv) Steel sheet piles
   (v) Inverted arches.

(b) What is the permissible bearing stress in tons per sq. ft. for
   (i) cement concrete 1:2:4, (ii) morum, (iii) black cotton soil.

(University of Poona, 1949 and 1951)

32. Under what conditions are piles required for supporting loads? What are the various types of piles used for foundations?

(University of Poona, 1949)
33 (i) What are the factors which make the adoption of deep pile foundations necessary or desirable?

EITHER

(ii) Describe briefly the types of C. I. situ piles ordinarily used and detail fully the method of sinking Raymond piles.

(iii) Compare the advantages and disadvantages of concrete piles and timber piles.

(University of Poona, 1951)

34. What are screw piles? State the circumstances under which they are used.

(University of Poona, 1953)

35. Explain the method of driving vibro piles in made-up soil.

(University of Bombay, 1952)

36. Describe the method of casting a precast R. C. C. pile (25 ft. long) in the factory. Show by sketches the details of reinforcement at the bottom and the method of fixing the cast iron shoe with reinforcement.

(University of Poona, 1953)

37. Write a note on different formulas for determining the bearing capacity of the precast piles.

(Karnatak University 1953)

38. Draw neat sketches showing the types of construction you will adopt in the case of any two of the following:

(a) A steel stanchion carrying an axial load of 50 tons, the foundation load not exceeding 1.75 tons per sq ft.

(b) Foundations of single-storied school building in an area where deep black cotton soil is met with.

(c) Foundations for the piers of a bridge across a stream in which the bed consists of 4 ft. sand, 16 ft. sandy loam and stiff clay below with some conglomerate accordingly.

(Karnatak University, 1954)

39 (a) Describe any one method of driving cast-in-situ piles.

(b) How would you determine the safe bearing power or capacity of a pile.

(University of Baroda, 1853 Karnatak

(University, 1955 and University of Bombay, 1946)

40. State the conditions under which well foundations are adopted.
Describe briefly the method of sinking a masonry well of 15 ft. in diameter to a depth of 25 ft. in a sandy soil. The level of subsoil water is met with at a depth of 16 ft.

(University of Baroda, 1953)

41. (a) Describe with the aid of sketches the method of sinking a masonry well, 15 ft. diameter in a sandy soil. What precautions will be taken to prevent the well from going out of plumb while sinking?

(b) Explain how you would rest the masonry casing of the well, if the top of the rock on which it has to rest, is not horizontal.

(University of Bombay, 1946)

42. State the different types of cofferdams.

A pier foundation 8' × 30' is to be laid in the bed of a river which consists of 3 ft. of sand, 10 ft. of clay below which rock is met. Depth of water is about 6 ft.

What sort of cofferdam you will use and why?

Describe with sketches how you will carry out the work.

(University of Poona, 1954).

43. What are cofferdams? Draw neat sketches to explain the different types of cofferdams used during the construction of foundations for structures. (University of Baroda, 1953).

44. Explain with the aid of sketches the various types of cofferdams used for constructing foundations in running water, and state the condition for which each type is best suited.

(University of Bombay, 1942)

45. Assuming that the materials for making cofferdams that you select for your work are available at the site and the cost construction is economical, what type of cofferdam would you recommend for the following site conditions for the construction of bridge piers:

(a) The river bed is rocky, the current is swift, and there is a risk of flooding while the cofferdam work is in hand. (Ans. Cellular cofferdam).

(b) The bed of the river has a hard clay substratum, water is shallow varying from 3 ft. to 6 ft. and flow of the water is slow. (Ans. Earth cofferdam).

(c) The river bed is clayey, a clear working space is required,
the depth of water is 15 ft. to 20 ft. and the flow is slow. (Ans. Single-wall cofferdam).

Describe each type that you recommend briefly with a sketch, showing a typical cross-section of the cofferdam.

(University of Poona, 1951)

46. Explain with the aid of sketches the types of cofferdams you would recommend for the following conditions at site of work, assigning reasons for your recommendations:—

(1) Shallow water with low velocities of current. Rock foundation is available at a depth of 5 feet below bed level. (Ans. Earth cofferdam).

(2) Depth of water not more than 5 ft., but the velocity of current very high. Rock is found at a depth of 7 ft. below bed of river. (Ans. Crib cofferdam).

(3) Depth of water 10 to 12 ft. above bed and the bed consists of compact blue clay. The space for the cofferdam is not restricted. (Ans. Double-wall cofferdam).

Describe the construction of cofferdams recommended by you in each of the above cases. (University of Bombay, 1953).

47. What are caissons? Sketch and describe the various types of caissons.

48. What are the usual kinds of soil met with in the foundations? Explain their characteristics and how the foundations are laid in them. Draw sketches wherever necessary.

49 (a) What precautions would you take and what general principles would you observe in providing foundations to structures?

(b) How would you provide a subsoil drainage for a foundation?

(c) Give a typical example of a foundation failure.

(University of Poona, 1950).

50. Enumerate the various causes of unequal settlement in foundation and state how to tackle such problems successfully.

(Karnatak University, 1954).

51. A 1'-13/8" thick brick wall carries a load of 12 tons per foot run at ground level. The angle of repose of the soil is 30° and the weight of soil is 96 lbs. per cubic foot. Safe bearing
capacity of the soil is 1.75 tons per sq. ft. Sketch the foundation which you consider will be suitable.

52. Design the foundation of a residential building, two storeys high, with a roof of Mangalore tiles (11 to 1 slope) on 2" Moulmein teak ceiling. The height of the wall from the ground level is 25 feet. The angle of repose of the soil is 30° (1.7 to 1 slope). The soil weighs 96 lbs. per cubic foot. The safe bearing capacity of the soil is 1.75 tons per square foot. The walls are 1'-4" thick in cement mortar plastered on both sides. The maximum span of the R. C. C. slab between two walls and of roof is 17 feet. The floors are of R. C. C. 6" thick.

53. Design the foundation for the main wall of a building 1'-6" thick, with the following data:
Total live load and dead load calculated upto the plinth level = 10 tons per linear foot of plinth.
Height of plinth above ground = 2 feet.
Safe bearing capacity of the soil = 2.5 tons per sq. ft.
Angle of repose of the soil = 30 degrees.

(University of Bombay, 1946).

54. Design and sketch the footings of a steel stanchion with a base plate 1'-6" X 1'-6" X 1" fixed by anchor bolts on the top of a stone block. The stanchion carries an axial load of 65 tons. The safe bearing capacity of the soil is 2.25 tons per sq. ft.

55. Describe in detail how you will set out for excavating the foundations of a new building from a given plan and section of the building and state the precautions you will take to ensure that the setting out is correct in all respects.

Write a brief note on the earthwork excavation for the building and how you will carry it out.

56. What is meant by shoring for foundations and when and why has it to be used?

Describe the general methods of timbering in different kinds of soil with sketches.

(University of Poona, 1951).

57. What are the normal methods for dewatering foundation trenches and areas, both deep and shallow?

(University of Poona, 1951).
58. The depth of foundation for a building is 8 feet on an average in loose soil. Water level is 5 feet below the ground. Describe the excavating and shoring operations with neat sketches.
(Karnatak University, 1954).

59. Write short notes on any six of the following bringing out clearly the importance and peculiarity of each:
(a) Cantilever foundation
(b) Rotary-boring
(c) Raymond pile
(d) Simplex pile
(e) Disc piles
(f) Water jets
(g) Well—point system.

60. Explain the use of freezing and chemical methods for deep foundations. Why are they not in general use?
(University of Poona, 1954).

61. In a foundation trench through fine sand 7 feet deep, where rock is met for founding upon, there is found water issuing from underground current. Explain how you would tackle the laying of the foundations, if the current is (a) small (b) strong.
(University of Bombay, 1946).

Ans. (a) If the current is small and weak, it may be treated by one of the following two methods:

(i) By plugging method: In this method, sufficient quantity of quick setting cement is forced inside the current and a block of concrete made on the face. The moving water will find its way elsewhere and get diverted thus leaving the trench free.

(ii) By diversion method: If the plugging method is not successful, the current is diverted away from the work, and a suitable passage is provided for the water till it gets outside the damaging limits. This is generally obtained by forming a channel for the water to flow away by the side of the constructional limits.

(b) If the current is strong, it has to be treated specially. The best method to treat such a current is to pass in its own way, but carried in R.C.C. or cast iron pipes for the whole length of the building area. The direction of the current is first ascertained.
with the help of the points its crossing with the trenches, and
then a cut is made across the foundation trench, of the required
width and at the depth at which the current is observed for about
25 feet upstream and about 10 feet downstream outside the limits
of the building, and carried through the building area. R.C.C. or
cast iron pipes of the required diameter are laid for the entire
length, and the upstream end is enlarged by a bellmouth in order
to make the current to flow through the pipes. The success of
this remedy will be known after 7 days if there is no water coming
in the trenches except through small leakages. When this is found
satisfactory, the pipes are packed around their sides and they are
filled with concrete. The small quantity of water collected in the
trenches are pumped out by means of hand pumps. At the crossing
of the pipe with the wall an arch should be constructed so as not
to allow any load on the pipe.

62. What remedial measures do you provide in the follow-
ing situations:—
(a) a strong current of water is met with while excavating
for foundations of a structure.
(b) old foundations of another building are noticed in the
excavations for the foundations of a new building.
(c) a deep layer of sand is met with in the foundations.

(University of Karnatak, 1955)
CHAPTER II.

MASONRY—STONE MASONRY.

Masonry: The art of construction in stone or in brick is called masonry. Except in the case of dry masonry, cement or lime mortar is used to bind the stones or bricks to each other. Masonry may be broadly divided into two classes, viz., Stone Masonry and Brick Masonry.

Comparison of Stone Masonry and Brick Masonry, or Stone Masonry versus Brick Masonry:

1. In stone walls either natural stones made to rectangular blocks and roughly dressed, or artificial stones made from concrete to the required size and shape are used. On the other hand, bricks, made of good tempered clay and designed to possess good strength, durability and insulation properties, are used in brick masonry walls.

2. Stone walls are stronger and more durable than brick walls, and for public buildings and works of monumental nature stone masonry is very suitable rather than brick masonry. As a rule, better architectural effect can be given in stone masonry than in brick masonry.

3. Brick walls absorb moisture and are liable to make the building damp. When damp rises into brick walls, certain salts, dissolved in it, also rise with it and cause the exposed surface of brick walls to disintegrate and fall to powder. Hence the walls should be protected by a suitable damp-proof course. This increases the cost of walls.

The brick walls should not be allowed to come in contact with urine or sewage, and in such cases its external face must be protected by a covering of cement plaster. This item involves extra cost.

4. Brick wall is of less watertight and of less solid appearance than stone wall.

5. Though stone masonry is stronger than brick masonry, the latter is sufficiently suitable for ordinary buildings, and is easy to construct. Brick masonry possesses certain other advantages over stone masonry.
When compared with stone masonry, brick masonry affords proper bonding, and requires comparatively a smaller quantity of mortar. The work of building a brick wall is more mechanical in nature, whereas for stone masonry wall extra time and labour are required to dress a stone and to make it fit into the wall. For walls meeting at obtuse and acute angles, brick offers greater facility than stone. Even with careless masons the regular size and shape of the brick considerably reduces the possibility of hollows being left in the wall. This is not so in the case of stone wall.

The bricks can be more easily handled and require no lifting apparatus. The size and shape of bricks are such that the brick layer can continuously lay them for hours together without fatigue.

Except in hilly areas, bricks are far cheaper than stone. Stones are usually more costly than bricks, are difficult and expensive to quarry and dress down to the required size and shape, and require lifting apparatus.

Bricks can be easily moulded from tempered clay into any required size and shape at a moderate cost. This is not possible as in the case of stones. They must be dressed at greater cost for ornamental effect. And plaster does not stick as well to stone as it does to brick.

Brick walls can be constructed to any thickness, viz., 3\text{\textquoteright}, 4\text{\textquoteright}, 13\text{\textquoteright} and above, whereas a stop wall is generally constructed to a thickness of 15\text{\textquoteright} or above. Generally the faces of brick wall are plastered either with lime or cement plaster to prevent the absorption of moisture. This increases the cost. But stones do not require plastering.

Brick does not absorb as much heat as stone does, and it is also more fire-resisting than stone.

Good bricks stand the effects of weather and of acids in the atmosphere better than stones. Under certain atmospheric conditions, stones are not suited. Hence the stones should be carefully selected to suit the local atmospheric conditions.

Terms:
The following technical terms are generally used in masonry:

(1) Headers (Fig. 161): These are bricks or stones which
are laid with their length perpendicular to the face or direction of the wall, they form, when so arranged, a header or heading course. In thicker walls, instead of a single header a row of headers is used. In stone masonry headers are also called through stones, and they extend from one face of the wall to the other so as to bind the two faces together (see Fig. 162). The headers are also termed as bond stones in stone masonry, and their lengths overlap each other by six inches as shown in Fig. 162. The headers increase the transverse strength of a wall and secure good bonding between the facing and the backing. The definitions of terms 'facing and backing' are given below.

(2) Stretchers (see Fig. 161): These are bricks or stones which are placed with their lengths in the direction of the length of the wall; they form, when so arranged, a stretcher or stretching course. Stretchers increase the longitudinal strength of a wall.
(142)

Course: A complete layer of bricks or stones is called a course (see Fig. 161). The thickness of a course is generally taken as thickness of brick or stone plus one mortar joint. In brick masonry, unless otherwise stated, it will be considered as 3 inches, or, as technically described, four courses to a foot. As a rule, the thickness of a course in masonry should not be more than that of the course below it.

Fig. 162
CROSS SECTION OF A STONE WALL SHOWING THROUGH STONES, AND BOND STONES (B. S.) WHOSE LENGTHS OVERLAP EACH OTHER BY SIX INCHES

A header or heading course consists of headers and a stretcher or stretching course comprises stretchers (see Fig. 161); a brick on edge course consists of bricks placed on their \(9'' \times 3''\) faces (length \(\times\) depth) and a brick on end or soldier course is composed of bricks laid on their \(4\frac{1}{2}'' \times 3''\) (breadth \(\times\) depth) faces (see Fig. 163).
Fig. 161
VARIATIONS

Fig. 163
SHOWING A WIRE CUT OR HAND-MADE BRICK

(4) **Bed:** The lower surface of bricks or stones of each course is called the bed.

(5) **Sides:** The surfaces forming the boundary limits of the bricks or stones in a direction transverse to the faces and bed are called sides.

(6) **Face and facing:** The outer or exposed surface of a wall or a structure is termed as face, and the material used for facing is called facing.

(7) **Back and backing:** The internal surface of a wall or structure which is not exposed is termed as back, and the material used for backing is called backing.

(8) **Heating or filling:** The interior portion of a wall between the facing and backing is called heating or filling.

(9) **Joints:** These are of lime or cement mortar used for binding the bricks or stones so as to form one unit together. The mortar joints parallel to the beds of the bricks or stones are called bed joints; the joints transverse to the beds and faces are termed side or vertical joints, or simply joints. Although the vertical joints are sometimes unavoidable, they should never appear on the face of masonry. The thickness of mortar joints varies from 1/8" to 1" — the 3/8" joints shown in Fig. 151 are generally used in first-class facing work.

(10) **Perpends:** These are imaginary lines which include vertical joints as shown in Fig. 161; these should be plumb or true.
(11) **Lap**: It is the horizontal distance which one brick projects beyond a vertical joint in the course immediately above or below it (see Fig. 161); it generally varies from 2" to 4".

(12) **Bond**: It is the arrangement of bricks or stones to overlap each other, in such a manner that no continuous vertical joints occur, either on the face or in the inside of the wall, (See Fig. 161). The mortar joints are the weakest parts of a wall. If the vertical joints were in continuous lines, the wall would tend to give way along these lines. This defect may be prevented by adopting a suitable bond.

(13) **Quoins**: The external corners or angles of walls are called quoins. This term is sometimes used to the bricks or stones which form the quoins, e.g. quoin brick, quoin stone. See Fig. 161.

(14) **Spalls**: These are chips of stones used for packing up and filling the interstices in stone masonry.

(15) **Bat**: This is a portion of an ordinary brick with the cut made across the width of the brick. Four different sizes of bats are shown in Figs. 164 to 167.

(16) **Closer**: This is a portion of an ordinary brick with the cut
made longitudinally and usually having one uncut stretcher face. Seven forms of closers are shown in Figs. 168 to 174. The queen closer is made by cutting an ordinary lengthwise into two portions by means of the edge of a trussel (see Fig. 168). The queen closer is generally used next to the quoin header for creating bond in brick masonry, as shown in Fig. 161. Sometimes the abbreviated closer is used (see Fig. 169). The queen closer shown in Fig. 170 is obtained by cutting an ordinary brick into two half-bats and then splitting one into half. The King closer is generally larger than the queen closer, and is usually half the width at one end and half width at the other, as shown in Fig. 171. Sometimes the King closer is made by removing a section and leaving half-header and half-stretcher faces, as shown in Fig. 172. The mitred closers (Figs. 175 and 174) only used in exceptional cases as B. C. 10.
when the ends are required to be mitred (joined at an angle), i.e., quoins of certain bay windows.

(17) Squint quoins or bricks: These are special forms of bricks which are generally used for forming acute or obtuse angles or corners in brick masonry.

(18) Keyed brick: The keyed brick is used to provide an effective key for plaster (see Fig. 175).

(19) Cellular brick: The cellular bricks are used where it is necessary to lighten the weight of a wall (see Fig. 176).

Figs. 175 to 180

\(\text{SPECIAL BRICKS}\)

(20) Splay or plinth bricks: These are generally used to form plinths (see Figs. 177 and 178); the amount of splay varies according to the nature of the work.
(21) **Dogleg or angle bricks (Fig. 179):** These are used to ensure a satisfactory bond at quoins which depart from a right angle, and are to be preferred to the mitred closers. The angles and lengths of faces forming the dogleg vary.

(22) **Bullnose bricks (Fig 180):** A brick with only one rounded edge is called a single bullnose, and one with both edges rounded is termed as a double bullnose or a cow nose. The radius of the quadrant curve varies from 11⁄2" to 21⁄2". These bricks are used in copings and where rounded corners are preferred to sharp edges.

(23) **Footings:** These are projecting courses which are provided at the bottom of a wall in order to distribute the pressure over a greater area of the foundation. For brick masonry the footing projections are usually 11⁄2" and those for stone masonry 3" (see 'footings', page 79).

(24) **Plinth and plinth course:** Plinth is the term applied to the horizontal projecting course or courses at the base of the superstructure walls (see Fig. 181). It gives to a building the appearance of additional stability. The top-most course of the plinth masonry is called plinth course, and its top is generally at the level of the ground-floor. The upper arris may be weathered or moulded (see Fig. 181). It is generally intended to protect the interior of a building at the ground floor from the rain water and frost. The term plinth is also applied to indicate the height of the ground-floor level above the ground.

(25) **String course:** It is a horizontal projecting course of masonry, usually projecting from the face of a wall, intended to throw off rain water at intervals of height. It also gives an architectural appearance to the structure and adds to the strength of the wall. The string course may be flush with the rest of the wall (Fig. 182), or it may project from 1" to 3" beyond the face of the wall. In the latter case the projection on the upper side is weathered (see Fig. 183), and the under side throated or moulded (see Figs. 183 and 184).

(26) **Cornice:** This is a comparatively large projecting ornamental course which is fixed near to the top of a wall. Its object is to impart an architectural feature which will serve
to discharge water clear of the building and thereby protect the face of the wall (see Figs. 185 and 186). The upper

Fig. 181

VERTICAL SECTION OF A WALL, SHOWING VARIOUS PARTS FROM FOUNDATION TO TOP
portion of the cornice is weathered and the vertical joints are saddled to prevent water from penetrating them. A saddled joint

![Saddled Joint](image)

**SECTIONS OF STRING COURSES**

is formed by rounding off the stone from the top bed to the weathering at each end, this prevents rain water from lodging on top of the joint. The cornice stones are joggle jointed at the ends to prevent any movement due to unequal settlement (see Fig. 311).

**Frieze or Frieze rail** is a stone course which is surmounted by a cornice. This is illustrated in (Fig. 181).

(27) **Blocking course**: The topmost course of masonry placed on the top of a cornice is called blocking course. A blocking course adds to the appearance of a building, and, by its weight, stabilises the projecting cornice and thus prevents the tendency of the cornice from overturning. A typical blocking course is shown in (Figs. 185 and 186).

(28) **Parapet**: It is a low wall constructed round a terrace
in the case of buildings with flat roofs or along the edge of the
gutter at the eaves of sloped roofs or in front of open verandahs.

**Fig. 185**  
SECTION OF CORNICE AND BLOCKING COURSE WITH  
SADDLED JOINT

It is mainly intended to act as a fence wall for persons moving  
on the terrace, but it also adds to the appearance of a building.

**Fig. 186**  
PLAN OF CORNICE AND BLOCKING COURSE, SHOWING  
SADDLED JOINT

It is usually provided with a coping. A typical parapet wall is  
illustrated in (Figs. 181 and 187).

(29) **Coping**: This is a special course protective covering  
which is placed on the exposed top of a wall to exclude water
from the walling below. Copings are provided to walls such as boundary walls (yard and garden walls) and parapet walls (those which are carried up above roofs). The most effective coping is that which throws the water clear of the wall below. The fewer joints in the coping the better, and the jointing and the bedding material should be cement mortar. The copings may be formed of bricks, stone, concrete and terracotta, and all must be sound and durable. The copings should be weathered and throat-ed to throw off rain water. Different forms of copings are illustrated in Figs. 187 to 199.

(30) **Weathering**: Weathering (verb) is the dressing off of the upper surface of a stone to a slope so that rain water may flow off the surface without hindrance; or, (noun) it is the top surface of a stone worked to a plane surface inclined to the horizontal to throw off rain water. This term is also used to refer to one of the properties of stone, meaning its durability under exposure to the weather (see Figs. 183 and 184, and 188 to 199).

(31) **Throating**: This term (verb) is applied to cut a groove or throat on the underside of that part of a stone projecting beyond the face of a wall, so as to prevent water from running along the underside and so getting into the wall; or, (noun) it is a groove made on the undersurface of a coping or a sill so as to keep off creepage of water on to the surface of the wall. See Figs. 183 and 184, and 194 to 199.

(32) **Corbel**: It is a course (or a series of courses) which
projects (or project) to provide a ledge for structural purposes, such as a support for wall plates for floors or for detached roofs.

**Different Forms of Copings**

(see Figs. 200 and 201). The projecting course (or courses) is (or are) called oversailing course (or courses), and the arrange-
Illent is known as corbelling. The maximum projection of the corbel must not exceed the thickness of the wall. In stone masonry, the stones forming the corbel course should be carefully embedded in and anchored into the body of the wall. In brick masonry (a) each corbel must not project more than \( \frac{3}{16} \) in., (b) headers must be used, and (c) only first-class bricks and workmanship should be used.
employed. When great strength is required the courses may project only 1 1/2".

(133) **Jambs and Reveals:** Jambs are the vertical sides of the openings which are formed in walls to receive doors, windows, etc. They may be either plain or square (Fig. 202), rebated (Figs. 203 and 204) or splayed (Fig. 205) and may be provided with recesses to receive the frames of doors and windows. Splayed jambs are usually adopted as they afford sufficient room for the shutters to be opened at an obtuse angle and thus allow more light and air to enter a room.

The portions of brick masonry or stone masonry at the sides of openings for doors or windows are also called jambs (see Fig. 205).
Jambs are provided with a recess or rebate to form a reveal for receiving a door or a window frame. The width of the outer reveal is usually from 3" to 5". See Figs. 203 and 204.

The reveals may also be defined as the exposed portions of brick masonry or stone masonry at the sides of door and window openings at right angles to the face work (see Fig. 205).

Sills: These are the lower horizontal parts of window openings, which are fixed to form a damp resisting surface, and to support the vertical members of the frame. The top is weathered, i.e., sloped to throw off the water. They are made to project from 2" to 3" to throw the water clear off the wall, and throated on the under side to prevent the water running back. Sills are made of stone, concrete, bricks, tiles, and wood. The wall immediately under a window sill is called a curtain wall.

Frog or Kick: This is a shallow sinking or indent (either rectangular, triangular or trapezoidal in section) which is formed on either one or both of the long faces of a brick. A wire-cut brick has no frogs, a pressed brick has two frogs as a rule and a hand-made brick usually has only one frog. A frog affords a good key for the mortar and therefore walls which are required to show thin bed joints should be built of bricks with frogs. Bricks having only one frog should be laid with the frog uppermost so as to ensure it being completely filled with mortar.

Templates: These are pieces of stone which are placed under the end of a beam or girder to distribute the
weight over a greater area. For figure see the chapter on "Roofs".

(15) **Piers** (also known as pillars or pilasters): Piers of stone or brick masonry are adopted either to support concentrated loads such as transmitted by beams, lintels, arches and roofs, or to strengthen walls. Piers may be detached or isolated, or they may be attached to walls. The detached piers may be either square, rectangular or polygonal on plan.

(16) **Column**: A pillar of circular section is called a column.

(17) **Buttresses**: These are stepped masonry projections from a wall which are intended to give strength at intervals along long walls. See Figs. 206 to 209.

(18) **Lacing course**: A wall built of irregular small stones without proper bond is very often strengthened by building in lacing courses at intervals. A lacing course may consist of horizontal band of ashlar, coursed rubble, tile or brick. An uncoursed rubble masonry wall with brick lacing course is shown in Fig. 210.

(19) **Raising**: This term is applied to brick masonry and it has various significations. It is used for the rubbing of brick facings with a soft brick of the same colour, in order to
give uniformity of tint before pointing. The term is also used for the axing of old brick facings with a brick layer’s or mason’s axe in order to give a new face before repointing. And,

![Fig. 210](image126x225 to 486x783)

**UNCOURSED RUBBLE MASONRY WALL WITH BRICK LACING COURSE**

again, it is the smoothing of the face preparatory to white-washing or colour-washing.

**Grouting**: This consists in using thin mortar (generally made to a fluid condition and of about the consistency of cream) poured between the bricks to fill up completely any spaces not properly filled up during the laying of the bricks. It is applied over every second or third course of brick masonry in thick walls and foundations to fill up empty joints left through careless or hurried workmanship. It must not be at greater intervals than every fourth course, as otherwise the weight of the grouting may burst the mortar joints, besides encouraging slovenly and careless work.

**Lorrying**: It is the use of very soft semi-liquid mortar laid on the brickwork and pushed up in the vertical joints by sliding the bricks along. Thus lorrying completely fills all the interstices. Lorrying is often employed in thick walls after the face bricks are laid, and then consists in spreading soft mortar in a thick layer over the bed, and putting each brick down some distance from its ultimate position and pushing it into that position, thus filling up the joints between them. This, again, is not to be advocated, as all mortar should be used as stiff as possible. Its object is to get through the work quickly. Some engineers and architects prefer lorrying to grouting.
STONE MASONRY.

Dressing of stones; Objects: The art of construction in stone is called stone masonry. Most stone is obtained from quarries but where the stone beds are very deep it is obtained by underground mining; stone is removed from the quarries by blasting or by wedging process from the solid mass. In this state the stone is very irregular in shape and therefore not suitable for being used in masonry before being subjected to some cutting and dressing. Generally the stone should be dressed.

(i) to secure proper bedding and bonding;
(ii) to secure as thin mortar joints between individual stones as possible;
(iii) to secure a neat and pleasing appearance; and
(iv) to secure special shapes for the stones as in the case of voussoirs and skewbacks for arches, copings to piers, pillars, parapets or walls.

The type of dressing depends on the kind of work for which the stone is required. Stone blocks required for building or other construction work should be cut to the desired forms in the quarries, because (1) the blocks can be easily cut and squared, when freshly quarried, when they still contain some ground moisture, called quarry sap; (2) the local men, who are accustomed to handle the stone, can dress the same better and more economically; and (3) the reduced weight of dressed stone blocks reduces transport charges, etc.

Varieties of dressing: The different types of dressing used in stone masonry work are briefly described below:

(1) Hammer-dressed: It is the name given to the face of a stone when it is made to represent a rough, rock-like surface, as shown in Fig. 211. It is also known as quarry-faced, rock-faced, quarry-pitched, rustic-faced, hammer-blocked, hammer-faced, etc.

Very often stone is used in its rough state. In some quarries the stone lies in thin beds and splitting is all that may be necessary to fit the blocks for walling on account of their natural smooth faces and flatness of bed. Such smooth-faced stone is termed as self-faced.
When a stone is removed from the quarry, it is broken into suitable sizes such as Khandhis or face stones (Fig. 212), corners or quoin stones (Figs. 213 to 215), headers and rectangular blocks. These are then roughly dressed by means of quarry hammers. This consists merely in knocking off the sharp and irregular raised portions, so that the thin knife-like edges and pointed angles are removed and such that the stones could bond well with one another in the masonry. This method of dressing is generally adopted for random rubble masonry (see page 164).
2. Chisel drafted margins: After completing the above

[Fig. 213]

**SHOWING A GOOD SPECIMEN OF QUOIN OR CORNER-STONE**

method of dressing, a margin of 1" to 2" width is formed about

[Fig. 214]

**PLAN OF A GOOD CORNER-STONE OR QUOIN**

the four edges of the stone by means of a drafting chisel so as to

*After the stones are roughly dressed by means of quarry hammers as described above, they are usually conveyed to the building site, where they are prepared to the final shape before use on the work. Preparing the stone means converting the stone into finished product. This is also termed as milling.*
obtain reasonably uniform joints, and the general surface of the

Fig. 213

PLAN OF A BAD QUOIN OR CORNER-STONE

stone is left rough (see Fig. 216). This type of dressing is generally done for coursed rubble masonry (see page 180).

Fig. 216

HAMMER DRESSED SURFACE WITH CHISEL DRAFTED MARGINS

3. One line dressed or rough tooled: Stones obtained from quarry will generally have irregular surfaces and their corners and angles will not be true and square. In this type of dressing, all the projections are removed with chisels from the surfaces, and the surfaces approximately dressed true, testing now and then with the mason’s square. The corners and edges are also made square and true. There may be however be shallow depressions on the plane surfaces (see Fig. 217). The beds and the side joints are generally...
one line dressed as this is sufficient to obtain proper and satisfactory bed and side joints.

Fig. 217

ONE LINE DRESSED OR ROUGH TOOLED SURFACE

4. Two line dressed or tooled: In this method the surfaces of the stone are dressed with chisels at closer intervals to get rid of the depressions in the one line dressing and to secure even surfaces. There will be no larger chisel marks over the whole surfaces. A two line dressed surface is shown in Fig. 218.

Fig. 218

TWO LINE DRESSED OR TOOLED (POINTED) SURFACE

5. Three line dressed: This is employed to secure finer surfaces, and in this, the ridges or projections of the chisel marks will be quite tiny. See Fig. 219.

6. Fine tooled: After completing the above method of dressing, the surfaces of the stone are fine tooled with the many pointed, serrated or saw-like chisel and hammer. By this opera-
tion, all the projections caused by the dressing in the earlier stages are removed and a smooth surface is obtained. A fine tooled surface is illustrated in Fig. 220.

![Three Line Dressed Surface](image1.jpg)

**Fig. 219**

**Three Line Dressed Surface**

...are removed and a smooth surface is obtained. A fine tooled surface is illustrated in Fig. 220.

![Fine Tooled (Cut-Stone) Surface](image2.jpg)

**Fig. 220**

**Fine Tooled (Cut-Stone) Surface**

Cut stone work: In this, the surfaces are dressed true and out of winding with a sharp chisel. The chisel marks are practically imperceptible in this type of work. The appearance of the surface somewhat resembles that shown in Fig. 220.

7. Rubbled work: This is employed when a finer surface than that obtained by earlier stages is required. This work consists in rubbing the surfaces of stones until perfectly regular, and as smooth as possible. The work is accomplished with manual labour by rubbing a piece of stone against another. During the first stages of the work, pure water and fine sand are used, gra-
daily reducing the quantity of sand up to the finish. Large quantities of stones may be machine-rubbed by means of large horizontal revolving iron discs. The stones are placed on the disc, and kept from revolving with the disc by means of stationary timbers fixed across the table a few inches above the stone. No pressure is applied other than the weight of the stone block. Water and sand of good quality are added to accelerate the work. Only plane surfaces can be rubbed in this way. Fig. 221 illustrates a rubbed surface.

Fig. 221

RUBBED SURFACE

8 Polishing: Some dense stones take and hold the polish well, and such stones are polished after the rubbed work. This may be accomplished either by manual power or by machine-power. Polishing by hand is carried out by using rubbers and pads, sand and water, pumice, snake stone and putty powder.

In modern practice the polishing is carried out by means of a machine called rubbing bed. The machine consists of a steel circular table, about 10 ft. in diameter, which rotates. The stone is placed on the table bed, clamped from above, and as the table rotates, the abrasive action of carborundum, sand and water eliminates all the chisel marks. It takes about 20 minutes to polish one face of a stone block of average size. Small surfaces are polished by applying sand and water to the surfaces whilst a piece of the same stone, is worked over them. The other machines used for polishing include Jenny Lind and Disc Polisher.

Polishing the stone by manual labour is always a tedious operation, and hence machine-power should be employed for quick
and satisfactory work. Dense stones like granite, marble and basalt take a high polish. A polished surface is illustrated in Fig. 222.

Fig. 222

**POLISHED SURFACE**

**Tools and implements:** The various kinds of tools and implements commonly used for stone masonry are shown in Figs. 223 to 267 and 316 to 323. These commonly used tools may be classified under the following heads: (a) Picking and surfacing tools, (b) Cutting tools, (c) Saws worked by hand, (d) Setting out and setting tools, and (e) Lifting appliances.

**Picking and surfacing tools:** These include the following:

- *The sledge hammer* is used for striking jumpers.
- *The mash hammer* has a heavy head and short handle, and is used to remove the larger raised portions of stone and bring it to the required shape. It is also used upon the hammer-headed chisels.
- *The spalling hammer or spall hammer* weighing from 16 to 30 lbs., is used for roughly dressing the stones in the quarry.
- *The quarry hammer or sutter* is used for breaking up the larger blocks into pieces of suitable size.
- *The scabbling hammer*, weighing about 15 lbs., has one end pick-pointed as shown in the figure, and is used for removing irregular projections of the stone in the quarry.
- *The walter’s hammer* is used for roughly squaring stones in rubble work.
- *The club hammer or lump hammer*, weighing from 2 to 4 lbs., is used in conjunction with the chisels, etc.

*The pick* has a long head, pointed at both ends and weighs...
about 16 lbs., used for roughly dressing and splitting stones in the quarry.

Mason's Tools

The axe has a head roughly shaped like a double wedge, and
of about 9 to 12 lbs. in weight, used for roughly dressing the stones.

The serrat ed pick, the scabbling pick and the crow-bar are also used.
The mallet is formed of a truncated cone of hard wood with handle, and is used for striking the mallet-headed chisels for dressing stones.
The dummy is similar to the mallet, but with a smaller head and generally used for carved work.

Chisels: These are generally made of steel in order to withstand heavy impacts. Chisels are divided into two classes—those for use with the hammer and those for use with the mallet. The striking ends of mallet-headed chisels are broader than those which are hammer-headed so as to prevent the mallet from being damaged.

The pitching tool has a long edge with a thick point, and is used for reducing stones to the required size.

The bolster is used for tooling the surfaces of the stone.
The punch has a cutting edge about 1/4" long. It is used with the hammer for removing superfluous stone in roughly dressing. The point has an edge similar to the punch, but it is used for hard stones. The gouge is used for dressing the stones for cornices, string courses, etc. The drafting chisel is used for forming marginal drafts on the edges of the stones. The broad tool has an edge over two inches in width. It is used for forming fine chisel lines on the surface of the stone. This tool is sometimes called a nicker. The bolster is used for cutting soft stones. The wood handled chisel is used for dressing soft stones, and is usually struck with the dummy. The claw chisel or the tooth chisel is used for dressing surfaces of hard stones after the punch or point has been used. Jumbers: These are generally made of steel to withstand heavy impacts, and are used for boring holes in quarries for blasting purposes. Drag: The drag is a piece of steel plate with an edge cut similar to a saw tooth as shown in figure, and is used for obtaining the surfaces of stones to an even level. Wedges: These are made of steel and used for splitting stones. The plug and feathers are used for splitting hard stones. Small iron wedges, called gads, are used for splitting softer stones; these are inserted in chases made by the pick.

(c) Saws worked by hand: The principal types are:

Hand saw: It is about 2½ feet in length, and is used for cutting soft stones.

Cross cut saw: This is also known as double-handed saw, and is from 5 to 6 feet in length. This is worked by two men.

Frame saw: This is used for cutting large blocks of stone. It consists of a wooden frame, the weight of which is supported by being slung on to a system of pulleys, as shown in figure. Great care is taken to see that the arrangement of the pulleys gives necessary amount of vertical play to the saw. The blade of the saw is about one-tenth inch in thickness and four inches in
width, and is fixed to the frame by means of two steel pins. It is perhaps unnecessary to add that the length of the saw is always longer than the stone to be cut, i.e., about 2½ feet. The cutting action is usually assisted by coarse sand and water.

**Setting out and setting tools:** These are as follows:

- **The square** consists of a steel blade and wood stock or entirely of steel. Each arm is generally about 18 inches long. This implement is used for setting out right angles from the face of a wall and testing perpends.

- **The set squares,** made of steel or iron, are sometimes used.

- **The spirit-level** is used for getting horizontal surfaces.

- **The compass** is used for marking parallel lines to irregular surfaces and for describing circles and setting off distances. It is also used for dividing.

- **The two-foot rule** is used for taking measurements.

- **The trowel** is used for lifting and spreading mortar on to a wall and for forming joints. It consists of a blade of steel and shank into which a small wooden handle is fixed.

- **The line and pins** are used to maintain the correct alignment of courses. The line is generally wound round the pins. The length of the line should be at least three knots or 36 yards.

- **The plumb bob and the plumb rule** are used for testing verticality of a wall. The plumb bob, shown in figure, is also used for measuring distances along slopes in a hilly country in order to transfer the points to the ground, and also used for centering an instrument exactly over a station mark.

(e) **Lifting appliances:** The various kinds of appliances used for lifting stones are described, and illustrated in Figs 316 to 323.

**General principles to be observed in stone masonry construction:**

1. The stones selected for the masonry work should be hard, tough and durable. Only cement or hydraulic lime mortar should be used throughout the work. A wall should never be constructed of stones which are "face-bedded" i.e., with the laminae vertical and parallel to the face of the wall, for in this position the weather action may cause decay along the edges of the stone, and, in
In extreme cases the exposed layer may separate and flake off.

2. Natural bed: As a rule, every stone in ordinary walls should be bedded on the natural bed as in this position the lamina
tions of the stone are horizontal and at right angles to the pressure
and thus the stone is better able to support the superimposed
weight.

Corridors, string courses and similar projecting courses should
be built of stones which are "edge-beded" or "joint-beded", that
is, the stones are laid with the laminations vertical and at right
angles to the face of the wall, otherwise the moulndings may be dis-
figured owing to weather action.

Archies should be constructed having the natural bed of the
voussoirs normal (right angles) to the face of the arch and per-
pendicular to the line of thrust, i.e., parallel to the radial centre
line of each stone.

3. The stones to be used in the masonry work must be well

1Natural bed: Sedimentary rocks such limestones and sand-
stones, are stratified or laminated (due to the deposition of succes-
sive layers or laminae during the formation of the stone) and occur
in beds of varying thickness. The layers are usually parallel to
the bed and the term "natural bed" is used to the surface of the
stone which is parallel to these layers or bedding planes.

The beds are ordinarily more or less horizontal. Some stones
show the laminations very clearly and there is no difficulty in as-
certaining the natural bed. In some cases it can only be detected
with the aid of microscope. The direction of the natural bed of
certain limestones is indicated by an examination of the minute
shells which lie flat in the direction of the bedding planes, and that
of some sandstones by the position of the embedded flakes of mica
which lie flat and parallel to the natural bed. An experienced man
can easily detect the natural bed of the stone. In order to prevent
mistakes, in some quarries the direction of the natural bed on each
stone is marked before despatch.

It is important that the stone should be constructed in the
correct position in relation to the natural bed, otherwise serious
defects may occur.
watered before use so that they do not absorb the moisture from
the mortar and thereby decrease its strength.

4. Care should be taken to secure a good bond throughout the
masonry. There should be no hollows left during construction
and all the interstices should be well packed with mortar and
chips.

5. To bond the two faces of the wall, the facing and the
backing, and thus add to its transverse strength, through stones
(see Fig. 162) must be introduced in each course at 4 to 5 feet
apart, running for the full thickness of the wall. If the thickness
of the wall is 2½ feet or above, two headers should be used, one on the front face, and the other
on the rear face, so that they overlap each other at least 6 inches
(see Fig. 162). A header must have a length of at least thrice the
height.

6. Care should be exercised to get a thin and uniform mortar
joint throughout the masonry work.

7. The joints, though carefully dressed, should not be too
smooth, otherwise their surfaces will afford no key for the mortar,
or offer sufficient resistance to the sliding of the stones. Great care
must be taken to see that the bed joints are not worked hollow.
Sometimes this is done in order to show a very fine joint on the
face without the trouble of carefully dressing the whole bed. This
leads to the whole weight being thrown on to some point (say,
point A, Fig. 268) at the edge, and a piece (say, piece B, Fig. 268)
is splintered off at the edge. The stone is then said to be
splashed at this point. With the same object of
saving labour, the middle of the stone is dressed slack and under·
pinned as shown in Fig. 269. The stone is thus supported only
at the back and the front, and is liable to break across as shown
in figure.

8. The faces of the wall should be constructed truly vertical,
and their verticality should be tested by a plumb rule. If the
wall has got a batter, it should be tested with a wooden template
and a plumb-bob. A spirit level may also be used.

9. As a rule, the masonry in the entire length of wall should
be raised uniformly so that the pressure on the foundation under
the entire length may be uniform, and the danger of unequal settlement, which is the usual cause of cracks and similar defects

![Diagram](image1)

**Fig. 268**

**Flushed Joint**

Figuring in walls, floor etc., may be eliminated. If a wall is not built for the full length at once, and if on a later date additions have to be made to extend its length, proper racking must be formed by giving steps so as to allow a proper connection between the old and new work (see Fig. 161).

10. In building either on dry work or old work, the upper surface must be well cleaned and wetted before mortar is laid over
It, to form a bed for the new work. Otherwise the joint between
the old and new work will not be satisfactory.

11. The entire masonry work should be kept wet until the
mortar is set and become hard. During the watering operation,
care should be taken to see that the mortar is not washed out
from the joints by the pressure of water. Generally, watering
should be done for two to three weeks when lime mortar is used,
and for one to two weeks when cement mortar is used.

12. Normally the load or weight should act axially and
centrally on masonry sections. If eccentric loads and oblique loads
have to be supported by masonry, great care should be taken to
see that there are no resulting tensile stresses in any section in the
masonry.

13. As a rule, the length of a soft stone for resisting pressure
should not exceed three times its depth, and the breadth from one
and a half to twice its depth. The length of a hard stone should
not exceed four times its depth, and the breadth three times its
depth.

14. Generally mortar joints are the weak portions in masonry.
Hence the exposed surfaces should be properly pointed either
with cement mortar or good lime mortar, after properly wetting
and raking them at least one inch deep, in order to protect them
from the ravaging effects of atmospheric agencies.

Classification of stone masonry: The stone masonry may
be broadly divided into two classes:

1. Rubble masonry, which consists of blocks of stone (generally
under 9 inches in depth) that are either undressed or
comparatively roughly dressed by means of quarry hammers, and
having wide joints.

2. Ashlar masonry, which consists of blocks (generally
12' to 18' in depth) carefully dressed with narrow or fine joints.

1. Rubble Masonry: There are several kinds of rubble
masonry, each known by a technical name, depending upon the
regularity, thickness of the joints, dressing of the edges, etc.
However, it may be classed as given below:

(a) Uncoursed rubble masonry (Fig 270).
(b) Random rubble masonry (Figs. 271 to 277).
(176)

Fig. 270
UNCOURSED RUBBLE MASONRY

Figs. 271 and 272
RANDOM RUBBLE MASONRY (NOT BUILT TO COURSES)

(c) Coursed rubble masonry (Figs 279 and 280).
(d) Dry rubble masonry (Fig. 281).

(a) Uncoursed rubble masonry: This is the cheapest form of stone walling, and is constructed with roughest stones as received from the quarry, after merely knocking off weak corners and edges with a quarry hammer. The stones are picked from a heap and fitted into the work so as to get a proper interlocking with each other. The interstices are then properly filled with small or chips of stone and mortar. The horizontal and vertical joints are made in any angle for each stone, and hence the strength of the walling greatly depends upon the quality of mortar and workmanship. If possible, the stones should be placed on their widest beds, so that they may not be crushed, or act as wedges and force out the adjacent work. Headers or through-stones should be provided of sufficient thickness to resist fracture. All the stones should be well wetted before use. An uncoursed rubble masonry wall is illustrated in Fig. 270.

This type of masonry is employed in the construction of labour quarters, godowns, compound walls, garages, and stores.

(b) Random rubble masonry (Figs. 271 to 277): This kind of masonry is constructed with stones dressed either by a hammer and a chisel, or by a quarry hammer alone. Generally the face stones of this masonry have no regular shape, and in this state this masonry is called random rubble, second sort. For superior work (i.e., for random rubble, first sort) a fairly uniform size and shape of stones are used for the face work. More or less regular polygon shaped stones are preferred (see Fig. 277). The height of the stone should not be more than its horizontal dimension. The bond should be sound both transversely and longitudinally. Proper transverse bond may be obtained by using headers or bonders, and through stones or throughs. Satisfactory stability may reasonably be assured if one-quarter of the face consists of headers (about two numbers per square yard), in

1 Unlike bricks, the stones are not of uniform size and shape, and therefore greater care and cleverness have to be exercised in arranging that the stones shall adequately distribute the pressure over a large area and in the avoidance of long continuous vertical joints.

B. G. 12
Fig. 273 and 274

Random Rubble Masonry Built to Courses
Numbers such as 1, 2, 3, etc., indicate the order of laying stones.

Fig. 275

Squared Random Rubble (not built to courses)
addition to one-eighth of the face area of through stones (one number per square yard).

Fig. 216

SQUARE RANDOM RUBBLE BUILT TO COURSES

Random rubble masonry is used to construct inns (waiting places for pilgrims), residential buildings, godowns, boundary walls and large stores.

Fig. 277

FACE WORK OF SUPERIOR RANDOM RUBBLE MASONRY
With the object of saving time and labour, sometimes, the masons place the face stones like bricks on edge, and fill up the gaps with spalls or chips of stones, often leaving hollows which may or may not be filled even with mortar (see Fig. 278). This kind of work greatly reduces the strength of the masonry, and hence this type of work should be strictly avoided, and care should be taken to see that the face stones fall back sufficiently into the body of the wall. See Figs. 271 to 274.

(c) Coursed rubble masonry (Figs. 279 and 280): This is the most superior variety of rubble masonry, and consists of stones squared on all joints and beds. The face is hammer-dressed, and the projection of rock-faced surface does not exceed 1½" beyond the bed-joint. This is normally constructed in horizontal courses.
which are usually 6" to 8" high. This class of masonry is divided into third class, second class, and first class by gradually increasing the amount of dressing on the exposed surfaces of stones. Through stones and bond stones should be liberally used throughout the work, as already stated.

SQUARED OR COURSED RUBBLE MASONRY

Coursed rubble masonry is used for public buildings, hospitals, waiting places, schools, markets and residential buildings.

(b) Dry rubble masonry, or simply dry stone masonry is the name given to ordinary rubble masonry which is built without any mortar (see Fig. 281). This class of work is used for dwarf walls, boundary or compound walls, retaining walls, breast walls, etc.

General: Rubble masonry should be constructed with cement mortar composed of one part Portland cement to 3 parts standard sand, as the strength of the work depends greatly upon that of the mortar.

Corner-stones or quoins (Figs. 213 to 215): At the corners or turnings of walls corner-stones or quoins are laid to secure strength and to increase the appearance of the wall. They are usually of the same height as that of the course, but sometimes the height is equal to that of two courses. They are dressed to show two sides, and as they have no lateral support, their beds
must be dressed for at least 4' from the face so as to increase their stability.

Fig. 281

FLAT REDDED RUBBLE LAID DRY WITH RUBBLE-ON-EDGE FENCING

Ashlar masonry: The following are the various types of ashlar which are generally used in building works:

(a) Ashlar fine or coursed ashlar.
(b) Random coursed ashlar.
(c) Rough-dressed or bastard ashlar.
(d) Rock or quarry-faced ashlar.
(e) Chamfered ashlar.
(f) Block-in-course.
(g) Ashlar facing.

(a) Ashlar fine or coursed ashlar (Fig. 282). In this class of masonry stone blocks of the same height in each course are used, and every stone is fine-dressed on all beds, joints and faces, full and true. The thickness of the mortar joint is uniform throughout, and does not exceed one-eighth of an inch and the stones are usually over 12 inches in depth. Great care must be taken when determining the sizes and proportions of the blocks of stone to ensure that they will conform with the general scale of the
building. Badly proportioned stones, which may be either too small or too large for the purpose, will completely mar the appearance of the work. A satisfactory bond of stone blocks of uniform size can be easily obtained if the length of each block is from twice to thrice the height and if the courses break joints. There is a danger of the stone being split or fractured if uneven settlement happens, and if the length exceeds four times the height. It is the most expensive form of stone masonry work, owing to the labour and waste of material involved in reducing all stones to the same height.

(b) Random coursed ashlar: This consists of fine or coursed ashlar with the courses of varying depth, depending upon the size and character of the building.

(c) Rough tooled or bastard ashlar: In this type of masonry, all the beds, joints and faces of stone blocks are rough tooled or comparatively dressed with chisels. And all the stone faces exposed to view have a fine chisel dressed, brought all round the edges. The thickness of the mortar joint is uniform and does not exceed one-fourth of an inch.

(d) Rock or quarry faced ashlar: This class of masonry is similar to rough tooled or bastard ashlar, except that the exposed surface between the fine chisel-dressed margins is left rough,
I. Rock or Quarry-faced. The projections on the face, which are known as bushings, are not more than three inches from the bed joints.

(e) Chamfered ashlar: This is similar to rock or quarry-faced ashlar, except that the edges round the exposed face of each stone is bevelled or chamfered off to 45 degrees for a depth of one inch or more. The rock face or bushing does not project more than 3 inches from the bed joints.

(f) Block-in-course masonry or hammer dressed ashlar (Fig. 283): It is the name given to a class of masonry which occupies an intermediate place between rubble and ashlar. The stones are all squared and brought to good fair joints, the faces usually being hammer-dressed. The thickness of the mortar joint usually does not exceed one-fourth of an inch. The courses are usually from 7 inches to 9 inches high, and often they are not continuous. Block-in-course closely resembles coursed rubble, or rough tooled or "bastard ashlar, according to the quality of the work put upon it. This type is divided into first-class and second-class according to the amount of dressing on the face. Block-in-course is usually associated with heavy engineering work, such as in the construction of sea walls, retaining walls, etc., and is not very often used in general building work. Sometimes block-in-
course is used for big public buildings, theatres, temples, bridges and railway stations.

(g) Ashlar facing: Ashlar is the best grade of stone masonry. The heavy expense of ashlar masonry prevents its being used throughout the whole thickness of a wall except in works of great importance and solidity. In order to reduce the cost and at the same time give the appearance of ashlar facing to the wall, it is the usual practice in many a locality to construct walls faced with blocks of ashlar having a minimum thickness on bed combined with a backing of brickwork or rubble. Such walls are sometimes called "compound or composite walls". As the backing would have a greater number of joints than the ashlar, the backing should be built in cement mortar, and a satisfactory bond should be secured throughout the work by using the joints as thin as possible and by bringing the backing to a uniform level at every bed joint of the ashlar, to ensure equality of settlement.

If the backing is of rubble, then it is called rubble ashlar (Fig. 284), and if of brickwork, it is termed as brick ashlar.
Sometimes, the ashlar stones to be used in the brick ashlar are made more or less equal to the size and shape of bricks in order to get a satisfactory bond, and thus to safeguard against unequal settlement.

Ashlar masonry is used for heavy structures, architectural buildings, high piers and abutments and for machinery.

Detailed specifications for stone masonry. Specifications of stone masonry in general: See the fourteen points given under the head "General principles to be observed in stone masonry construction", page 171.

Specifications of uncoursed rubble masonry:

1. Dressing: Stones to be used as received from the quarry, after merely knocking off weak corners and edges with a quarry hammer or mason's hammer.

2. Laying: All the stones should be laid to break joints as much as possible, and vertical joints should be avoided. The stones should be placed on their widest beds so that they may not be crushed.

3. Mortar joints: No joints should exceed three-fourth inch in thickness. All the interstices should be filled with spalls or chips of stone and mortar, and care should be exercised to see that there are no hollows in the interior portions of the wall. All the stones should be set full in mortar, and only good hydraulic lime mortar or cement mortar should be used.

4. Face stones: These should be placed without any underplating. Only comparatively large stone blocks of good bedding and of uniform colour should be used to gain sufficient strength as well as appearance to the walling. About fifty per cent of the stones should not be less than one cubic foot in content, and twenty five per cent should be of headers tailing into the work at least 15 inches. The faces of the wall should be truly vertical.

5. Size of stones: A reasonable number of stones, having large size and good shape, should be used. The height of the face stone should not be more than the breadth or the length of the tail into the work.

6. Through stones and bonders: At least one through
stone should be used for every square yard of facing, and this should be for the full thickness of the wall. If the thickness of the wall is more than 6 ft, two stones, called bonders, should be laid side by side so as to overlap each other at least 6 inches. Care should be taken not to place the headers of successive courses above one another.

(7) Quoins or corner stones: These shall be of some selected good stone and dressed with a hammer to obtain correct angles, and laid header and stretcher alternately.

(8) Construction and watering: As far as possible, the masonry in the entire length of a wall should be uniformly raised, and the whole work should be well watered until the mortar is set, and become hard.

(9) Pointing: The exposed faces should be neatly pointed either with cement or good hydraulic lime mortar in all the joints, after properly wetting and raking at least one inch deep.

Specifications of random rubble masonry:

(1) Dressing: All the stones should be carefully hammer-dressed to secure neat and close joints. If necessary, the edges should be dressed with a chisel. This is generally done for superior work.

(2) Laying: Same as incoursed rubble masonry.

(3) Mortar joints: The thickness of the mortar joint should be half an inch or less. All the interstices should be properly filled with spalls and mortar, and there should be no hollows inside the wall. All stones should be set in good mortar.

(4) Face stones: These should be of good quality and of uniform colour. They should be comparatively large and uniform in size, and should be placed without any pinning. Care should be exercised to see that the faces of the wall are truly vertical.

(5) Size of stones: Normally the stone should be of uniform colour and of equal size, and solidly bedded in cement or good lime mortar. The stones in each course need not, however, all be of the same height, but not more than either the breadth or the length of the tail into the work. No course should be greater in height than those below it. All stones should be completely set in good mortar.
(6) **Throughs and bonders**: For every square yard of facing, one through stone and two headers should be provided to secure sound transverse bond. Through stones or throughs should extend to the full thickness of the wall. If the thickness of the wall is more than 2\(\frac{1}{2}\) feet, two headers or bonders should be laid side by side so as to overlap each other at least 6 inches. Care should be exercised to see that the bond stones and through stones are not placed one above the other in successive courses.

(7) **Quoins or corner-stones**—Headers, at least 18 inches in length, should be used for quoins, and laid lengthwise alternately along each face. They should be laid square on their beds and dressed for a depth of about 4 inches.

(8) **Construction and watering**: Same as in uncoursed rubble masonry.

(9) **Pointing**: Same as in uncoursed rubble masonry.

**Specifications of coursed rubble masonry:**

1. **Dressing**: The face stones should). be squared on all joints and beds. The beds should be hammer-dressed, true and square, for at least 3 inches from the face, and the joints for at least 1\(\frac{1}{2}\) inches. The face should be hammer-dressed. The projection of rock-faced surface should not be more than 1\(\frac{1}{2}\) inches from the bed joints.

2. **Laying**: All the stones should be laid in horizontal courses not less than 6 inches in height. The stones in each course should be of the same height. All the stones should be completely set in mortar.

3. **Mortar joints**: The thickness of the mortar joints should not be more than three-eighth of an inch. All the bed joints should be horizontal and the side joints vertical. The stones should be laid without any slumping. All the hollows in the masonry should be filled up with chips of stone and mortar.

4. **Break of joints**: All the stones should be so laid as to break joints at least half the height of the course.

5. **Size of stones**: The breadth of the stone should not be less than the height. At least one-third the number of stones, should tail into the work to twice their height, and in thick walls to three times their height.
(6) **Through stones and headers**: Same as in random rubble masonry.

(7) **Quoins or corner stones**: These should be of selected stone, and they should be of the same height as that of the course in which they occur. They should be of headers at least 18 inches in length, and laid alternately along each face. They should be placed square in their beds, and dressed to a depth of at least 4 inches.

(8) **Construction and watering**: Same as in uncoursed rubble masonry.

(9) **Pointing**: Same as in uncoursed rubble masonry.

**Specifications of dry stone masonry.**

(1) **Dressing**: No dressing should be done, except simply knocking off weak corners and edges with a mason's hammer.

(2) **Laying**: The stones should be as flat-bedded as possible.

(3) **Joints**: No mortar should be used. The side joints need not be vertical, but they should not be steeper than 60 degrees. The thickness of the joint (i.e., the space between the two stones) should not be more than five-eighths of an inch.

(4) **Break of joints**: All the stones should be so laid as to break joints as much as possible to avoid long or continuous vertical joints.

(5) **Size of stones**: A good proportion of the stones used, should be of large size. No stone shall be less in breadth or length than its height.

(6) **Through stones and headers**: The through stones should be liberally used throughout the work, and they should, as a rule, run for the full width of the wall. The headers in successive courses should not be one above the other, but they should be laid staggering.

(7) **Corner-stones or quoins**: Same as in coursed rubble masonry.

(8) **Construction**: The stones should be well wetted before use. As far as possible, the masonry should be raised uniformly. It should generally be constructed with a slight batter of 1 in 12 for safety and stability.
Specifications of ashlar masonry:

1) Dressing: Every stone should be fine-tooled all beds, joints and faces, and it should be square and true. It should accurately coincide to the design correctly.

2) Laying: All the stones should be set in fine lime or cement mortar. Care should be taken to see that the stones are properly bedded. All the courses should be of the same height, unless otherwise specified, but the upper course should always be thinner or smaller than the lower ones. When a stone is laid, it should be struck with hammer, in order to bring it to a solid bearing.

3) Size of stones: The height of the stone should not be less than 12 inches. The length of a soft stone should not exceed three times its height, and the breadth from one and a-half to twice its height. The breadth of a hard stone should not exceed four times its depth, and the breadth three times its height.

4) Through stones and bonders: Same as in random rubble masonry.

5) Mortar joints: Generally the mortar joint should not be less than one eighth of an inch. All the bed joints should be horizontal and the side joints vertical.

6) Break of joints: The stones should be so laid as to break joints at least half the height of the course. In each course the headers and stretchers should be laid alternately (As will be seen later, this arrangement is similar to the Flemish bond in brick masonry).

7) Construction and watering: Same as in uncoursed rubble masonry.

8) Pointing: Same as in uncoursed rubble masonry.

Specifications of block in course masonry:

1) Dressing: All the stones should be roughly dressed, and made true and square for at least the same distance as the height. The face of the stone should be hammer-dressed, and the rock-faced projections should not exceed 2 inches. At corner-stones or quoins a chisel draft should be provided all round the edges.
(2) **Laying:** All the stones should be set either in lime mortar or cement mortar. Care should be taken to see that they are properly bedded. The lower course should always be thicker than the upper ones. The stones should be laid without any pinning.

(3) **Size of stones:** The height of the stones should not be less than 7 inches, and the breadth not less than the height. At least one-third the number of stones should be tailing twice the height into the wall.

(4) **Through stones and bonders:** Same as in random rubble masonry.

(5) **Mortar joints:** No mortar joint should be more than one-fourth of an inch. All the bed joints should be horizontal, and the side joints vertical.

(6) **Break of joints:** A good bond should be obtained throughout the work, and the break of joints should be at least half the height of the course.

(7) **Construction and watering:** Same as in uncoursed rubble masonry.

(8) **Pointing:** Same as in uncoursed rubble masonry.

**Stone Masonry Joints:** In order to prevent stones from sliding over each other, or to more rigidly connect them together than that can be done by mortar or cement, various joints are used. The following are some of the various joints which are used in stone masonry:

(1) **Butt or plain joint:** This is the simplest type of joint, and is formed by placing the surface of one stone against that of another, as shown in Figs. 286 and 287. This type of joint is
extensively used for ordinary work.

(2) Rebated or lapped joint: This joint is used for stone roofs and copings to obtain water-tight joint. The rebated joint is generally made by cutting a rectangular piece in the thickness and along the edge of each stone to be connected, and overlapping the cut portions as shown in Figs. 288 to 290. The part that laps over should not be less than \( \frac{3}{8} \) thick. The rebated joint may also be formed as shown in Figs. 291 and 292 to get more water-tightness.

Figs. 288 to 290

REBATED JOINT

Figs. 291 and 292

ANOTHER FORM OF REBATED JOINT

(3) Tongued and grooved joint (Figs. 293 to 295): This

Figs. 293 to 295

TONGUED AND GROOVED JOINT OR Joggle JOINT
Joint is also known as joggle joint, and consists of a projection, called tongue or joggle, worked along one edge of a stone which fits into a corresponding groove in the adjacent stone. It is chiefly used in landings to prevent any movement between the stones connected and so retain a uniform level surface, and also to assist in distributing any weight over every stone in the landing. It is very expensive and hence it is now rarely used.

Cement joggles are very often used in the side joints of the top courses of masonry in order to prevent the movement or displacement in the same. They consist of a "V" shaped sinking in the side joint of each adjacent stone in the same course (see Fig. 311). These are employed for the end joints of a pier, especially when the blocks have a small bed, and for cornices.

(4) Tabling or tabled joint (Figs. 296 to 298): This is a type of joint for holding stones together by a wide projection or joggle left on one stone fitting into a corresponding sinking made in the other stone. The depth of the projection is about ⅜ inches, and the width one third the breadth of the stone. This joint is used to prevent lateral displacement in the stones of a wall subjected to lateral pressure, such as in a sea-wall, etc. On account of heavy expense, it is seldom used.

(5) Dowelled joint: In order to prevent lateral movement
or 'sliding of stones, the joints (both side and bed joints) are strengthened by means of dowels. A dowelled joint is normally formed with a slightly tapering pin, called dowel, which fits into the holes made in the stones opposite to one another (see Figs. 299 to 302). The dowels may be square, or circular in section. The dowels are either of hard stone, slate, or gun-metal (an alloy of copper and tin) which are from 1/4" to 2" square in section or 1/8" to 1/4" in diameter and 2 to 6 inches in length. They are usually set in cement mortar. They are largely used in the top courses of masonry where the weight on or of the individual stones is not great, and in the bed joints of the drums of columns, balusters, and in any position where lateral movement is likely to occur. A dowel used for columns, or in similar position is sometimes termed as a bed plug (see Figs. 303 to 305).

(6) Cramped joint: The joints between the stones which are liable to be pulled apart in the direction of their length are strengthened with metal or slate cramps and cement, or asphalt, and the joints thus formed are termed as cramped joints.
The cramp is a piece of non-corrosive metal, such as gunmetal (see above), copper etc., which is from 1" to 2" wide, 1/8 to 3/4 thick and 7" to 18" long with ends which are turned down from 1/4" to 1 1/4".

Corrodible metal, such as wrought iron, must never be used for cramps. The cramp is generally placed in a channel cut in the upper surface of the two stones, having sinkings at the ends, into which the turned down extremities of the cramp may fit. The cramp should always be sunk below the surface of the stone and it must be fitted in tightly. The turned down parts of the cramp are covered with lead, and the upper surface is covered with either cement or asphalt. Details of a metal cramped joint are shown in Figs. 306 and 307.

A state cramped or Keyed joint, consisting of a double dovetailed piece of slate set in cement, is shown in Figs. 308 and 309. It is not so effective as the metal cramped joint. Cramped joints
are used for securing stones for copings, blocking courses, etc.

**Metal Cramped Joint**

(7) **Plugged joints**: It is an alternative to the cramped

**Slate Cramped or Keyed Joint**
joint, and is frequently used to connect such stones as copings, blocking courses, overhanging cornices, etc. It is formed by pouring cement or molten lead into the dovetail-shaped plug holes made below the top surface of the stone, as shown in Fig. 310.

![Fig. 310](image)

**PLUGGED JOINT**

The holes slope downwards, as shown in figure, in order that the cement or lead may run at once into the ends and corners so as to fill them completely. The stones are thus prevented from sliding laterally. If cement is used to form the joint, then it is called cement plugged joint, and if lead is used, it is termed as lead plugged joint.

(8) **Saddled or water joint** : This is illustrated in Figs. 185 and 186, and has been described on page 149. See Fig. 311 also.

(9) **Rusticated joints** : Sometimes the margins or edges of stone blocks, such as plinths, lower storeys of buildings, quoins, etc., are made to sink below the general face. The term "rusticated" is applied to such masonry. Four different forms of such rusticated joints are shown in Figs. 312 to 315.

**Lifting appliances** : Ordinarily stones are lifted to a considerable height by means of chains, called sling chains, or ropes passing round them and with the help of pulley blocks. The stones are tied in such a manner that the position and the balance is maintained without drooping, swinging or rotating, and the raising is done by manual labour. The ropes or the chains tied to the stones are likely to damage the edges and corners by getting pressed. This can be prevented by using gunny bags or timber battens as packings near the corners and the chains or ropes passed over the packings. Though this method is extensively adopted, it is only a rough method and is not suitable for lifting
finely dressed heavy stones. Sometimes the stones are to be lifted from one place, moved horizontally and lowered gently to another place where they are to be fitted in the construction. Under these circumstances sling chain or rope method cannot be used. If the stones are too large to be lifted by hand, they may be raised by means of a crane or other hoisting apparatus. The various appliances, other than the sling chain or rope, used for lifting heavy blocks of dressed stone are briefly described below.

Fig. 311
SHOWING CORNICE, PARAPET AND COPING.

Lewis: Normally a lewis (Fig. 316) consists of a rectangular piece of steel, two dovetailed pieces of steel, a pin, a cotter or key and a "I" shaped shackle, and fits in the dovetailed hole cut in the top of the stone. Eyes or holes are provided at the top of rectangular and dovetailed pieces, and two holes are made at the bottom of the shackle, one at each end of the shackle as shown in the figure. The two dovetail shaped pieces are first inserted and placed
against the sides of the hole. The rectangular piece is then placed into the hole centrally so as to act as a wedge between the two dovetail-shaped pieces. A "T" shaped shackle is put on the three pieces, and a pin with a head at one end is inserted through the eyes or holes in the shackle and the three pieces, and secured by a cotter. Key or split pin at the other end. If the hole in the stone has been too large, a piece of zinc passed between a pair of pieces before they are assembled may be sufficient to enable the lewis to grip the stone properly. The lewis hole in the stone is from 2 to 10 inches deep according to the weight of the stone. The lewis is dismantled by first withdrawing the cotter and the pin, and then the rectangular piece and the two dovetailed pieces. This type of lewis is sometimes called a three legged lewis.

The lewis shown in Fig. 317 is a modified form of three legged lewis. The central piece is wedge shaped and can slide through...
Fig. 316
LEWIS (THREE LEGGED LEWIS)

Fig. 317
LEWIS (MODIFIED FORM OF THREE LEGGED LEWIS)
the pieces P. P. While lifting, the central wedge shaped piece presses against the two sides of the pieces P. P. and prevents the lewis from being drawn out.

Another form of lewis, called chain lewis, consists of three steel rings and two curved steel legs (Fig. 318). The legs vary in size. The hole which is formed in the centre of the top of the surface of the stone is slightly dovetailed. If it is dovetailed too large, there is a tendency for the lewis to be pulled out owing to the legs bursting the stone during the hoisting operations. The lewis is placed into the hole, one at a time. If the hole in the stone is found to be too large, a wedge shaped steel piece, called silver, is driven down between the legs. When the crane chain is wound up, the two smaller rings (see Fig. 318) pull the upper ends of the legs together and thus cause the lower ends to grip the stone. The size of the hole varies from 2" to 3" deep.

Another type of lewis, used for lowering and setting stones under water, is illustrated in Fig. 319. It consists of a piece of steel with one side only slant, the other being vertical. This piece is placed into the hole made in the centre of the top bed of the stone, and the key which has both the faces vertical wedged
In. The key is tied with a separate thin chain, and it is withdrawn after the stone is lowered into position by loosening the same. The pull is applied to the piece, and not to the key.

**Fig. 319**

**LEWIS (SUITABLE FOR LOWERING AND SETTING STONES UNDER WATER)**

Fig. 320 illustrates another very simple type of lewis consisting of a pair of iron or steel pieces let into the holes, which they closely fit, sloping towards each other. When a pull is applied to the lifting chain these pieces jam in their places and support the weight of the stone.

Lewises are used for lifting stones up to 20 cwt. in weight.
and as they can be expeditiously fixed, they are largely used than any other form of lifting device.

**Chain dogs:** Dogs are made of steel and are shaped as shown in Fig. 321. Dogs vary in size. A hole, about 2" deep, is punched in the centre of each end of the stone to be lifted and from 3" to 4" down. A steel chain is passed through the ring of each dog and is hooked on to the lifting chain and the points of the dogs are placed in the holes of the stone. When the crane chain is wound up, the two dogs bite into the stone, which is hoisted and lowered to the required position. The arrangement is shown in Fig. 322. Chain dogs are very suitable for lifting heavy stones and long stones with narrow beds.
Nippers: This type of device for lifting stones is illustrated in Fig. 323. The nippers consist of two curved and pointed arms rotating on a pivot. A hole is made in the centre of each side of the stone to be lifted, as described above. The points of the nippers are then placed in the holes of the stone. The catch is automatically tightened when a pull is applied to the lifting chain.

The quantity of mortar required per 100 cubic feet for various kinds of stone masonry along with their safe loads in tons per square foot are given in Table No. 11.

**Table No. 11.**
Mortar required for 100 c. ft. of masonry and safe loads in masonry.

<table>
<thead>
<tr>
<th>No.</th>
<th>Kind of masonry</th>
<th>Mortar required per 100 c. ft. of work</th>
<th>Safe load in tons per sq. ft. if lime mortar is used</th>
<th>Safe load in tons per sq. ft. if cement mortar is used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Uncoarsed rubble masonry</td>
<td>35 to 40%</td>
<td>2 to 3</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Random rubble masonry</td>
<td>30 to 35%</td>
<td>4</td>
<td>6 to 8</td>
</tr>
<tr>
<td>3</td>
<td>Squared or coursed rubble masonry</td>
<td>20 to 25%</td>
<td>5</td>
<td>10 to 12</td>
</tr>
<tr>
<td>4</td>
<td>Ashlar (trap)</td>
<td>8 to 12%</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>Ashlar (granite)</td>
<td>8 to 12%</td>
<td>12 to 14</td>
<td>18</td>
</tr>
<tr>
<td>6</td>
<td>Block-in-course</td>
<td>18 to 20%</td>
<td>10</td>
<td>12 to 15</td>
</tr>
</tbody>
</table>

Note: It is always a good practice to test the materials before use. The figures given in the table are only approximate.
CHAPTER II.

QUESTIONS FOR REVISION.

1. Explain in detail the points upon which the strength of masonry depends. (Karnatak University 1952 and 1955) 
   Or
   What are the general principles to be observed in the construction of masonry? (University of Baroda, 1952)

2. Give short notes on the following and illustrate your answers by neat sketches:
   (1) Lewis (Baroda University 1954)
   (2) Frieze rail (Karnatak University 1954)
   (3) Dressings (do 1952)
   (4) Joggles (do 1952 and '55)
   (5) Block in-course (Gujarat University 1952)

3. Explain the following terms with sketches:
   (1) Corbel
   (2) Cornice
   (3) Jambs
   (4) Reveals
   (University of Baroda, 1952)

4. Write short notes on, with sketches:
   (a) Quarry-faced ashlar
   (b) Weathered coping of a compound wall
   (c) String course
   (d) Ashlar masonry.

5. What is dressing of stones? Describe various methods of dressing with sketches.

6. Explain the meaning of the following terms and illustrate your answer with sketches:
   (a) Queen closer
   (b) Corbel
   (c) Template
   (University of Sind, 1950)

7. Enumerate the classification of stone masonry normally used in building construction. Give detailed specification of any one of them and state the safe compressive load per sq. ft., and the quantity of mortar that may be required for 100 c. ft. of that type of masonry.
   (Poona University, 1951)
8. What do you understand by course-rubble masonry first sort? Give important details about such construction.
(Gujarat University, 1952).

9. Give a complete section of 13” thick wall showing all the details from foundation to roof, giving names of its various parts. There are two floors supported by the wall. On one floor, the section should be taken through a door and on the other through a window, you may take a flat roof or a pitched roof resting on the wall. (University of Baroda, 1952).

10. Distinguish between first class coursed rubble masonry and block-in-course masonry.
(b) How will you lower big dressed stone blocks below ground for the construction of a dock wall?
(c) Give the safe load on random rubble masonry constructed in lime mortar.
(University of Bombay, 1953).

11. (1) Classify the difference between uncoursed rubble and random rubble masonry. Draw sketches.
(2) How would you lift heavy dressed stones from ground to upper floors for construction.
(University of Bombay, 1954).

12. State the safe working strength of the following varieties of masonry with lime mortar and with cement mortar:
(1) Uncoursed rubble masonry
(2) Random rubble masonry
(3) Coursed rubble masonry
(4) Ashlar (trap) masonry
(5) Ashlar (granite) masonry
(6) Block-in-course masonry.

13. What are the different types of stone masonry used in building construction? Illustrate Block-in-course masonry for a 2 feet thick wall and state its characteristics.
(Gujarat University, 1953).

14. What type of stone masonry will you specify for the following:
15. Write brief specifications for first class random rubble masonry for an important building making special reference to the construction of door and window jambs. Draw sketches showing the masonry in plan, section, and elevation.


17. Briefly describe and illustrate with sketch if necessary what is meant by the following terms:
   (a) King closer
   (b) Plinths
   (c) Lacing course
   (d) Dingling
   (e) Lorrying

18. In masonry jointing, briefly describe the function and give detail sketches of:
   (a) Cement joggle
   (b) Metal cramp
   (c) Slate cramp
   (d) Saddled joint.

19. Describe the various kinds of appliances used for lifting stones in stone masonry supported by neat sketches.

20. Compare the merits and demerits of stone masonry and brick masonry.
CHAPTER III

MASONRY—BRICK MASONRY

The art of construction in brick is called brick masonry. Brick masonry may be built in either cement mortar, lime mortar or mud. Brick masonry in mud is known as Kutcha-pukka masonry, and is frequently utilised for economy in inferior classes of work. Lime mortar is very commonly used for all kinds of work. For superior work cement mortar is generally used, as brickwork built in cement mortar is much stronger than that built in lime mortar. It is also used for general walling, especially if built during cold weather, as it sets more quickly than lime mortar and the work is therefore less liable to damage from frost.

General principles to be observed in brick masonry construction: Most of the general principles of stone masonry, given in Chapter II., are also applicable to brick masonry. The important ones are, however, given here for the guidance of students.

1. Qualities and dimensions of bricks: Bricks should generally be hard, durable, rectangular and parallel in shape and uniform in size, flat, but not too smooth as to prevent adhesion of mortar, free from stones, and from lumps of lime and cracks, and without twist, warp, bend or excessive. The colour of the bricks should be uniform and the structure should in all cases be uniform and compact.

Bricks should not absorb more than one-sixth of their weight if left in water for twenty four hours or one day. The hardest bricks will sometimes absorb as little as one-fifteenth.

The use of bats should be avoided except when they are required as closers for securing the necessary bond.

2Cement mortar is sometimes referred to as compo, and in some places this is also applied to a mixture of sand, lime and cement.

Cement grout is cement mortar which has been reduced to a thick liquid consistency by the addition of sufficient quantity of water.
Bricks in common use vary in size from 8\(\frac{1}{2}\)" to 9" long by 4\(\frac{1}{2}\)" to 4\(\frac{3}{4}\)" wide by 1\(\frac{1}{2}\)" to 3\(\frac{1}{2}\)" thick. The following sizes are recommended in the British Standard Specification (No. 657-1936) for clay facing and backing bricks:

- Maximum length, 8\(\frac{3}{4}\)" in.; minimum length, 8\(\frac{1}{2}\)" inches.
- Maximum width, 4\(\frac{1}{4}\)" inches; minimum width, 4\(\frac{3}{8}\)" inches.
- Maximum depth or thickness, 2\(\frac{1}{16}\)" in.; minimum thickness, 1\(\frac{11}{16}\)" inches.

The length of a brick should be twice its width plus the thickness of one vertical joint in order that proper bond may be maintained.

**Method of measurement:** The bricks laid dry shall measure as follows:

(a) Eight bricks laid end to end, in contact, in a straight line.
   - Maximum length 71 inches; minimum length 69 inches.
   - Maximum length 34 inches; minimum length 33 inches.
   - Maximum length 16\(\frac{1}{2}\) inches; minimum length 15\(\frac{1}{4}\) inches.
   - Maximum length 21\(\frac{1}{2}\) inches; minimum length 20\(\frac{3}{4}\) inches.
   - Maximum length 23\(\frac{1}{4}\) inches; minimum length 22\(\frac{1}{2}\) inches.

2. **Wetting of bricks:** All bricks should be completely saturated in water before they are used in masonry in order to prevent them absorbing the moisture from the mortar, and also to remove all loose dust from the surfaces that are to be in contact with the mortar. The cessation of air bubbles coming out of the water in which bricks are immersed, is an indication of complete saturation. Merely spraying with a hose is quite inadequate.

3. **Beds:** The beds of the courses should be perpendicular to B. C. 14.
the line of pressure which the brick masonry has to bear, care should be taken to see that the bricks are well bedded in mortar.

4. Bond in brickwork: A good bond should be secured throughout the masonry work.

5. Joints: Considerable care should be exercised to get a uniform mortar joint throughout the masonry work, and the thickness of the mortar joint should not exceed $\frac{1}{8}$ to $\frac{3}{16}$ inch. Every joint must be thoroughly filled with mortar. Bricks should be floated and pressed into position in mortar, which should surround each brick.

6. Laying of bricks: Unless brick-on-edge is specified, all bricks must be laid on their proper beds. Bricks having only one frog should be laid with the frog uppermost so as to ensure it being completely filled with mortar. Sometimes the brick layers place the bricks with the frog at the bottom in order to save mortar, but this should be avoided. Machine-pressed bricks, having two frogs, should have the "lower" frogs filled with mortar before being laid in position.

7. Testing verticality: The faces of the wall should be constructed truly vertical, and their verticality should be tested by a plumb-rule. If the wall has got a batter, it should be tested with a wooden template and a plumb-bob. A spirit level may also be used.

8. Axis of the load: Generally the load or weight should act axially and centrally on masonry sections.

9. Wetting the bed for new work: In building either on dry work or on old work, the upper surface must be well cleaned and wetted before mortar is laid over it, to form a bed for the new work. This will ensure a satisfactory joint between the old and new work.

10. Construction of buttress etc: If any buttress or counterfort is to be built, it should be constructed along with the original work and not added later on. See Figs. 206 to 209.

11. Racking back: If the full length of a wall is not constructed at once, the work should not be left off with a vertical end AB (see Fig. 324), but should be set back $\frac{1}{2}$" inches at each course, to reduce the possibility of any settlement that may take
place in the most recently built portion of the wall. The racking back also saves the foundation from cracking when the weight of the new portion settles down.

12. Tothing: When a main wall is to be connected at

![Diagram](image-url)

Fig. 324 to 327
Some future time with a cross wall, recesses, called toolings, should be left in the alternate courses in order to allow the new work to be bonded well to the old. See Fig. 325.

The common practice in joining new cross walls to old main walls is to cut out a number of rectangular recesses in the main walls equal in width to the width of the cross wall, three courses in height, and half a brick in depth, a space of three courses being left between the sinkings; the new cross wall is then bonded into the recesses with cement mortar to avoid any settlement. This is called block-bonding. See Fig. 326.

13. Thickening: When an old wall is to be thickened, recesses of 9" x 9" x 4½" should be cut in the old wall, at one for every square yard. The new work should then be built in cement mortar against the old and block-bonded to it at every recess. The surface of the old work should be well cleaned, brushed and wetted before the new work is added. This is also called block-bonding. The method of thickening a wall is illustrated in Fig. 327.

14. Fixing timber to brickwork: Timber should not be built into the substance of brickwork, as it leads to the decay of timber. Wooden plates, for the end of joints, rafters, etc., should be carried on corbels of brick, stone or iron brackets built into the wall. Woodwork let into, or supported on, walls should be well tarred or painted.

15. Prevention of unequal settlement: No part of a wall during its construction should rise more than 3 feet above another to avoid the danger of unequal settlement. Generally, the entire length of a wall should be raised uniformly.

16. Watering brickwork: The entire brick masonry work should be kept wet until the mortar is set and become hard, care being taken to see that the mortar in the joints is not washed away while watering. Watering should be done for one to three weeks when lime mortar is used, and for one to two weeks when cement mortar is used.

17. Building during frosty weather: As a rule, brickwork should be suspended during frosty weather, as the stability of the same is endangered by the disintegration of the mortar by
the frost while it is wet. When the work is very urgently required it should be built in cement mortar, as it sets more rapidly than lime mortar. The entire work should be carefully covered and protected on any recurrence of the frost, and always during the suspension of work for the night.

18. Protecting brickwork: Generally mortar joints are the weak portions in masonry, and hence the exposed faces of brickwork should be covered by a rendering coat of plaster in order to protect them from the atmospheric influences, and also to give them a good appearance. Sometimes the vertical and bed joints may only be solidly filled and pointed well if the bricks used in the work are of a perfect durable quality to withstand the destructive effects of atmosphere.

Bonds in brickwork: The definition of the term "bond" is given elsewhere. Due to the uniform size and shape of bricks, a proper bond can easily be maintained by using systematic methods of laying bricks. The advantage of adopting a systematic method is that the work can be done in a short period, and more masons can be put on a job at a time. The arrangement may be varied according to the appearance required on the two faces. It is usual to lay as many headers as possible in the interior, except that in thick walls raking bond (see Figs. 400 and 501) is occasionally used. To ensure good bond, the following points should be noted:

(i) The arrangement of the bricks must be uniform.
(ii) As few bats as possible should be used.
(iii) The vertical joints in every other course must be perpendicular both to the external and internal faces.
(iv)Stretchers should be employed only on the faces of the walls, and the interior should be filled up with headers only.
(v) All the bricks should be rectangular and uniform in size. Generally the dimensions of bricks should be such that when bedded the length should equal twice the width plus one mortar joint.

An unbonded wall, with its continuous vertical joints, has little strength and stability and such joints must be avoided. The comparative strength of a bonded wall and weakness of an unbonded wall are illustrated in Figs. 328 and 329. The portion of the
load transmitted to the wall, shown in Fig. 328, is distributed over a relatively larger area, as indicated within the dotted lines A and B, whereas that transmitted to the wall, shown in Fig. 329.

![Diagram showing load distribution]

**Fig. 328 and 329**

**SHOWING THE COMPARATIVE STRENGTH OF A BONDED WALL AND WEAKNESS OF AN UNBONDED WALL**

is practically concentrated on the portion between the continuous vertical joints C and D, with the result that this portion may tend to drop as shown in figure.

A bond is ordinarily identified by the appearance of the external face of the wall. Thus the expression "alternate courses of headers" refers to the arrangement of the bricks on the face, even if the headers in each course are backed by stretchers. In drawings, joints are generally indicated by single lines.

**Types of bond**: The following types of bond are employed in brickwork:

1. English bond.
2. Flemish bond.
3. Heading bond.
5. Garden wall bond.
English bond and Flemish bond are generally employed than other types of bond.

1. **English bond**: The following particulars apply to the English bond:
   - (a) English bond is also known as old English bond.
   - (b) It consists of *alternate courses* of headers and stretchers. (See Fig. 330).
   - (c) In every heading course a queen closer is placed next to the quoin header and the remaining bricks are headers. (see Q, Fig. 330). Sometimes, instead of the queen closer in this course,

![Fig. 330](image)

**Fig. 330**
**FRONT ELEVATION OF A BRICK WALL CONSTRUCTED IN ENGLISH BOND**

A three-quarter brick is used to begin the stretching course (see Fig. 331). A heading course should not be commenced with a

![Fig. 331](image)

**Fig. 331**
**FRONT ELEVATION OF ENGLISH BOND WITHOUT CLOSERS**
queen closer, for, in this position it would be liable to displacement.

d) Generally there are no continuous vertical joints.

e) At least every alternate transverse joint is continuous.

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**Figures 312 to 337**

**Alternate Plans of 1, 1A, 2, 2A and 3 Brick Walls in English Bond**
Fig. 335; a stretcher course of a 2 bricks wall is formed of units having a stretcher on each face with two headers in the middle (see dotted lines, Fig. 337).
Walls of an odd number of half bricks in thickness will show each course consisting of headers on one face and stretchers on the other. See Figs. 334, 335, 338 and 339.

Walls of an even number of half bricks in thickness present the same appearance on both external and internal faces, i.e., a course consisting of stretchers on the front elevation will show stretchers on the rear elevation. (See Figs. 332, 333, 336, 337, 340 and 341.)

Walls having a thickness of 2 bricks or more, the middle portion is thoroughly filled with headers (see Figs. 335 to 341). This prevents the formation of vertical joints in the body of the wall. Thus for thicker walls more headers are used than the corresponding number of stretchers. This deficiency of stretchers practically weakens the wall in the longitudinal direction, and is set right by the adoption of diagonal bond in the interior of the wall.

(i) As the number of vertical joints (also known as side joints) in the heading course is twice the number of joints in the stretching course, all the joints in the former course are made thinner than those in the latter, approximately in the proportion of 1:1.3.

Alternate courses of 1, 1½, 2, 2½ and 3 brick walls in English bond are shown in Figs. 332 to 341, and their cross sections in Figs. 342 to 345. A two and a half brick wall in English bond is shown in isometric view in Fig. 347, and the locations of closer bricks are indicated by hatched lines.

(2) Flemish bond:—The following particulars relate to the Flemish bond:

(1) Flemish bond consists of alternate headers and stretchers in every course—that is, each course contains both headers and stretchers, the headers of one course being central between the stretchers of the adjacent course. Thus it is evident that each header comes centrally over a stretcher and, unlike English bond, no header comes over a vertical face joint. See Fig. 348.

(2) Every alternate course is commenced with a header at the corner (see Fig. 348.)

(3) In every alternative course a queen closer is placed next
to the quoin header so as to provide a lap of approximately 24".

Fig. 342 to 346
CROSS SECTIONS OF 1, 1½, 2, 2½, AND 3 BRICK WALLS
CONSTRUCTED IN ENGLISH BOND

Fig. 347
ISOMETRIC SKETCH OF A 2½ BRICK WALL IN ENGLISH BOND
This agrees with the rule for English bond. But a stretcher is placed next to this queen closer which is then followed by a header and a stretcher alternately.

**Fig. 348**

**FRONT ELEVATION OF A BRICK WALL CONSTRUCTED IN FLEMISH BOND**

In walls having a thickness equal to an uneven number of half bricks, half bricks are required to be used. These constitute the objections to this form of bond. Half bricks are known as "false headers or false stretchers."

The Flemish bond may be classified into two classes, viz.,

- **Double Flemish bond**
- **Single Flemish bond**

(a) **Double Flemish bond** — This has headers and stretchers alternately in the same course, both in front and back elevations. It is not as strong as English bond because of the large number of short continuous vertical joints (see the thick lines shown in Figs. 349 to 354) which occur in the longitudinal joints. But double Flemish bond has a more pleasing appearance, and is more economical than English bond as a good number of bricks can be used for the work. By using double Flemish bond for walls one brick in thickness, it is easier to obtain a fair or uniform face on both sides than with the English bond. The reason for this is that the stretchers faces of bricks vary in length owing to the unequal shrinkage which may occur during the burning process and thus the combined length of two headers together with the thickness of a vertical joint is more than the length of a stretcher. Consequently when a one brick wall is built in English bond one face is fair but the opposite face shows each heading course set back
slightly in relation to the stretching course; this irregularity does not occur if the wall is constructed in Flemish bond as each course

Fig. 309 to 354
Alternate Courses of Brick Walls in Double Flemish Bond with Square stopped ends.
Continuous Vertical Joints are shown in thick lines
consists of alternate headers and stretchers, and therefore the slight set back of the short headers is better distributed and is considered to improve the surface texture or character of the work.

First and second courses of 1, 1½, 2, 2½ and 3 brick walls in double Flemish bond.
The first and second courses of 1, 1½, 2, 2½ and 3 brick walls in double Flemish bond are shown in Figs. 355 to 364, and their cross-section in Figs. 365 to 374. A two brick wall in double Flemish bond is illustrated in isometric view in Fig. 375. The location of closer bricks are indicated by hatched lines.

(b) Single Flemish bond:—This consists of a facing of
Flemish bond with a backing of English bond in each course. This combination is made in order that the work may, on the face, look like Flemish bond, the appearance of which is considered superior to that of the English bond, and at the same time, to get rid of the defects of Flemish bond in the interior of the wall, but this is questionable. It is also employed where very expensive facing bricks are required to give the characteristic appearance of Flemish bond and where comparatively cheaper bricks are used as a backing. This bond cannot be adopted to walls which are less than 1½ brick thick. In this type of bond 9 in. or one brick long continuous vertical joints appear in the longitudinal direction and thus considerably weak in strength (see Figs. 376 to 379).

Plans of two courses and sections taken at two points of walls of different thicknesses in single Flemish bond are shown in Figs. 380 to 391. The front elevations are the same as in double Flemish bond. A two and a half brick wall in single Flemish bond is shown in isometric view in Fig. 392. The locations of closer bricks are indicated by hatched lines.

It will be noticed that snap or false headers are employed in alternate stretching courses throughout the Flemish facing. These can be avoided; but they are more convenient and economical, and are, therefore, generally preferred though their adoption sometimes leads to bad work in more ways than one.

Comparative merits and demerits of English bond and Flemish bonds:

(1) The English bond is stronger than Flemish bond for walls thicker than 1½ bricks. For walls of 1 brick or 1½ bricks thick, the two bonds have practically equal strength.
(2) The Flemish bond has a better appearance on the face than the English bond, as headers and stretchers are alternately used.
(3) The Flemish bond admits of the use of a large number of bats, and in this respect it is economical.
(4) To construct the wall in Flemish bond, greater care is required by the workman in order to keep the "perpends", that is, to keep each vertical joint in any one course directly over the corresponding vertical joint in the course next but one below.
A neglect of this precaution detracts considerably from the appearance of the finished work. Consequently only experienced men are to be posted to get a satisfactory work and this involves extra cost.

Figs. 365 to 374
CROSS SECTIONS OF 1, 1\'\, 2, 2\', AND 3 BRICK WALLS
CONSTRUCTED IN DOUBLE FLEMISH BOND.

3. **Heading bond:** In this bond all bricks are laid as headers on the face except that a three-quarter bat is used at quoin, in alternate courses to break bond. The bond is weak along the length of the wall. This is chiefly used for rounding 9. C. 15
First and Second Courses of Single Flemish Bonded Brick Walls with Square Stopped Ends. Continuous Vertical Joints are shown in Thick Lines.
curves, for footings, corbels and cornices. This bond is illustrated in Figs. 393 to 395.

4. Stretching bond—In this bond all bricks are laid as stretchers. It is used for half brick thick, such as partition walls, brick nogging in partitions and in half-timbered work, and should
not be used for walls of greater thickness, as it creates no internal bond. The stretching bond is also known as "running bond" or "chimney bond" and is illustrated in Figs 396 and 397.

5. Garden wall bond:—As its name implies, this bond is suitable for garden, boundary and other similar walls which
usually do not exceed one brick in thickness. Bricks vary more in length than in breadth, and owing to the variation in the

Fig. 392
ISOMETRIC SKETCH OF A TWO BRICK WALL IN SINGLE FLEMISH BOND

Fig. 393 to 395
PLANS OF FIRST AND SECOND COURSES

Fig. 396 and 397
STRETCHING BOND
lengths of bricks it is difficult to built a one brick wall in English bond if a fair or uniform face is required on both sides. This is overcome by using the garden wall bond in which the number of headers is minimised. Though garden wall bond is not so strong as English bond (the transverse tie being weak), it is sufficient for most dwarf walls and for those not required to withstand large stresses. Sometimes garden wall bond is used instead of stretching bond for the construction of the outer leaves of cavity walls. It has a good appearance, and on this account is greatly to be preferred to stretching bond. The garden wall bond is also known as 'boundary wall bond'.

There are two kinds of garden wall bond, i.e., (a) English garden wall bond and (b) Flemish garden wall bond.

(a) English garden wall bond (see Fig. 398): This consists of one course of headers to three or five courses of stretchers. As in English bond, a queen closer is placed next to the quoin header in the heading course. A header is introduced at the quoin of each middle course of stretchers to give the necessary lap and face appearance of stretching bond. This type of bond is very suitable for houses not exceeding two storeys in height.

(b) Flemish garden wall bond (see Fig. 399): This type is also known as Sussex bond and Scotch bond. It consists of one header to three or five stretchers in each course. A three quarter bat is introduced next to the quoin header in every alternate course, and a header is placed over the middle of each central stretcher.

Monk bond: This is a variation of Flemish garden wall
bond. It consists of one beader to two stretchers in each course.

**Fig. 399**

**FLEMISH GARDEN WALL BOND**

The header rests centrally over the joint between a pair of stretchers.

6. **Facing bond**: This bond is used where the thickness of the facing and backing bricks vary in size and shape, and where the facing bricks are expensive and it is necessary to economise. This bond consists alone of heading course to several stretching courses, the distance between the heading courses being the least common multiple of the backing and facing bricks, there should be at least one course of headers to every foot in height. For example, take the thickness of the backing bricks as 3 in. with mortar joints and that the thickness of the facing bricks as 2\frac{1}{2} in. with mortar joint; then the least common multiple is 15, and hence the heading courses should be spaced at 15 in. vertical distance.

The facing may be built in either English, Flemish or any suitable bonds, and the backing is built in English bond. Owing to the use of the different thicknesses of backing and facing bricks, the joints in the backing and facing vary, and consequently unequal settlement may happen between the two portions, which in due course may endanger the structure as a whole. Hence facing bond is used only in exceptional cases.

7. **Racking bond**: A characteristic defect in a thick wall built in English bond is a deficiency in the longitudinal bond due to the absence of stretchers in the body of the wall. This defect is generally remedied by using raking courses (rake=inclination) at regular intervals, of from four to eight courses in the height of the wall. There are two forms of raking bond, viz., (a) Diagonal
(212)

bond and (b) Herring-bone bond: In both forms of raking bond, the bricks in the interior of the wall are placed in directions oblique to the face. In both, alternate courses rake in opposite directions.

(a) Diagonal bond: This is generally employed in walls which are from two to four bricks thick. In this the face bricks are first laid, and then bricks are laid diagonally at such an angle with the face that the bricks will just fit in without being cut. The triangular spaces at the ends of the bricks are filled up with small pieces of brick cut to shape, as shown in Fig. 400.

Fig. 400
DIAGONAL BOND

(b) Herring-bone bond: This bond is best suited for walls which are at least four bricks thick. In this, the bricks are laid at an angle of 45° in both directions from centre. Like diagonal bond, alternate herringbone courses are reversed. Fig. 401

Fig. 401
HERRING-BONE BOND
shows the plan of herring-bone bond.

Diagonal and herring-bone patterns are often used to form ornamental panels in the face of walls, and also in floors paved with bricks.

Longitudinal bond:—This is an alternative to raking bond for increasing the longitudinal tie in thick walls. A course built in this bond consists entirely of stretchers with exception of a row of queen closers adjacent to each outer row stretchers. This bond may be used at every fifth course.

Zig zag bond:—This bond is similar to herring-bone bond, and is illustrated in Fig. 402. This bond is used only for panels.

Fig. 402
ZIG-ZAG BOND

8. Dutch Bond:—This is a modification of English bond, which strengthens the angle. The bond consists of alternate courses of headers and stretchers, but each stretching course commences at the quoins with a three-quarter bat, and every alternate stretching course has a header introduced next to the quoins three-quarter bat. The elevation of Dutch bond is shown in Fig. 403.

Fig. 403
DUTCH BOND

9. English cross bond:—This is also known as St.
Andrews Cross bond, and is similar to English bond. The bond consists of alternate courses of headers and stretchers, with queen closers next to the quoins headers. Each alternate stretching course has a header introduced next to the quoin stretcher. This causes the stretchers to break joint in alternate courses. Fig. 404 shows the elevation of English Cross bond.

10. Brick on-edge bond:—This differs from ordinary bond, the bricks being laid on edge and not on bed. It is economical, as compared with English bond, considerably fewer bricks and less mortar are required. Its strength is deficient, and the appearance is also unsatisfactory. Only wire-cut bricks are used in this bond. This bond is sometimes used for garden and similar walling, and occasionally for walls of small houses. It is frequently employed in the construction of partition walls. There are two best known forms of brick-on-edge bond, viz. (a) Rat-trap bond and (b) Silverlock’s bond.

(a) Rat-trap bond (see Figs. 405 and 406):—In this bond all the bricks are placed on edge, and are arranged to give an appear-
(235)

ance of Flemish bond. Each alternate course (A) begins with a three-quarter bat, followed by a header, and each alternate course (B) commences with a header, succeeded by a stretcher. As indicated on the plans, there is a 3 in. cavity between each pair of stretchers, except at the jambs, which are solid. It is found that, compared with a one brick solid wall, a rat-trap bonded wall shows a saving of nearly 25 per cent. Occasionally 9 in. rat-trap bonded walls are built solid, the cavity being filled with stretchers placed on edge.

(b) Silverlock’s bond (see Figs. 407 and 408):—This bond consists of alternate courses of headers and stretchers, but the headers are placed on bed and the stretchers are laid on edge with a continuous cavity between as shown. The jambs are solid, and a three-quarter bat is introduced at the beginning of each heading course to secure necessary bond. Though this is stronger than rat-trap bond, it is not so economical.

Quoins or External angles:—There are several connections made between walls. One type of connection is known as junction and another form is known as a quoin. There are two forms of quoins, i.e., right-angled or square quoins and squint quoins.

As implied, a right-angled quoin is formed by two walls which meet at 90° and it is most commonly employed in buildings. See Figs. 332 to 341, 347, 355 to 364, 375, 380 to 383, 388, 389, 392 and 396.

Squint quoins are of two forms, viz., (a) obtuse and (b) acute
Examples of obtuse squint quoins are shown in Figs. 409 to 412, and acute squint quoins in Figs. 413 to 420.

Figs. 409 and 410

OBTUSE ANGLE IN ENGLISH BOND

Figs. 421 and 422 show bonding that can be adopted in the construction of bay windows. The key plan of a bay window is shown.

Figs. 411 and 412

OBTUSE ANGLE IN DOUBLE FLEMISH BOND

ACUTE ANGLE IN ENGLISH BOND

in Fig. 423. Squint quoins are rarely employed.
The above are only a few examples of squint quoins. There are a number of alternatives. The aim should be to obtain the maximum lap with the minimum of cutting. Whilst the correct

Figs. 417 and 418
FIRST AND SECOND COURSES SHOWING BIRDSMOUTHED ACUTE SQUINT QUOIN IN ENGLISH BOND

Figs. 419 and 420
FIRST AND SECOND COURSES SHOWING BIRDSMOUTHED ACUTE SQUINT QUOIN IN DOUBLE FLEMISH BOND
face appearance is not necessary if the walls are to be plastered, the principles of sound bonding should be observed and continuous straight joints avoided.

Figs. 421 and 422

ARRANGEMENT OF BRICKS FOR BAY WINDOW

Bond at the Junctions of main and cross walls:—Junctions are classified into right-angled junctions and squint junctions. Most junctions between walls are right-angled junctions, and squint or oblique junctions are rarely called for.

Fig. 423

KEY PLAN OF A BAY WINDOW

Right-angled Junctions:—There are two forms of right-angled
( 239 )

junctions, viz., (a) Tee-junctions and (b) Cross-junctions or intersections.

(a) Tee-junctions:—A tee junction is a connection between two walls which on plan is in the form of the letter T. Plans of tee-junctions between walls constructed in English bond are shown in Figs. 424 to 429. In Fig. 424, one of the courses of the 2 brick or 4½ in. internal wall enters the stretching course of the

![Diagram of Tee Junction between 4½ in. and 9 in. Walls in English Bond](image1)

In Fig. 426 and 427, the heading course of the external main wall. In Fig. 426, the heading course
of the internal wall is bonded into the stretching course of the external main wall, the first header or tie brick (indicated by hatched lines), giving a 2½ in. lap and being adjacent to a queen

![Diagram](image.png)

**Fig. 428 and 429**

**The Junction Between 13½ in. and 18 in. Walls in English Bond**

closer. In Fig. 428, the stretching course of the cross wall butts against the heading course of the external main wall.

Plans of junctions between external main walls built in double Flemish bond and internal walls built in English bond are shown in Figs. 430 to 433. Plans of junctions between single Flemish external main wall and English bonded internal wall (or party wall) are shown in Figs. 434 and 435.

(b) Cross-junctions or intersections:—A cross-junction is an intersection between two continuous walls. Plans of cross-junctions between walls built in English bond are shown in Figs. 436 to 439. Note the following particulars in connection with these figures: (i) one of the courses is continuous and the course at right-angles butts against it; (ii) these continuous courses alternate; (iii) a key header forms a 2½ in. lap at each side of the non-continuous course.

2. Squint or oblique junctions:—Some typical examples of squint junctions in English bond are shown in Figs. 440 to 443. Note down the following points in connection with each case: (i) the heading course of the squint wall is bonded into the stretching course of the main wall; (ii) the alternate stretching course of the squint wall butts against the heading course of the main wall,
Some equit junctions in double Flemish bond are shown in Figs. 444 to 447. In this type of work the amount of cutting necessary to avoid continuous vertical joints should be kept to a minimum.

The above are only a few examples of several methods of bonding at junctions. The aim should be to obtain a good bond with the adoption of the minimum number of broken bricks.

**Fig. 430 to 433**

**JUNCTIONS BETWEEN DOUBLE FLEMISH BONDED EXTERNAL WALLS AND ENGLISH BONDED INTERNAL WALLS**

**Bonds for brick piers or pilasters:** Some particulars regarding brick piers are given on page 156. A plan of portion of a building in which piers are employed is shown in Fig. 448. Maximum strength is obtained if piers are built with first class bricks in English bond. Generally cement mortar is used for brick piers.

The bonding of isolated or detached brick piers, in English and H. C. 16
double Flemish bonds is shown in Figs. 449 to 467 and 468 to 481 respectively. A stone pad or template is usually provided at the top of a pier to ensure a firm bed for a beam or roof truss, and to distribute the load effectively. Piers may be formed with rounded arrises by using bell arch bricks.

A circular brick pillar constructed with sector shaped bricks is shown in Figs. 482 to 484. In these pillars, bond stones of 4 to 9 in. in thickness are frequently employed at intervals of about 3 feet to strengthen the pillar as shown.

A typical example of a detached octagonal pier is shown in Figs. 485 and 486. Hexagonal shaped piers are also sometimes used.

An example of a foundation suitable for a detached pier is shown in Figs. 116 to 120.

Some typical examples of attached piers or pilasters built in English and double Flemish bonds are shown in Figs. 497 to 499 and 493 to 498 respectively. Rounded arrises may be obtained by employing bell arch bricks. The stability of walls is increased by...
the adoption of these piers at regular intervals, and like those of
the detached or isolated type they may be used as supports for

\[ \text{Fig. 436 and 437} \]

**Cross Junction between 9 in. and 13\(\frac{1}{2}\) in. Walls in English Bond**

Concentrated loads. The projection of the attached pier is usually
4\(\frac{1}{2}\) in or 9 in.

**Buttresses** are also piers, which are explained on page 155.

**Bricklayer's tools**:
The tools generally used by a bricklayer are: straight edge, level, brick axe, trowel, plumb-bob, plumb-rule, line and pins, square, spirit level, two-foot rule, bolster, club hammer, and saw.

**Straight-edge**:
This is a piece of wood, about 3 in. by 6 in. by 3 ft. long having parallel edge. It is used for testing brickwork (especially at quoins) and checking if faces of bricks are in alignment. Longer straight-edges are used for leveling concrete, etc.
Figs. 438 and 439
CROSS JUNCTION BETWEEN 13\(\frac{1}{2}\) IN. AND 18 IN. WALLS IN ENGLISH BOND

Figs. 440 and 441
SQUINT JUNCTION BETWEEN 9 IN. AND 13\(\frac{1}{2}\) IN. WALLS IN ENGLISH BOND
Fig. 442 and 443
SQUINT JUNCTION BETWEEN 13\frac{1}{2} IN. AND 13\frac{3}{4} IN. WALLS IN ENGLISH BOND

Fig. 444 and 445
SQUINT JUNCTION BETWEEN 9 IN. AND 13\frac{1}{2} IN. WALLS IN DOUBLE FLEMISH BOND

Fig. 446 and 447
SQUINT JUNCTION BETWEEN 13\frac{3}{8} IN. AND 13\frac{1}{2} IN. WALLS IN DOUBLE FLEMISH BOND
Gauge-rod or Storey rod:—This is similar to the straight-edge but \(4'' \times \frac{3}{4}'' \times 9''\), upon which the courses, including the joints, are marked by horizontal lines: courses which conform with the tops and bottoms of window sills, springing points of arches, etc. are also indicated on the gauge. This is used at quoins in setting out the work and ensuring that the courses are maintained at correct level and uniform thickness.

Bevel:—This is used for setting out angles, and is illustrated in Fig. 499.

Brickaxe:—This is used for cutting bricks to the required shape, and is illustrated in Fig. 500.

The remaining tools are described on page 165.

Method of construction of a brick wall\(^1\):—The corners, called leads, are first constructed to a height of 1 to 3 feet, and the base of corners is extended in steps. The walling between the corners is then completed course by course. Generally the height of the corners should not be more than 3 feet.

---

\(^1\) The setting-out of buildings is described on page 139.
Each quoin is set truly vertical by placing on edge of the plumb-rule against one of the faces, any adjustment of the bricks being made until the cord coincides with the gauge-line marked down the centre of the rule; the return face is then plumbed. The gauge-rod is used to ensure that the brick courses and joints are correct and of uniform thickness. Two strings are then stretched between the two leads so as to mark the two external upper edges of the course to be built. Each course is now constructed with the aid of the strings.

 Bonding of Detached Piers in English Bond

In building a wall, sufficient quantity of mortar is collected on the trowel and is spread evenly on the lower course already laid. The point of the trowel is then pressed into the mortar, and the trowel is drawn in zig-zag fashion along the centre of the layer to form a level and uniformly thick bed. A brick is taken, set in position, and pressed into the mortar against the last laid brick, until mortar squeezes out at the joints and fills all voids; a smart
Figs. 464 and 465
ALTERNATE COURSES OF THREE AND-A-HALF BRICK PIER IN ENGLISH BOND

Figs. 466 and 467
ALTERNATE COURSES OF FOUR BRICK PIER IN ENGLISH BOND
BONDING OF DETACHED PIERs IN DOUBLE FLEMISH BOND

ALTERNATE COURSES OF THREE AND A-HALF BRICK WALL IN DOUBLE FLEMISH BOND
tap with the edge of the trowel or the end of the handle may be necessary to bring the brick into line. The mortar which has been squeezed out beyond the face of the wall is cut off by a trowel and the same is collected on to the trowel and returned to the heap nearby.

**Fig. 482 to 484**

**CIRCULAR BRICK PILLAR**
**CONSTRUCTED WITH SECTOR-SHAPED BRICKS**

In the construction of thick walls, mortar is spread on the bed and the outer bricks on both faces are first laid as described above; the inner bricks are then placed, in position by pressing and gently moving them horizontally so as to cause some of the mortar to rise between the vertical or side joints, which are finally filled flush with liquid mortar or grout.

All the bricks should have been well wetted before being placed in position in order to prevent them from absorbing moisture from the mortar as already stated. *Perpends* must be kept vertical. The principles given on page should be strictly observed during the construction of brick masonry.

*Certain smooth-surfaced machine-pressed bricks should not be watered, otherwise they are difficult to lay.*
After the intermediate portion is filled with brick courses, beams are again raised to a height of about 1 to 3 feet, and the process is repeated until the required height of wall is obtained. When the wall is built to a height of about 4 to 5 feet, the brick layers (or masons) require some kind of raised platforms for the full length of the wall to proceed with the work vertically. The raised platforms are called scaffolding, the details of which are given in chapter 2, page 139.

Alternate Plans of Attached Piers in English Bond

Thickness of brick walls:—The strength and stability of a brick wall largely depend upon the thickness to which it is built up, assuming that other factors such as the type of bricks, mortar, bonding and workmanship are satisfactory. The thickness of the walls must be sufficient to withstand the forces or loads acting on
Generally there are three kinds of forces acting on the wall, i.e., (1) Dead load, (2) Live load and (3) Wind load. Of these, dead load and live load act vertically, and the wind load acts obliquely. The vertical load, when acting along the centre line of the wall, is known as concentric load, and it produces uniform compression in the material constituting the wall. An eccentric load has its point of application away from the centre line, and it produces greater compression on the edge to which the load is nearer and smaller compression on the other edge. The values of the maximum and minimum compression at the extreme edges...
of the wall are given by the following formula:—

\[
\text{Stresses at the extreme edges in tons: } \frac{P}{t} \left( 1 + \frac{6a}{t} \right)
\]

where \( P = \) Load in tons per running foot of the wall,
\( t = \) Thickness of the wall in feet,
\( a = \) Eccentricity of the load, that is, the distance of its point of application from the centre line of the wall.

Taking the negative value, since no tensile stresses are allowed in masonry, the allowable eccentricity is restricted to \( \frac{1}{6}t \) where \( t \) is the thickness of the wall, i.e., the thickness of a wall should be six times the eccentricity.

For a circular section of masonry, the allowable eccentricity for an axial load is \( \frac{d}{8} \) where \( d \) is the diameter of the column.

The positive sign gives the maximum direct stress at the outer faces of the wall. This should not exceed the safe permissible limit specified for the material of the wall.

Wind pressure and its effect on walls:—Wind pressure acts on walls in a direction transverse to their axis, and consequently produces bending and sliding effect on the walls. Bending produces tensile stress on the outer face and compressive stress on the inner face. Sliding produces shear stresses. The tensile and compressive stresses, due to bending, are calculated by the following formula:—

\[
\text{Tension or compression} = \frac{Bending \ moment \ in \ ft. \ tons \times t}{6}
\]

Where \( t \) is the thickness of the wall in feet.

1 As the brick masonry wall is constructed of independent small units, it should not be stressed to bending or tensile stresses. Otherwise, the cohesion between these small units may be destroyed. Hence it should be stressed only in direct compression and shear, which should not be more than the safe stress limit, allowable for that class of masonry.
The cumulative effect of stresses due to the vertical load and bending should be taken into account while designing a wall and testing it for stability.

Though the thickness of walls may be designed by calculation, it is not absolutely necessary to do so for walls of ordinary buildings. In the Bye-laws of various Municipalities and authorised local bodies dealing with similar matter are included tables giving the minimum thicknesses for different kinds of buildings. The thicknesses of walls provided in accordance with these tables are usually safe, as they are based on past experience. These thicknesses of walls, if necessary, may be corroborated by theory. The thicknesses of walls of domestic buildings and the thicknesses of walls for public or warehouse type buildings are prescribed by Bombay Corporation are given in Tables 12 and 13.

A solid wall and a hollow or cavity wall suitable for a four-storeyed domestic building are shown in Figs. 501 and 502 respectively.

Classification of structures:—There are chiefly three systems of building a structure, viz., (1) Load bearing structure, (2) Framed structure and (3) a combination of these two.

1. Load bearing structure:—The load bearing structure or simply bearing structure consists of load-bearing walls, the latter being constructed on a continuous foundation. The beams, trusses, or other heavy parts and fittings in the walls are always made to rest on load-bearing walls. Thus load-bearing walls support the entire load, including their own, and hence they should be carefully designed to support the loads to be carried by them.

2. Framed structure: In a framed structure a number of piers or columns is erected on its own independent foundation, and is braced together by beams and floors. In this way the whole structure is constructed, and the gaps between the piers or columns are filled with walls which are called panel, curtain, screen or filler walls. The panel or filler walls are primarily intended for screening and partitioning with a view to enclosing a space for privacy. They carry no superimposed load and are only strong enough to support their own weight. The entire load on the structure—both live and dead—is carried by the frame.
Brick, hollow or solid pre-cast blocks, and such other lightweight materials are used for the construction of panel walls.

**Figure 501 and 502**

**SHOWING A SOLID AND A CAVITY (OR HOLLOW) WALL SUITABLE FOR A FOUR-STOREYED DOMESTIC BUILDING**

From the above it is evident that the floors and walls transfer their loads to their supporting beams, which in their turn, by
# Table No. 12

**Thickness of masonry walls of domestic buildings**

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<th>Story Height above Finish Fl.</th>
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**Table No. 13.**

 Thickness of masonry walls for public or warehouse type buildings

 Thickness of wall in inches.
virtue of their resting on piers or columns, transfer their loads to them. The columns or piers then finally transfer the loads to the soil below.

In designing the frame and foundation, the effect of wind load should be taken into account. The framework must be made rigid and strong enough against bending, twisting or buckling by properly situated struts and braces from bottom to roof. The braces must not cause an obstruction in the open spaces. In the case of factory buildings the cross bindings should be so located as to be helpful for fixing shaftings, runners, carriers, steam, gas, water, electricity and air-conditioning services. In all such cases the amounts of inclined stresses generated in the vertical members must be carefully calculated, particularly the columns and stanchions, to accurately design their footings and foundations. Proper care should be taken to secure good bondage between the members of the frame and the panel walls.

Advantages of framed structures:—

Framed structures have some advantages over bearing structures. They are given below:—

1) The work of several building trades can be kept in progress at a time. The framework of the building can be kept in progress on the upper floors and the walling and the other finishing work can be carried on the lower floors. Thus a greater number of persons can be put in job, and this results in a greater speed of erection.

2) An increased floor space may be obtained as piers or columns and panel walls are constructed.

3) Subsequent additions and alterations can be easily made to the structure.

4) Framed structures are best suited to resist vibrations of machines such as in factories, earthquakes, etc.

5) Large rooms can be obtained for factories, etc.

6) The classification load-bearing and non-load-bearing members enables cheaper materials to be employed for the latter where strength is not the criterion.

7) In made-up soils and for pile foundations, framed structures are best suited.
In the case of multi-storeyed buildings, stereo-typed construction work from floor to floor is always economical. Framed structure admits of such a design, and if it is of R.C.C., the form work for slabs, beams and columns can be used several times.

There are four materials commonly used for the construction of the frame work of a building, viz., (1) Wood, (2) brick, (3) steel and (4) R.C.C. The first one is used for cheap and temporary work whereas the last three are used for permanent work. The brick is not as strong as either steel or R.C.C., and hence it is not suitable for heavy buildings. In large buildings the frame consists of mild steel or R.C.C. A frame of R.C.C. has the following advantages over a steel frame:—

(i) An R.C.C. frame is cheaper than a steel frame.

(ii) The construction is easy, as there are no joints to be riveted, welded or bolted.

(iii) An R.C.C. frame is more durable and not affected by weather conditions.

(iv) An R.C.C. frame is fire-proof. But a steel frame is not completely fire-proof and it is subject to corrosion.

(v) Steel is embedded into concrete and is thus better protected. A steel frame, on the other hand, requires to be occasionally painted at a considerable recurring expense.

(vi) Even the panels or filler walls can be interconnected with the columns and beams, and thus the whole structure becomes monolithic.

R.C.C. construction is discussed in a separate chapter.

3. The third type of framed structures is a combination of the two, which is commonly employed for buildings of residential type. This consists of bearing walls on the outside and a frame of columns and beams with one end resting on the bearing wall, and the other on the inner columns with thin partitions between the latter.

General:—In residential and public buildings the external walls may be constructed to a thickness of 14" for the purpose of safety. All other internal walls are treated as light non-load bearing partitions to suit the internal requirements. In practice it is found that 6 in. thick walls of bricks plastered on both sides or plain and decorative hollow concrete blocks are best suited. The
thickness of partitions is sometimes reduced to 4½ in. or half-a-brick.

Construction of fire-places. Fire-places are generally required in Kitchens and living-rooms of buildings constructed in cold regions. They are always a source of trouble, if not properly designed and constructed. The following points should be noted while designing the fire-places:—

1. Each open fire-place must be provided with a flue or duct for the removal of the smoke. A fire-place commonly requires greater depth than can be provided in the thickness of a wall. If the chimney in which the fire-place opening and flue are formed projects (and it usually does) it is called a chimney stack. The chimney must be well bonded to the adjacent wall and be provided with a proper damp proof course. The width of a chimney breast depends on the size and importance of a room. The thickness of the walls of a chimney stack should not be less than 4½ in. chimney stacks should be built in water-proofed cement mortar from the bottom-most point of intersection of the roof: the parging of the fire above this level should also be of this material. Parging is a mixture of cement, sand and cow-dung.

2. The head of a fire-place opening must be finished with either a stone or concrete lintel or a brick arch.

3. Woodwork (such as joists, etc.) shall not be built in a wall or chimney breast within 12 in. of a flue or fire-place.

4. Metal fastenings such as nails, screws and holdfasts, shall not be placed within 3 in. of a flue or fire-place opening.

5. The jamb (attached piers at the sides of a fire-place opening must not be less than 9 in. wide. The size of fire-place opening depends on the actual requirements, but roughly a modern kitchen range of medium size will require an opening 3½ ft. wide by 4 ft. high, whilst the smallest bed-room fireplace opening require only be 1½ ft. wide by 2 ft. high.

6. Flues may be round or rectangular. A round flue is more advantageous than a rectangular one, as it prevents rain from beating vertically on the fire and impedes down-draughts of cold air. The flue must in no place be inclined at an angle less than
45 degrees to the horizontal. The bends in each flue must be properly rounded off, and no abrupt offsets should be given as these will obstruct the draught.

(7) The size of a flue is usually 9 in. by 9 in. and this should be uniform through its length, except at its outlet, where it may be slightly restricted. The brickwork above the fire-place opening is corbelled or gathered over in order to reduce the opening to the size of the flue and avoid a large space which may produce eddies and reduce the upward current (or draught) of the flue. This reduced opening is called a throat. The gathering over should be arranged to bring the narrowest part of the throat centrally over the fire, as shown in Fig. 504. The inside of a flue must be rendered with mortar to prevent the escape of flame and smoke through any cracks or open joints; this is known as paring or pargeting, and should be at least 1 in. thick. A good mixture of paring is composed of one part of cement to three parts of fine sand to one part of cowdung.

(8) The hearths must be of combustible material and they should be securely supported. They should not be less than 6 in. in thick. No woodwork shall be built in under a fire-place opening within 12 in. of the upper surface of the back hearth (that within the fire-place recess).

(9) Normally it is better to gather all the flues from the fire-places in a building and group them in a stack, which is carried about 3 feet high above the roof, and is then fitted with a stone or concrete capping so as to prevent rain or snow from getting access to the flues. Smoke outlets are employed in the side walls of the stack.

Details of fire-places are shown in Figs. 503 to 509.

In a hot country like India, fire-places are not generally required except at some of the hill-stations and a few places in North India during the winter season, and in most cases they are constructed on the ground floor.

Hallow or Cavity Walls: This type of construction is now very common and it has some advantages over solid wall construction. They are given below:

(i) They efficiently prevent the dampness from getting access
to the inside of a room, provided adequate precautions are taken in their construction and sound materials and workmanship are employed.
(ii) As air is a good non-conductor of heat, it follows that the air in the cavity is effective in reducing the transmission of heat through the wall. Therefore the heat-losses through an 11 in. cavity wall are less than through a 9 in. solid wall (which is equivalent in thickness of brickwork to an 11 in. cavity wall).
walls and hence they are more effective in excluding external
noises.

(iii) They are economical. For example, take an 11 in. cavity
wall and a 13\(\frac{1}{2}\) in. solid wall. An 11 in. hollow wall costs less
to construct than a 13\(\frac{1}{2}\) in. solid wall (which is the prescribed
minimum thickness if dampness is to be avoided). It is found
that the cost of an 11 in. cavity wall is about 20% less than
a 13\(\frac{1}{2}\) inch solid wall (a 13\(\frac{1}{2}\) in. wall is often referred to as a
14 in. wall.)

A cavity wall is usually an external wall and it consists of two
separate walls, called leaves or skins, of brickwork, having a con-
tinuous cavity between, and connected together by bonding bricks
or metal ties. This double-wall is generally 11 in. thick, consist-
ing of 4\(\frac{1}{2}\) in. inner and outer leaves and a 2 in. continuous cavity.
This wall is sufficient for a two-storied building of the domestic
type. This outer leaf is usually only 4\(\frac{1}{2}\) in. thick and the inner
leaf is increased to 9 in. or more in thickness when heavier floors,
etc., loads have to be supported. The width of the cavity varies
from 2 in. to 3 in., but it should not exceed 3 in. (see Model By-
Laws, 1939).

As already stated above, the inner and outer leaves are tied to-
gether by either special bonding bricks or metal ties to afford the
necessary transverse strength. The metal ties must be sufficiently
strong enough for the purpose, be non-corrodible and so shaped
that water from the outer leaf will not pass along them to the inner
leaf. The metal ties are usually made of either mild steel or wrought
iron, and they are galvanised\(^1\) or dipped in hot tars and sanded to
protect them from rust. For first-class buildings and those near
the sea, either copper or bronze or similar durable and highly corro-
sive-resistant metal ties are preferred. The ties are generally
placed at distances apart not exceeding 3 ft. horizontally and 1 ft.
6 in. vertically which is equivalent to two per sq. yard. This
agrees with the Model By-laws, 1939. \(^1\) The ties are staggered and
the distribution is as shown in Fig. 510. This should be placed at

\(^1\) This is generally effected by hot dip process. This consists
of cleaning the metal and removing any rust by putting it in dilute
hydrochloric acid, washing it to remove the acid and then passing
it through a bath containing liquid zinc.
1 ft. 6 in. Vertical intervals at all angles and door and window jambs to increase stability.

**Fig. 510**

**ELEVATION SHOWING THE DISTRIBUTION OF CAVITY WALL TIES**

Three types of cavity metal ties and two forms of special bonding bricks are illustrated in Figs. 511 to 515. Metal ties are now largely used rather than special bonding bricks. Four cavity walls with ties are shown in Figs. 516 to 519.

**Construction details of hollow or cavity walls:** A hollow wall is frequently constructed with the outer leaf of facing bricks and the inner leaf of ordinary bricks. There arises no difficulty if the facing bricks are thinner than the ordinary bricks, as the ties are placed at vertical intervals (not exceeding 1 ft. 6 in.) where the bed joints of both leaves nearly coincide. The 4½ in. leaves are normally constructed in stretching bond. As this bond has a poor appearance, this may be improved by inserting a course of flange or nap binders to three or five courses of stretchers (this bond is known as English Garden Wall bond, see Fig. 398 Page 230). The 4½ in. thick wall may also be built in either Flemish bond or Flemish Garden wall bond. Brick footings are rarely employed to cavity walls. In first-class work the walls are constructed with cement mortar.

Normally the cavity is extended down to the concrete foundation (see Fig. 520) and then the lower portion of the cavity is filled with 1:2:4 concrete, the coarse aggregate being not more than 3/4" gauge. The top of this concrete is 3 to 12 in. below the
CONSTRUCTION OF CAVITY WALLS

If the lower portion of the cavity is level with the damp proof course, or if the damp proof course is the full width of the wall, water may be conducted to the interior leaf through the accumulated mortar droppings, and produce damp and unsanitary conditions.
wall may be constructed as shown in Fig. 521, in which the bottom portion of the cavity is 3 to 12 in. below the damp proof course. Rain water gaining access to the cavity through the exterior leaf or skin will stream down the inner face of this leaf. The accumulation of water at the base should be prevented by providing weep holes (or narrow outlets) in the course immediately below the damp proof course in the exterior leaf.

During construction care should be taken to see that mortar is not allowed to drop and lodge upon the ties, as water may penetrate through this porous material and cause dampness on the inner face of the wall. In order to maintain a clean cavity, a wood batten of a thickness slightly less than the width of the cavity and with a piece of cord attached to each end is employed. This is supported on the ties, raised as the work proceeds, and any intercepted mortar and brick chippings removed. Neglect of this precaution is a frequent cause of dampness in hollow walls.

In cavity walls the damp proof course is usually provided at least 6 in. above the ground level. This must not extend across the cavity, and each must be provided with a separate damp proof course (see Figs. 520 and 521).

Dampness is very liable to be caused at parapet walls if adequate precautions are not taken during construction. In order to avoid dampness in parapet walls, the cavity should be extended to the coping (see the dotted lines, Fig. 520), or alternatively, either a lead or asphalt felt damp proof course should be provided above the cavity as shown in Fig. 520. It is always a good practice to continue the asphalt roof covering for the full thickness of the wall to prevent the moisture through defective coping joints, porous stone or brickwork. The top of the two sections of the walls is built solid for supporting the roof truss, and a damp proof course is inserted immediately below the solid top to ensure safety from dampness (see Fig. 521).

Dampness will occur round the openings of doors and windows, if adequate precautions are not taken during construction. A damp proof course should be provided as shown in Figs. 523 and 524. Dampness will happen at the hands of openings if proper attention

1See the foot note given on page 271.
Cross Sections of 11 in. Cavity Walls Showing Damp Proof Courses, Lintel, Sill, Window Frame, Ground Floor, Upper Floor, Roof, etc.
is not paid. Thus, water penetrating through defective joints, etc. in the exterior leaf will pass down its inner face until it comes into contact with a lintel, when it will spread along the top to the inside face of the interior leaf; the water will also drip at the soffit. This is prevented by a lead or asphalt damp proof course as shown in Fig. 521.

Fig. 522
CROSS SECTION OF A 13\(\frac{1}{2}\) IN. CAVITY WALL SHOWING AN AIR BRICK, A WALL TIE, DAMP PROOF COURSE, ETC. AIR BRICKS SHOULD NOT BE PROVIDED TO THE CAVITY RATHER THAN THE WEEP-HOLES FOR THE REASONS GIVEN ON PAGE 267

In brief, the following principles should be observed in the construction of hollow walls:

1. As far as possible the interior leaf shall be entirely disconnected (except for the cavity ties) from the exterior leaf.
2. Mortar shall not be allowed to drop and lodge upon ties.
and any old ties should be removed.

3. The main horizontal damp proof course must be in two separate widths, and the lower portion of the cavity must be 3 to 12 in. below the damp proof course.

4. At all openings care should be taken to prevent the entrance of moisture. The brickwork should be constructed solid around the openings and the heads of openings must be properly protected by a lead or asphalt felt damp proof course.

5. Weep-holes must be provided immediately below the main horizontal damp proof courses over openings. No other ventilation to the cavity should be provided.

6. Only sound and well seasoned timbers should be used for all kinds of work. They should be creosoted or treated with some other preservatives, if necessary.

7. Ties must be rust-proof, capable of preventing rain transmission and easily cleaned of droppings.

8. The cavity should be extended to the coping, or alternatively a lead or asphalt felt damp proof course should be provided above the cavity where indicated.

9. The top of the two sections of the walls should be built solid to support the roof efficiently. A damp proof course should be provided above the cavity.
Retaining walls:—The term retaining wall is applied to one supporting an artificial bank, and breast wall to that supporting the face of a solid ground. The chief function of a retaining wall is to retain or hold back either loose earth, soil, or gravel which cannot stand vertically. Retaining walls are generally employed in the construction of cellars, that roads, and bridges, the wing walls and abutments of which are nothing but retaining walls.

The design of walls to retain earth is based on the fact that few types of earths will stand vertically under all considerations, but assume their natural slope, beyond which they no longer move. The natural slope or angle of repose varies with the type of earth. It is this wedge of earth resting on the line of the natural slope which has to be supported by the retaining wall (see Fig. 525). This is done by walls which rely on their own weight to resist this thrust or by walls which rely on leverage. All vertical mass concrete or mass brick walls entirely rely on their weight. R. C. C. walls rely on leverage and battered walls rely mostly on weight and partly on leverage.

Retaining walls are sometimes rectangular in section and they entail considerable waste of material. As a rule, the outer face of a retaining wall has a batter, and the inner face is very often sloped or stepped. The battered face is more stable and economical than the vertical face. Generally the curved work in building is a laborious one and hence it is costly. Consequently the curved batter is not frequently utilised although it more nearly approaches the theoretical section for retaining walls.

Formerly, it was considered desirable to ventilate the cavity by means of purpose made air bricks fixed just above the ground level and also near the top (see Fig. 522). Though this circulation of air sufficiently helped in obtaining a dry cavity and reduced the risk of defects arising in floor timbers, it also destroyed the insulating value of the wall to such an extent that an 11 in. hollow wall so ventilated gave less best insulation than a 9 in. solid wall. Hence the only ventilation of the cavity which is now advocated is that provided by the weep-holes. But the usual ventilation may be provided to ground floors of timber construction.
The pressure against the wall is greatest at the bottom and least at the top, and the theoretical section of a wall of equal resistance throughout will be triangle. The top must, however, have a certain thickness to enable it to resist weathering and the accidents to which the wall is liable, and so in practice the section is of a trapezoidal form. This form is obtained by giving the front face a batter varying from $1/24$ to $1/3$ the height of the wall.

Fig. 525

**ILLUSTRATING THE PRINCIPLE ADOPTED IN THE DESIGN OF RETAINING WALLS**

When a wall of which $AB$ is the side, supports a mass of earth, there is a triangular portion $ABC$ of the earth which would slip downwards, if the wall were removed, and which, therefore, now presses against the wall with a force varying with its height, its specific gravity and the angle $ABC$. The line $BC$, along which the slip of earth would occur, is known as the **line of rupture**, and the slope which the earth would eventually assume if left unsupported, is called the **natural slope or angle of repose** of the soil. Note that the **line of rupture** $BC$ generally divides the angle $ABD$ into two equal parts. I. e., angles $ABC$ and $CBD$ are approximately equal to one another.
In order to drain water from the retained earth, weep-holes or outlets are provided through the walls near their bases. They are however, often distributed over the wall face, and one weep-hole is generally inserted for every 4 sq. yds. of the superficial area of the retaining wall. Normally the bottom-most weep-holes are 6 to 9 in. above the ground level. To facilitate the flow of water to the weep-holes, a six inch layer of gravel, pebble or broken stone is put vertically behind the retaining wall. At the feet of the walls regular drains are formed to carry all surplus water. This item of work prevents the softening of the earth about the foundations.

The height of the earth to be supported by the retaining wall is generally equal to the height of the wall. But sometimes the earth to be supported is higher than the top of the wall and in this case the wall is said to be surcharged (see Fig. 526). The resultant

![Fig. 526 Surcharged Retaining Wall](image)

of the weight of the wall and the pressure of the material which it retains should, to ensure stability, cut the base well within its outer edge, i.e., the point of intersection should generally be within the middle-third of the base.

(6, C. 18)
Retaining walls are constructed in either masonry, concrete or R.C.C.

Masonry or Concrete Retaining Walls:—This type of walls is commonly employed. The thrust on the walls tends to over-
turn the retaining walls, and hence they are formed to such a thickness that by their own weight, they resist the overturning face, and the resultant is made to fall within the middle third of the base. If a water-logged earth is to be supported, the wall should be made water-tight, and also heavy enough to withstand water-pressure. Occasionally, counterforts are built at the back of the retaining wall in order to get a plain faced wall (see Fig. 534). This type of construction requires less material than ordinary method of construction of retaining walls. The counterforts are well tied to the main wall with internal metal ties to counteract any tendency to shear at the junction. A brick counterfort retaining wall is illustrated in Figs. 534 and 535.

Dry stone retaining walls (Fig. 536).—As there is no mortar used in the work, the strength and stability of these walls largely depend upon the quality and size of stones, and hence greatest care is required in the selection of stones. Good workmanship is also required as the strength of the walls partly depends on it.

The correct section of the wall depends on the quality of workmanship, the type of material to be supported and the height. As a rule, a drystone retaining wall should not be more than 20 feet in height. As a thumb rule, the top width of the retaining wall should not be less than 2 feet, and the face
batter 1 in 4 or 1 in 3, the latter being used for walls higher than 10 feet.

The beds of the courses must be laid perpendicular to the face batter, and necessary precautions should be taken to ensure a good bond. Always it is a wise action to put the earth filling at the near after a few feet of the wall are constructed and approved by the competent officer.

Sometimes the interstices of drystone retaining walls are filled with mud, and the face is pointed with either cement mortar or lime mortar. In such a case, weep-holes are provided at intervals over the whole surface of the wall in order to drain off water from the earth behind the wall.

R.C.C Retaining Walls: These walls are of two classes, and they are given below:

1) The plain wall of continuous section, with a wide projecting base for heights up to 20 ft. The face may be divided into two types, (a) internal base and (b) external base. In internal base a heel-beam is provided to resist sliding and the base is designed to act as a cantilever to resist downward pressure of soil (see Fig. 537). The external base is designed to act as a cantilever to resist upward pressure from subsoil and is employed where the projection cannot be used on the inner side (see Fig. 538).

2) Thin cantilever walls and counterforts for heights over 20 feet. In this type, the wall is designed to act as a series of beams to resist the pressure of the soil, and the base is designed to act as a series of beams under the counterforts to resist the downward pressure of the soil. (see Fig. 539). Weep-holes are also provided in both the types of R.C.C. walls.

It may be noted here that R.C.C. walls have a more sliding tendency than masonry walls, but the latter are very much heavier.

General: In designing retaining walls it is generally best to assume a section from empirical rules or rough calculations, and then to inquire into its stability, altering the dimensions where necessary. The following rules will serve as a guide:

Retaining walls for earth: For light soils mean thickness
\[ h' = \frac{h}{4}, \text{ where } h \text{ is the height of the wall in feet. For stiff clay the mean thickness } = \frac{h}{3}. \]

**Surcharged walls:** For surcharged walls substitute \( g \) for \( h \), of being the perpendicular at the end of a line \( h' = \frac{h}{4} \) measured along...
the slope to be retained. See Fig. 526.

Retaining wall for water: Mean thickness = \( \frac{h}{2} \)

Various forms of retaining walls are shown in Figs. 525 to 540.

Breast Walls: The chief function of a breast wall is to protect the natural slopes of cutting in natural ground from the bad effects of weather, and incidentally it has to support the pressure of earth behind.

The section of a breast wall largely depends on the slope of the cutting and the soil to be supported. Water should not be allowed to get access to the back of the wall.

The breast walls are generally constructed in either masonry or concrete. Drystone breast walls have been largely used. In the construction of breast walls care should be taken to see that the beds of the courses are laid perpendicular to the face batter and
a good bond is secured throughout the work. All the interstices should be filled either with puddle or small broken-stone.

Different forms of breast walls are illustrated in Figs. 541 to 543. Fig. 544 illustrates the difference between a retaining wall and a breast wall.

Fig. 541 to 543
FORMS OF BREAST WALLS

Fig. 544
SHOWING A RETAINING WALL AND A BREAST WALL FOR A ROADWAY.
NOTE THE DIFFERENCE BETWEEN THEM CLEARLY.
CHAPTER III.

QUESTIONS FOR REVISION.

1. Show in Isometric projection to a scale of 3 inches to the foot the standard building brick used in four districts. Name the brick and figure on the maximum and minimum sizes of the brick.

Show in elevation, to a scale of 1\(\frac{1}{2}\) inches to the foot, eight bricks as stretchers, and eight bricks as headers.

Figure on the maximum and minimum length of the eight bricks in line.

Show to the same scale a height of six courses of brickwork, including the mortar joints.

Figure on the height of four courses of brickwork.

Show to the same scale the elevation of six courses of the following bonds in brickwork:

(A) Flemish bond. (B) English garden wall bond.

2. (a) Two brick walls, the one 18 inches and the other 14 inches thick, meet at right angle at the external corner of a building. Draw neat sketches showing the plan of two consecutive courses of bricks laid in English bond.

(b) Specify the safe load on brickwork constructed in 1 : 4 cement mortar.

(University of Bombay, 1953).

3. Give your views with reasons about the selection of stone masonry and of brick masonry for the construction of a residential building for a middle-class family in its various stages from foundations to roof level.

(Karnatak University, 1955).

4. What are retaining walls? Give all the types you know.

(Karnatak University, 1952 and 1955).

5. Write short notes on the following with sketches:

1. Hollow walls
2. Flemish bond
3. Retaining wall
4. Breast wall

(Karnatak University, 1955)

(Karnatak University, 1952 and 1954)

(University of Baroda, 1951)

(University of Baroda, 1952).
6. State the advantages and disadvantages of framed structures over structures built on continuous foundations? (University of Baroda, 1954).

7 (a) Describe the general principles to be observed and precautions to be taken in the construction of brick masonry.

(b) Describe the construction of a cavity wall showing the details of damp proof course. (University of Baroda, 1954).

8. Give short notes on the following and illustrate your answers by neat sketches:

2. Hollow walls (University of Sind, 1950 and Gujarat University, 1954).
3. Dry masonry (Karnatak University, 1954).

What is a bond? Explain by means of sketches the difference between English and Flemish bond in brick wall.

Explain the meaning of the following terms and illustrate your answer with sketches:—Queen closer, Corbel, Template and Cavity wall tie. (University of Sind, 1950).

10. What is the significance of bond in brickwork? What do you understand by English and Flemish bond? Draw sketches to illustrate these two types for 14" thick wall. (Gujarat University, 1952).

11. What are the essential characteristics of an efficient domestic fireplace? Draw a dimensional sketch to illustrate them. (University of Sind, 1950).

12 (a) Explain the construction of a hollow wall of the following description:

Inner stone wall 18' thick, outer brick wall 4½' thick, with an air space of 3'.

(b) Show by sketches the method of fixing a window frame in the same wall. (Karnatak University, 1954).

13. What is the fundamental difference between a solid structure and a framed structure?
Show by sketches in plan and elevation the arrangement for a framed structure of any building constructed in materials of your own choice. (University of Bombay, 1954).

14 (a) Draw two consecutive courses of the junction of a two brick wall with one and half brick wall.
(b) Sketch the arrangement of bricks in a wall pilaster 1' - 6" X 1' - 6" in a wall of one and a half brick thick.

15 (a) Compare with sketches English bond with Flemish bond for laying a brick wall two brick thick.
(b) Draw plans of two consecutive courses showing the arrangement of bricks at the corner of two 1 foot 10½ inches thick walls constructed in English bond. Write a short specification to suit this work in the ground floor of a multi-storied building.

16. What is the permissible safe load of brick masonry in cement mortar? What is the minimum thickness of a load bearing brick wall? What thickness of walls will you adopt for a three storeyed building? (Gujarat University, 1954).

17. Discuss the circumstances under which you would prefer framed buildings in preference to masonry walled buildings. What type of building you would design on the reclaimed area on sea coast in Bombay? Mention the different types of suitable material that can be advantageously used in the construction of framed structures. Which would you prefer for a construction project in Bombay? (University of Baroda, 1953).

18. (a) Draw to 1 inch scale a section through an 11 inch thick brick built hollow wall.
(b) Show position of damp-course in relation to the ground, cavity and floor, the floor being taken as 12 inches above the ground.
(c) How would you protect the door and window heads?
(d) How would you tie the inner and outer walls together?

19. Draw, to 1-inch scale, the plans of adjacent courses, showing the arrangement of bricks at the corner of two 13½ inch walls. One example is to indicate English bonding and the other Flemish bonding.
20. Describe the following with sketches.
1. Squint quoin;
2. birds-mouth angle;
3. toothing;
4. Racking back.

21. Draw, to any convenient scale, the plans of adjacent courses, showing the arrangement of bricks at the corner of a bay window. Special made quoin bricks are to be used. The external angle is 135°, the walls are 18 inches thick, and are built in English bond.

22. Two brick walls, one 18 inches and the other 14 inches thick, meet at right angles at the external corner of a building; draw, to a scale of 1 inch to 1 foot, plan of two consecutive courses, at the angle, showing the bricks laid English bond.

23. To 1-inch scale, draw the alternate courses of a right-angled quoin for a cavity wall, which has an outer thickness of 4½ inches, built in Flemish bond, and an inner thickness of 9 inches, built in English bond, the cavity being 2½ inches wide.

24. Illustrate with large-scale free-hand and dimensioned sketches of the following items connected with brick masonry:
(a) King closer; (b) footings; (c) block-bonding.

25. Briefly describe English bond and double Flemish bond of brickwork, and draw the two following examples. Scale ½ Inch to 1 ft.
(a) A 9-inch internal wall makes a right angle junction with a 14-inch external wall. Draw plans of two consecutive courses of brickwork in English bond.
(b) Two 14-inch external walls meet at right angles at the corner of a building. Draw plans of two consecutive courses of brickwork in double Flemish bond.

26. What treatment should bricks receive before being laid. Give reason, and state under what conditions particular care should be exercised.

27. Describe the following terms as applying to brickwork:
1. Quoins. 4. Header.
2. Perpend. 5. Bat.
3. Stretchers.
28. Draw to a scale of 1 inch to 1 foot, plans of alternate courses of two 13\(\frac{1}{2}\) inch walls in double Flemish bond, meeting at a right angle quoin. Mortar joints may be indicated by a single line.

29. Sketch cross-sections of six different methods of coping the top of a 9 inch brick wall.

30. Name four types of bricks in general use, and state the purpose—for which each is most suited.
Give a sketch of a portion of brickwork showing where a king closer would be used.

31. Describe and illustrate with sketches two alternative types of bonding you would suggest for the external skin of an 11 inch cavity wall.

32. Draw to a scale of 1 inch to 1 foot plans (one course only) of the external corner of a building having:
   - (a) 27 inch walls in English bond.
   - (b) 9 inch walls in English bond.
   - (c) 27 inch walls in double Flemish bond.
   - (d) 9 inch walls in double Flemish bond.

33. Draw to a scale of 1 inch to 1 foot, plans (one course only) of the external corner of a building having 14 inch brick walls in:
   - (a) English bond, (b) Single Flemish bond, (c) Double Flemish bond.
   Also brick pier 18 inches by 18 inches in:
   - (d) English bond (e) Double Flemish bond.

34. Write short notes on any five of the following with sketches:
   2. Difference between retaining walls and breast walls.
   3. Lap.
   5. Bevelled closer.
   6. Queen closer.
CHAPTER IV

COMPOSITE MASONRY

Ashlar facing with rubble or brick backing:—This type of composite masonry is described with sketches in Chapter II, under the head "Ashlar facing", Page 185.

Stone facing slabs with brick or concrete backing:—In this type, 4 in. to 6 in. thick stone slabs are used as facing and brick or concrete is used as backing. The stone slabs used for facing may be either artificial or natural, and the concrete used for backing may be either plain or reinforced. Metal cramps are used at all horizontal and vertical joints to fix the stone facing slabs to either brick or concrete backing, whereas dowels are used at these joints to bind the stone slabs with each other (see Figs. 545 and 546). This type of composite masonry is very suitable for steel or R.C.C. framed structures. Walls constructed in this type are sometimes called "veneered walls".
Brick facing with rubble or concrete backing (Figs. 547 and 548): Sometimes external walls are built in this type of masonry, in which bricks are used as facing and rubble or concrete is used as backing. Special types of glazed tiles of clay are now manufactured as facing tiles to effect the desired decorative appearance. Marble slabs and terra-cotta products are also used as facings for walls.

Concrete block masonry: The term "concrete block masonry" is used for the construction of walls with cement concrete blocks, which may be either solid blocks or hollow blocks. This type of masonry is now very commonly adopted as it has the following advantages over brick and stone masonry:

1. Saving of material and also of space. The concrete block walls are stronger than brick and stone work of the same thickness, and therefore thinner walls can be used. Hollow concrete block walls make at least a saving of 30 percent of material. An 8 in. wall constructed in concrete masonry, is as strong as 14 in. thick brick wall or 15 in. thick stone wall.

2. Saving in the cost of labour as the work could be speeded...
up with the rectangular large size of blocks. There is also a
saving in mortar as the number of joints is less.
(3) Durability and capacity to resist wear and damage during
handling.
(4) Greater resistance to fire as concrete is not easily attacked
by fire. Concrete block walls are also not attacked by insects.

Fig. 547

CROSS SECTION OF A COMPOSITE MASONRY WALL WITH
BRICK FACING AND RUBBLE BACKING

(5) Greater resistance to atmospheric influences as the con-
crete surface is harder and denser than that of bricks.
(6) Walls constructed with hollow concrete blocks afford
good insulation against heat, cold, damp and sound. The cavities
can be used for conveying pipes and electric wires.
(7) Plastering and pointing can be eliminated, at the same
time producing superior quality of work.

The concrete blocks are moulded in various sizes in machines
either by the cast or tamped process. The standard sizes are
given below:
(288)

(a) Concrete building blocks \(15\frac{3}{4}\text{"} \times 7\frac{3}{4}\text{"} \times 8\text{"}.
(b) Concrete building tiles \(11\frac{3}{4}\text{"} \times 7\frac{3}{4}\text{"} \times 5\text{"}.
(c) Hollow or solid partition blocks or slabs from \(12\text{"} \times \) to \(18\text{"} \times 7\frac{3}{4}\text{"} \times 3\text{"} \) to \(6\text{"}.

The above sizes of concrete blocks are illustrated in Figs. 549 to 556. It may be noted that the thickness of mortar joints are not included in the above sizes. The thickness of the mortar joint (side or bed joint) is usually \(\frac{1}{4}\text{"}.

The composition of concrete is \(1 : 2 : 4\) or \(1 : 3 : 6\). The concrete blocks (both hollow and solid) are also cast with steel reinforcement to give them extra strength.

The amount of air space in concrete building blocks ranges from 20 to 40 per cent of their total volume and in concrete building tiles ranges from 50 to 75 per cent of their total volume. Two or more hollow spaces side by side are better than one big hollow space. The sides of the blocks round the hollows must not be less than \(\frac{1}{2}\) in. thick.
All sound blocks regular in size and shape only must be used.

CONCRETE BUILDING BLOCKS

CONCRETE BUILDING TILES

HOLLOW PARTITION BLOCKS

HOLLOW WALL WITH SMOO BLOCKS

CONCRETE BLOCK WALL

Figs 549 to 558

Concrete Blocks and Concrete Block Masonry Walls

B. C. 19
As the surface of the blocks are sufficiently rough, it may be plastered with a coat of cement plaster. If not, the front face of the concrete blocks should be finished smooth during manufacture so as to avoid any necessity of plastering. The joints of the concrete block masonry should then be filled with cement mortar, well robbed and made smooth.

Special types of blocks and tiles to suit the requirements of corners, sills, lintels, jambs for window and door openings in walls are also manufactured.

In Fig. 557, is shown portion of a hollow wall constructed with concrete solid blocks, metal wall ties being used to bind together two thin solid walls. Fig. 558 shows part of a 12 in. concrete masonry wall built with 8" wide concrete building tiles.

The thicknesses usually adopted for concrete block masonry walls are given in Table No. 14. Sometimes concrete block masonry walls are constructed with bricks as facing, as shown in Fig. 559.

### Table No. 14.

<table>
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<tr>
<th>No. of floors</th>
<th>Basement (Inches)</th>
<th>Ground Floor (Inches)</th>
<th>First Floor (Inches)</th>
<th>Second Floor (Inches)</th>
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<td>16</td>
<td>12</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Glass walls:—This type of construction is coming more and more into prominence day by day. In this type, glass slabs are used as facing and concrete is used as backing (see Fig. 560). Glass walls
may also be reinforced. The advantages of glass walls are given below:—

1. As the surface of the wall is smooth, it does not catch dust easily, and it can be easily cleaned by any suitable process.

2. Glass walls act as a good insulator against heat, cold and noise, and at the same time they give privacy and security.

3. Glass walls are very suitable where sanitary conditions are to be strictly maintained.

4. Glass walls scatter the light, and they may be given any desired tinge of colour, pleasing to the appearance.

Structural glass is available in different colours in sheets of thickness from $3/8''$ to $1''$. Some varieties have a highly polished surface and decorative features.

Glass blocks or bricks have been recently manufactured, but they are not suitable for load-bearing walls. They may be either...
solid or hollow, and are used for partitions and for panel walls to steel or R. C. C. framed buildings, etc.

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Fig. 560
SHOWING A GLASS WALL WITH GLASS SLAB FACING AND CEMENT CONCRETE BACKING. THE GLASS SLABS ARE HELD IN FRAMES OF STAINLESS STEEL ANGLES

There are several types of glass blocks. In one type, there are joggles cast on the top and one side which interlock with the adjoining block (see Figs. 561 and 564). In another type there are two thin slabs before being joined to form a hollow unit as shown in Fig. 563. There is a channel at top and bottom to receive steel reinforcement embedded in cement mortar to form a rigid continuous partition. In a third type a solid rectangular block is made with etched lines forming squares on one face (see Fig. 564).

The glass blocks or bricks are bedded and jointed with lime or cement mortar like clay bricks. Panels exceeding 6 ft. in width should be reinforced with hoop iron or expanded metal.
at every third to fifth course. Vertical rod reinforcement is also required if the width of the panels is more than 20 feet. Necessary provision must also be made for expansion at the sides and tops of panels. The blocks are made in many sizes and patterns.

Fig. 561 to 564
GLASS BLOCKS OR GLASS BRICKS WITH A PARTITION OF SOLID GLASS BLOCKS
CHAPTER IV.

QUESTIONS FOR REVISION.


2. What are the advantages of concrete block masonry over brick and stone masonry? Draw the sketches of concrete blocks that are generally used in building construction.

3. Write a note on "Glass walls".
CHAPTER V

PARTITIONS.

Partitions are thin walls or screens, which are used to divide buildings into rooms, corridors and cubicles. Though their essential purpose is to serve as divisions, they are also used to support the joints of floors, parapets and ceiling joints of roofs, etc. They are generally carried for the full height or just above the eye level at 7 ft. to 8 ft., and a door-way is commonly placed in the middle of the partition wall. A good partition should be thin, light affording privacy both in respect of sound and sight, simple and easy of construction, fire-resisting, and cheap.

The following types of partitions are generally used:—

1. Brick partitions:—plain, brick-cogging, or reinforced brickwork.
2. Clay or terr-cotta block partitions.
3. Concrete partitions:—plain or reinforced.
4. Concrete slab partitions.
5. Plaster slab partitions:—plain or reinforced.
6. Asbestos-cement partitions.
7. Metal partitions.
8. Glass partitions.

1. Brick partitions:—Plain brick partitions are usually one brick or 9 in. thick, and further the partitions are plastered on both sides. 9 in. is the minimum thickness and is essentially required for self-supporting and for reasonably sound-deadening. Thus plain brick partitions are very heavy and expensive, and they also occupy much space.

Cellular and keyed bricks (see Figs. 176 and 173) are often used to lighten the weight on floors, but they should not be used in cavity wall skins.

Sometimes half-brick partitions are constructed in plain brickwork with cement mortar, which are considerably strong and fire-resisting. Both the sides of the partitions are also plastered with cement plaster.

Brick-nogged partitions were at one time abundantly used, but in modern practice they are rarely employed in buildings.
The usual thickness of brick-nogged partitions is 4½ in., though often for the sake of economy or to gain room they are made 3 in. thick, having the brickwork laid on edge. Thus the thickness of the brick-nogged partition walls including that of plaster is 6 in. when the bricks are laid on their flat side, and 4½ in. when they are laid on their edges. For brick-nogged partition, a timber framework consisting of vertical members called studs or quarters and horizontal members called nogging pieces or bonding strips, is made. The top and bottom horizontal members are called head and sill respectively. The studs are usually placed at intervals of 2 ft. 3 in. or 3 ft., and the nogging pieces are housed into the studs at 2 ft. vertical intervals. The studs are 4½ in. by 3 in. when the brickwork is 4½ in. thick, and of 3 in. square stuff if the bricks are laid on edge. Nogging pieces are usually 4 in. by ½ in.

The object of the studs and nogging pieces is to increase the rigidity of thin brick walls, especially long and high walls. The spaces between the studs and nogging pieces are then filled with brick masonry, which is plastered on both sides. Cement mortar should be used for brick-nogged partition walls. This method of construction is known as brick-nogging. A brick-nogged partition is illustrated in Fig. 565.

Reinforced brick partitions are similar to brick-nogging, except that instead of the nogging-pieces, either straps of hoop iron 1 in. to 1½ in. wide and 1/16 in. or ½ in. thick, or patent expanded metal bands are laid horizontally in every third or fourth course between the studs. The ends of the hoop iron straps and the patent expanded metal bands are bent at right angles about an inch and nailed to the ends of the studs at sides. The hoop iron should be tarred and tinned and placed in the centre of the bricks to bind them properly. The centre work should be carried out in cement mortar.

2. Clay or terra-cotta block partition—These blocks

*Note: The term "terra-cotta" means baked earth. It is a kind of earthenware which is made from a mixture of clay, crushed pottery, white sand and powdered glass with a quantity of colouring substance according to the shade of colour desired. It is modelled in either hollow or solid blocks and carefully dried and burnt in special kilns without contact with fire. High class, glazed terra-cotta is called "faience".*
are cast either solid or hollow. An example of a hollow block is shown in Fig. 565. The tongues and grooves on the beds help in making the joints rigid and facilitate erection. The grooved faces afford a good key for the plaster. Sometimes these blocks are cast without keyed faces, and are glazed on one or both sides in a variety of colours. These blocks are generally 12 in. by 9 in. by 2 in.
Solid blocks are also manufactured which are only 1½ in. thick.

Another form of hollow block is illustrated in Fig. 567 which is about 12 in. by 9 in. by 4 in. The fluted sides and beds provide a good key for the plaster. The hollows in the block reduce the transmission of sound and heat, besides decreasing their weight. The clay and terra-cotta blocks are reasonably strong, fire proof, vermin proof, non-shrinkable, and have good heat and sound insulation qualities.

The clay and terra-cotta blocks are built in cement mortar (composed of 1 part Portland cement and 3 parts sand) and are bonded in the usual way with staggered vertical joints in order to form a strong, sound and fire-resisting partition.

3. Concrete partitions:—Concrete walls of 3 in. thickness may be cast in-situ, by timber shuttering on both sides. Generally it is better to reinforce them with 3/8 in. diameter mild steel rods. The vertical mild steel rods are spaced at about 6 in. intervals and securely fixed at their ends to the floor and ceiling. Similar rods at 10 in. centres, are then wired horizontally to the vertical rods. Timber shuttering is then placed on both sides, and concrete is poured in the framework for the entire length and height of the wall. The completed partition should be well watered for at least 15 days.

4. Concrete slab partitions:—Concrete slabs should be as light as possible, but they should be strong enough for the purpose. A very suitable material for these slabs is light weight concrete consisting of a mixture of Portland cement and aggregates such as...
The composition varies from 6 to 12 parts aggregate to 1 part cement by volume; sand may also be added. The aggregate must be crushed to pass through a \( \frac{1}{4} \) in. sieve. The slabs manufactured either solid or hollow, but hollow slabs are extensively used.

An example of a solid concrete slab is shown in Fig. 568. There are many sizes, but the standard dimensions are 12 in. to 18 in. by 7\( \frac{1}{2} \) in. to 6 in.; the radius of the tongue and groove are \( \frac{7}{16} \) in. and \( \frac{9}{16} \) in., respectively. A hollow concrete slab is shown in Fig. 569. The dimensions are similar to the above, with a minimum thickness of 3 in. Three more examples of hollow concrete slabs are given in Figs. 554 to 556 (see also page 289).

Concrete slab partitions are built in cement mortar and both clinker, breeze, pumice, foamed slag and expanded slate. The materials resulting from the burning of coal. Clinker or ash is obtained from furnaces, while breeze is obtained from gasworks and coke ovens. Breeze is also known as coke breeze. They are cheap and light in weight. These materials should be free from particles of coal, as they are very weak. The particles of coal, when associated with cement or cement concrete will expand and cause failures; they will also cause the spalling off of the concrete. Clinker and breeze should not be used as aggregates for reinforced concrete work.

Pumice is a whitish or yellowish material of volcanic origin which is highly honeycombed. It is crushed and graded as required. Dust and shaly fragments should be removed. It is relatively weak, but light in weight.

Foamed slag is produced from blast-furnace slag by cooling the molten material with water (Blast-furnace slag is a product of the blast-furnace in which iron ore is smelted as a preliminary in the manufacture of steel, cast-iron, etc.). It is light in weight and is crushed and graded as required.

Expanded slate is produced by heating waste slate to a high temperature until its thickness is considerably increased. It is then crushed and graded as required. It is light in weight, but it is not much used on account of its high cost.
sides are plastered. The slabs can be easily cut, and most slabs (excluding clinker slabs) will firmly hold screws and nails. Some concrete slabs, such as pumice concrete slabs, have good fire-resisting qualities, but others such as coke breeze, etc. are combustible. Light-weight concrete slabs have a good insulation value because of their porous nature, but they are not very resistant to the passage of sound. The concrete slab partitions may be made thoroughly fire-resistant, sound-proof and strong by employing concrete slabs made entirely of cement concrete. But such partition walls are heavy and hence they cannot be used unless provision in the form of girders or lower walls is made for their support.

A new concrete product, called **wood-wool cement or fibrous wood cement** is being used for the manufacture of slab partitions, which consists of a mixture of Portland cement and wood-wool or wood shavings, and sometimes a small quantity of gypsum. Long shavings from 1/8 in. to 1/4 in. wide are coated with liquid cement, consolidated into slabs by means of a machine press, and are then stored to mature. These slabs are very light in weight, the average weight of the material being only about 30 lbs. per cubic foot (brickwork weighs about 120 lbs. per cu. ft.). The slabs have good heat and sound insulation qualities and are not easily attacked by fire. They provide a good key for the plaster which is applied to the surfaces, and they can be easily fixed and sawn. Nails and screws can also be driven into these slabs. **Thermacoust** is a patent slab, which is manufactured by wood-wool cement. The Thermacoust slabs are 8 in. by 23 3 in. by 3, 4, 5 in. 2 in. to 5 in. thick slabs are recommended for partitions to get sufficient strength for the purpose. The slabs are bedded and jointed in cement mortar and the vertical joints are staggered. The surfaces of the partitions are plastered with two coats of plaster.

Partition slabs are also manufactured with **sawdust concrete**, which consists of a mixture of sawdust and cement. These slabs are light in weight and have a good heat insulation value. Nails and screws can be easily driven into these slabs, and they can be readily cut and sawn like wood-wool cement slabs. These slabs are bedded and jointed in cement mortar. Plastering of the sur-
faces completes the partition. The only disadvantage of these slabs is that they have a tendency to expand and shrink. Small cracks may also happen on the plastered surfaces.

Another type of lightweight concrete slab is made with aerated or foamed cement, which is an excellent material for the construction of non-load bearing partitions. These slabs are manufactured thus: Portland cement and finely powdered aluminium in the proportion of 1:1000 by weight are mixed and a sufficient quantity of water is added to make them a liquid paste. A metal mould is then partially filled (about 1/3 its depth) with this paste, which gradually rises to completely fill the mould. This is effected by means of hydrogen gas. The upper surface is finished smooth after removing any superfluous material. The slab is then allowed to harden in the mould. The slabs should be matured thoroughly, otherwise shrinkage cracks will occur.

When building the concrete slab partitions, 4 in. by 2 in. uprights or vertical posts are strutted plumb between the floor and ceiling at about 4 feet intervals, the slabs can then be erected rapidly and each slab does not require plumbing individually. Thus much time and labour can be saved, and the work can be carried out easily without fatigue.

5. Plaster slab partitions:—These are made of calcium sulphate (burnt gypsum or plaster of Paris). Water is added to this, and sand may be added to the mix. Sawdust is also sometimes added to reduce their density. These slabs are made by casting the material in moulds (made of wood or iron) from 2 to 4 in. in thickness, from 3 to 6 ft. in length, and about 1 foot in height. Sometimes the thicker slabs are cast hollow to decrease their weight, and the slabs are usually finished smooth and hence they are not required plastering. When the partitions are to be plastered, the slabs are formed with keyed or rough surfaces and only one coat of plaster is ordinarily required. An example of a plaster slab is shown in Fig. 570. The tongues and grooves on the beds assist in making the joints rigid and facilitate erection. These slabs are less subjected to shrinkage cracks than concrete slabs.

Temporary wood liners or frames are employed to save time and labour in erecting plaster slab partitions. Otherwise each slab has to be carefully plumbed.
Reinforced plaster partition: There are several methods of forming thin partitions which consist of expanded metal lathing or similar metal reinforcement, covered with plaster. The following is one method, which is usually adopted.

Vertical mild steel rods 3 in. to 6 in. diameter, are spaced at about 15 in. intervals and securely fixed at their ends to the floor and ceiling. To these vertical rods expanded metal lathing is tied down by wires. Similar 1 in. to 1 1/2 in. diameter mild steel rods are then wired horizontally to the vertical rods at about 21 in. intervals on the opposite side to the expanded metal lathing after their ends have been built into the side walls or screwed to door, etc., frames. At first, one side is carefully plastered, and when this has set a coat of plaster is applied to the other side. Scratches are made on these initial coats by means of a mason's trowel when they are wet, and a second coat is then applied to each side of the partition. The wood studding for door openings should be erected before plastersing. The finished partition will be about 2 in. thick. This makes an excellent and very rigid partition, which is fire-resisting.

Metal laths are of various kinds, and most of them are the subjects of patent. Some of the metal laths like expanded metal sheets, wire-netting, B R C. fabric (British Reinforced Company's fabric), etc., require a framework of steel for rigidity (as described above), while metal laths like Hy-tib, Jobilit, Trussit, etc., possess stiffening ribs to make them sufficiently rigid, and hence they do not require any framework of steel. Hy-tib steel lathing
and Trusslt steel lathing are shown in Figs. 571 and 572 respectively.

**HY-RIB STEEL LATHING**

6 Asbestos cement partitions:—A portion of an asbestos-cement sheet which is generally used in the construction of partitions is shown in Fig. 571. It contains two flat sheets of asbestos cement, each about 5/16 in. thick, attached to an inner corrugated sheet, about 1/5 in. thick, of similar material. These sheets are laid in cement mortar and can be painted or distempered.

"TRUSSLT" STEEL LATHING

As implied, this material is composed of asbestos and Portland cement. Asbestos is a silky fibrous mineral existing in veins in metamorphosed volcanic rocks. There are several kinds, but white asbestos, which is a compound of magnesia and silica, is that ordinarily used.
as required. The asbestos-cement partitions are light in weight, durable, fire-resisting, and have good heat and sound insulation qualities.

Fig. 573

**PORTION OF AN ASPEROS CEMENT SHEET**

7. **Metal partitions**:—Mild steel and bronze metals are normally used in the construction of partitions. These partitions may be designed to consist of a series of panels, secured to posts, walls, etc., or the whole of both surfaces may be flush. The thickness of the panels ranges from 1/2 in. to 2 in. and may be of 20 gauge (0.035 in.) mild steel or 1/4 in. to 1 in. thick bronze; the thickness of the mild steel for the posts may be increased to 18 gauge (0.048 in.). The panels may be filled with some kind of good insulating material. A sectional plan of a steel post and portions of adjacent panels are shown in Fig. 574.

8. **Glass partitions**:—For these partitions, a timber framework is made, and sheets of glass are fixed in it in the form of

1 Bronze is a copper-zinc-tin alloy. It is stiffer and stronger than brass, and is more resistant to corrosion.
panels (see Fig. 575). Glass partitions transmit diffused light, and any decorative effect pleasing to the eye can be given to

**Fig. 575**

*Portion of a Glass Partition*

them. On account of their smooth and polished surface, they catch less dust, and they can be very easily cleaned by any suitable process. Glass partitions are very light in weight, damp-proof, vermin proof, take less space, afford a reasonable degree of privacy and have good sound insulation qualities. The only objection of these partitions is that the glass is breakable. But in modern practice this defect is overcome by improved methods of manufacture. Thus, **wired sheets of glass reinforced with steel wire netting** are very hard, durable, and practically unbreakable, and they do not produce splinters if they break. **Bullet proof glass** consists of very thin sheets cemented together under heat and pressure. Another kind of shatter-proof safety glass is the **three ply glass**, which consists of three pieces of glass cemented together with thin laminae of transparent celluloid. Another “sheer glass”, called **Armour plate glass**, possesses shock-resisting properties to a remarkable extent.

Glass bricks and slabs are also used in the construction of partitions, which are described in detail on page 304. The glass bricks and slabs do not require either steel or wooden framework to the construction of partitions.

9. **Timber partitions**—These partitions may be divided
Into two classes, viz., common partitions and trussed partitions.

The weight of the common partition is borne by the floor, while that of the trussed partition is borne by the side walls upon which the trussed partition is placed. The former class of partition is in common use. It is light in weight and hence it is advantageously employed where there is no supporting wall below. The latter class of partition is rarely employed nowadays except for buildings of a temporary character, or in those places where timber is largely found and can be cheaply and readily obtained.

Generally timber partitions are light in weight. The rigidity of these partitions may be easily obtained by the triangulation of the framing. They may be constructed in any position, and the load may be conveniently transmitted and concentrated in any part or parts of the wall. But sanitary fittings and heavy fixtures cannot, of course, be supported by this type of partitions. They are deficient in fire-resisting qualities, and certain types of timber are attacked by white ants. They do not prevent the passage of sound to any great extent. Timber partitions should not be erected in basements or floors next to the ground unless they are thoroughly protected from damp.

Common partitions:—These are also known as stoothings, or stoothed, stud or quarter partitions, and are employed where the floors are strong enough to take the weight of the partitions. An example of a common (timber) partition with a central doorway is shown in Fig. 576. It is composed of upright pieces of wood or vertical members of wood called studs or quarters, which are fixed to two horizontal members of timber, the upper being the head and the lower the sill. One or both sides may be either lathed and plastered (wooden or steel lathes may be used for this work), or covered with boarding, plywood sheets, wall board, etc.

The dimensions of the studs are usually 4 in. by 2 in., and the studs are spaced at 12 in. to 15 in. centres for lathing and up to 24 in. centres for boarding or panelling. The short lengths of studs, such as those above doors, are called puncheons. Both the ends of the studs or quarters may be either housed (Fig. 577), or stub or stub-tenoned into the head and sill (Fig. 578) or, as shown in Fig. 579, slotted over 1½ in. by 1 in. fillets nailed to the head and sill. To stiffen the studs, short horizontal pieces of
timber 4 or 3 in. by 2 or 1½ in., called **nogging pieces** or **noggings**, are fitted and nailed between the studs in rows, at vertical intervals of from 3 to 4 feet; alternatively, the noggings may consist of pairs of 2 in. by 1 in. continuous pieces let in flush with the faces of the studs. The wall studs are either securely plugged to the walls or packed out from the walls.

**Fig. 576**

**Common Timber Partition. Inclined Places of Wood called Braces may be provided for strengthening the Partition. Braces are shown in Figs. 584 to 585.**

The dimensions of the head and sill are usually 4 in. by 3 in.; but sometimes their sizes are the same as that of the studs. The head is securely nailed to the ceiling joists and the sill is fixed to the floor. The ends of the head and sill are built into the side
walls to give additional strength to the partition. When placing the sill in position care should be taken to see that it lies either at

Fig. 577
HOUSED JOINT

Fig. 578
STUB OR STUMP-TENONED JOINT

Fig. 579
SHOWING THE CONNECTION BETWEEN THE STUD AND THE SILL BY MEANS OF A FILLET 1 1/2" X 1"
right angles to the floor joists below, or directly over one of the joists if it be parallel to them, so that a solid and uniform support may be obtained throughout its length. Care must be taken to see that the common partitions are not placed on the floor boards between the joists, as in the event of the floor being taken up to be relaid the partition would fail.

A doorway is generally provided in the middle of the portion; but it may be provided anywhere as desired. The door posts or door studs should be sufficiently rigid, generally 4 in. by 4 in., to resist the impact of the door. The posts should be continuous from floor to ceiling. The doorhead is stump-tenoned into the door-post (See Figs. 580 and 581).

Figs. 580 and 581

**Joint at Door Head in Timber Partition**

The foot of the door-post is stump-tenoned into the sill, and may be secured with a wrought-iron (W. L) strap and bolts, as shown in Figs. 582 and 583.

Another form of this type of partition in which studs are employed is the *brick nogged partition*, which is referred to on page 295.

**Trussed or framed partitions**—Trusses are deep-braced girders, which are designed to be self-supporting. These trusses may be required to carry one or more floors and ceilings. A truss is made rigid by triangulating it, the triangle being the only polygon that is unalterable in shape when stressed within the limits of its resistance. The truss is also tied carefully at the various points of support and the loads are applied at the apices of the triangles. As far as possible transverse stresses should be avoided.
To comply with this condition, the centre line principle should be strictly observed when setting out the members at the joints (see Figs. 590 to 596). All the joints should be so arranged that they are least affected by shrinkage. Well seasoned timber should always be used in the construction of timber partitions.

A trussed partition is composed of at least a head, sill, doorposts, inclined members called braces, nogging pieces and studs. An intermediate horizontal wooden member, generally 7 in. by 4 in., called an interline, is usually provided in partitions exceeding 10 feet in height, which increases the rigidity of the frame. It is always a good plan to use mild steel straps for forming tensile joints. Very often a mild steel bolt is substituted for the entire tensile member. Generally an expanded metal lathing is fixed to timber studs in order to provide a base to receive plaster. The trussed partition may also be covered with galvanized iron sheets, wall boards, etc.

Three types of trussed partitions are shown in Figs. 584 to 586.

The studs are usually spaced at 12 in. to 15 in. centres. The studs are generally 4 in. by 2 in. and the door-posts are 4 in. by 4 in. The studs are stub-tenoned in the sill, head, and interline. The door-head is stub-tenoned into the door-post (see Figs. 580 and 581). The foot of the door-post is stub-tenoned into the sill, and is secured with a steel strap and bolts (see Figs. 582 and 583).
The dimensions of the sill vary according to the weight to be carried. It is generally 9 in. by 4 in. The sill receives the weight of the studs, and also receives at both extremities the thrust of the braces, causing them to be under a tensile stress.

Fig. 584
TRUSSED PARTITION

The head is generally 7 in. by 4 in. It acts as a straining beam (see the queen post roof truss,) for the braces, serves as a fixing for the studs and door-posts, and also as a support for the joints above which are nogged to it.

The braces are normally 4 in. by 4 in. They are generally in compression, and they assist in transmitting the weight to the walls. They also give rigidity to the frame. Each brace should always be in one length.

Fig. 587 shows the joint at the foot of the brace. The joint may be bridled, as in Fig. 588, or may be halved on (Fig. 589).
In either case a bolt (or a strap and a bolt) is required to secure the connection. See Fig. 587. In Fig. 590 is shown the joint at the head of the brace. Here the door-post is wider above the door to allow for the abutment of the brace, and thus this arrangement necessitates increased labour as well as a waste of material. An alternative method is shown in Fig. 591. The various other
Fig. 586
TRUSSED PARTITION CARRYING ITS OWN WEIGHT AND TWO FLOORS

Fig. 587
JOINT AT THE FOOT OF THE BEACe
Joints and connections are shown in Figs. 592 to 596.

Fig. 588
BRIDLED JOINT

Fig. 589
HALVED JOINT

Figs. 590 and 591
ALTERNATIVE JOINTS AT THE HEAD OF BRACE

Fig. 592
JIOINT BETWEEN STUD AND Brace
Figs. 593 and 594
JOINT BETWEEN STUD AND NOGGING PIECE

Fig. 595
JOINT BETWEEN THE HEAD, BRACE AND DOOR POST

Fig. 596
JOINT BETWEEN INTERTIE, BRACE AND DOOR POST
The ends of the sill, head and intertie are supported on 4 to 6 in. thick hard stone templates to get satisfactory bearings. Provision is also made to ventilate the ends of the above members thoroughly.

The size and arrangement of the framing are, of course, dependent upon the width of span between the walls, the number, size and position of doorways, and the number, if any, of floors to be supported by the partitions.

CHAPTER V.

QUESTIONS FOR REVISION.

1. Describe with the aide of sketches the methods of carrying out the following works:
   (a) Reinforced brickwork for partition wall. (University of Bombay, 1954).
   (b) Brick-nogging partition (University of Baroda, 1952 and University of Poona, 1951).

2. Draw neat sketches to explain the details of the construction of a timber partition between two rooms 14 feet wide and 12 feet high with a two-panelled door 2' 9" x 6' 9" in centre. Dimensions all the structural members of the partition and the door and add notes where necessary to explain the construction.
   Give the list of fixtures and fastenings required in the joinery work. (University of Bombay, 1953)

3. Draw to a scale of 1/4 inch to foot elevation of a timber framed partition across a room 20 feet wide. The partition to carry the floor above and below. There is a doorway opening at each end 7 feet high by 3 feet 6 inches wide.
   Height from floor to floor, 13 feet.

4. It is necessary to form an internal partition across a first floor between party walls and it is essential that the weight is not taken on the floor itself. A bressumer cannot be used. Give details to 1 inch scale of the partition you would design for this. Assume width to be 16 feet and height between floors 9 feet.

5. A room is 12 feet wide and 10 feet high from floor to ceiling. To 1/4 inch scale, draw the elevation of a braced wood
studded partition, supported at the sides only, and provided with a
doorway opening, 3 feet 3 inches wide and 7 feet high, placed
2 feet from one end.

6. Draw to a scale of $\frac{1}{8}$-inch to 1 foot, an elevation showing
the construction of a timber-framed partition across a room 18
feet wide, on the second floor of a dwelling-house, with a doorway
opening, 3 feet 6 inches by 7 feet, in the centre. Height, floor to
floor, 11 feet. The partition to be constructed to support the
floor above and below. Figure the sizes.

7. A room, 14' wide, is to be divided into two by a quarter
partition. It is to rest on the 4$\frac{3}{4}$" × 3" plates which carry the
floor joists on brick offsets.

Give, to a scale of 2 feet to an inch, an elevation of the
framing of the partition, showing a central opening 7' × 3' for
a door.

The scantlings, which are to be marked on the different mem-
bers are to be as follows:

- Sills 4" × 4".
- Stubs or quarters 4" × 2".
- Braces 4" × 2".
- Door stubs 4" × 3".

The details need not be filled in on both sides of the doorway.

8. Describe the following with sketches:

(a) Glass partitions.
(b) Terra cotta block partitions.
(c) Asbestos-cement partitions.

9. A half-brick partition wall is to be built in a big hall
across the width of 18 feet on the upper floor. The partition is
9 feet height. Show by sketches the details of its supports,
junction with the main wall built in rubble masonry, and give the
number of bricks required to build the partition.

(University of Poona, 1951).
CHAPTER VI.

CIRCULAR BRICKWORK, REINFORCED BRICKWORK AND DAMP-PROOF COURSES

Various sequences of brickwork except circular brickwork and reinforced brickwork are given in the Chapter on "Masonry-Brick Masonry." In this chapter the details of circular brickwork, reinforced brickwork and damp-proof courses are given.

Circular Brickwork. Circular brickwork is sometimes required for bay windows, wells of staircases, chimney stacks, apsed ends, steps, oval windows, factory chimneys, stelng to wells, etc. When circular brickwork is required, it is the general practice, even in cheaper class work to use only purpose-made bricks. Such bricks are moulded, to the required shape either by hand or by the machine. The radius of the curve should be stated when ordering the bricks. As purpose-made circular bricks are relatively expensive, it is usual to back the curved facings with common rectangular bricks which are axed to obtain radial joints. If the internal surface of a hollow or cavity wall is to be plastered, the interior leaf is normally built of common standard bricks, and unless the curvature is too sharp these bricks are not cut to obtain radial joints.

Alternative plans of a portion of a 13½ in. circular wall in English bond is shown in Figs. 597 and 598, and of an 11 in. circular cavity wall in Figs. 599 and 600.

The unsuitability of uncut standard common bricks for circular work is clearly shown in Figs. 601 and 602. They have produced very wide joints on the surface, as shown. The width of the joints can, however, be reduced by cutting each brick to a wedge-shape to form radial side joints. This method is not only an expensive one, but the appearance is also not satisfactory. In order to conform more closely to the curve, and when purpose-made bricks are not readily available, heading bond (see Figs. 393 to 395) may be advantageously adopted. But such a wall has an unattractive appearance, and is deficient in strength in the longitudinal direction.
Setting out circular brickwork:—There are two methods of setting out circular brickwork, viz., (a) Trammel method and (b) Temple method.

(a) Trammel Method:—A trammel is a board, usually ½ in. thick and 6 in. wide, upon which the positions of the concrete
foundation, brick footings and the wall are accurately marked. The trammel is holed at one end and passed over an iron or steel rod which is securely fixed in vertical position at the centre of the circle. The metal rod must be long enough to reach the top course of the proposed wall, and must be vertical as tested by a plumb-rule. The setting-out and construction of the circular or semi-circular or segmental wall are aided by the trammel as it is caused to rotate, and by plumbing. The trammel is raised as each course is completed. See Fig. 603.

(b) Templet Method:—A templet consists of two wide thin pieces of board, overlapped and nailed to each other. The outer and inner edges are made true to the required curve. The two ends are connected by a horizontal piece of wood, called tie, which projects beyond the two ends. The templet is strengthened by three wood struts called stays, which afford facility for handling. The templet is placed on the top of each course as required during its construction, any bricks not conforming to the curve being tapped in or out until their faces correspond to the curve. Though the templet method affords an accurate check than the trammel method, it is not generally used.

Reinforced Brickwork (R.B.W.). This type of construction is now very common. It is brickwork which has been strengthened by the introduction of wrought iron or steel in the
form of either bars, woven wire, or expanded metal. The W. I. or steel reinforcement is placed in the joints, or in grooves, or perforations in the bricks. Very often the reinforcement is placed in the bed joints. Reinforced brickwork, built skillfully, is reflect-ently capable of resisting tensile and shear stresses, in addition to compressive stresses. The work should be carried out in cement mortars, and the reinforcement should be carefully bedded and surrounded with the mortar to prevent the rusting of the material. A coating of liquid cement will also protect it from rusting. Rusting of reinforcement may cause serious damage because of the resultant expansion. The bricks should be hard, well burnt and free from defects such as cracks, flaws, lumps, etc. The cement mortar is usually composed of 1 part Portland cement to 3 parts sand. The reinforced brickwork may be advantageously used where settlements are liable to take place. Reinforcement of brickwork also improves the strength of thick walls in the longitudinal direction. A brick wall may be reduced in thickness by 4 in. provided it is effectively reinforced and such reduced thickness is not less than 8 in. Hence an increased floor area may be obtained by employing this type of construction.

There are several patents on the market for reinforcements, notably the Exmell, an expanded metal strip by Expanded metal company, London, and the Brietex, a steel wire lattice by the Johnson Reinforced Concrete Engineering Company, London.

The Exmell is sold in the market in 270 feet coils or bundles of 16 ft. long flat strips in three standard widths, viz., 2\(\frac{1}{2}\) in., 7 in., and 12 in. They are suitable for 4\(\frac{1}{4}\) in., 9 in., and 13\(\frac{3}{4}\) in. walls respectively, and they are made in thicknesses of 20 (0.015 in.), 22 (0.030 in.), and 24 (0.032 in.) B. W. G (Birmingham Wire Gauge). The size of the mesh is usually 5/8 in. Combinations of these widths are used for thicker walls. Sometimes only 2\(\frac{1}{2}\) in. wide strips are used for any thickness of wall, one strip to each half-brick thickness of the wall. Another method consists of staggering the strips, thus in a 9 in. wall, one 2\(\frac{1}{2}\) in. strip is provided on one course at one inch from the external face, and in the next course another strip is placed one inch from the internal face; this procedure is adopted for the entire height of the wall.
The 2½ in. wide strip is very suitable for cavity walls, curved walls, retaining walls, partitions, etc.

To prevent corrosion the metal in the coil form is coated with oil and then dipped in asphaltum paint. A piece of 2½ in. wide Exmet is shown in Fig. 604. Brick walls are usually reinforced at every third or fourth course, but sometimes it may be necessary to reinforce every course depending upon the nature of the loading. A brick wall reinforced at every third course with Exmet is shown in Fig. 605. The Exmet is uncoiled and carefully pressed down into the cement mortar immediately the latter has been trowelled on the bed. It lies sufficiently flat when uncoiled and thickness of the bed joints is therefore not increased. Footings, chimney stacks, boundary and balcony walls and parapets are also reinforced with expanded metal.
The Bricktor is a well known form of meshed reinforcement, which is produced in 2 and 2½ in. widths and supplied in coils. The former width is used for partitions while the latter is used for walls. One strip is provided at every half-brick thickness of the wall. This is used for all purposes for which the Exmet is used. A piece of 2½ in. wide Bricktor is shown in Fig. 605.

**Fig. 606**

**PIECE OF 2½ IN. WIDE BRICKTOR**

Hoop-iron Bond (Fig. 607 to 609). This is a type of reinforcement which is used to give additional strength to brick walls.

**Fig. 607 to 609**

**HOOP-IRON BOND**

This consists of wrought iron (called hoop iron) flat bars which are usually 1 in. wide and 1/16 in. thick. They should be well embedded in cement mortar (1:3) to prevent oxidation. Sometimes
they are dipped in hot tar to prevent them from rusting; they are then immediately sanded to increase adhesion of the mortar. They are provided in parallel rows, one for each half-brick thickness of the wall, at every sixth course. They are hooked at angles and junctions. Hoop-iron bond may be advantageously used where the tie at any part of the wall is weak or defective.

Sometimes 1/4" diameter steel bars are used at the bed joints of walls in lieu of hoop-iron or patented reinforcement. Such bars are well tarred and sanded to prevent oxidation.

Rod reinforcement:—Retaining walls are frequently reinforced. Generally 1/2" wide Exmet or Bricktor strips are embedded in vertical joints in addition to the bed joint reinforcement. Alternatively, they may be reinforced with vertical mild steel bars of circular section near each face, in addition to Exmet or Bricktor strips at every third or fourth course. But purpose made bricks are required for this type of construction (see Fig. 610). The bars should be carefully placed in position and the ends should be bent and anchored into the concrete foundation.

Fig. 610 to 612
SPECIAL BRICKS

Detached or isolated piers are very often reinforced with a 2½ in. wide strip of Exmet or Bricktor, which is set back 1 in. from the external face at every second course. Alternatively, they may be reinforced as shown in Figs. 613 to 619. This 9 in. square pier is reinforced with four vertical mild steel rods (3/8 in. diameter), well anchored into the concrete bed, and 8 in. by 8 in. by 1/4 in. steel plates or 10 gauge wire ties provided at every fourth course. All the steel rods and steel plates or wire ties are well bedded in cement mortar to prevent them from rusting. Details of an 18 in. square brick pier are shown in
Figs. 620 to 623. Steel plates, 17 in. by 17 in. by \( \frac{1}{4} \) in., may be embedded in lieu of the wire ties at every fourth course when heavier reinforcement is required. The purpose-made (specially

![Diagram of 9"x9" Reinforced Brick Pier]

![Diagram of 18"x18" Reinforced Brick Pier]

Figs. 613 to 623
Reinforced Brick Piers
Attached piers may also be reinforced as described above.

At the present time brick lintels are generally reinforced. They must be provided with additional support when the span is more than 3 feet, otherwise failures may occur. Two reinforced brick lintels are shown in Figs. 624 to 627. The lintel shown in Figs. 624 and 625 is reinforced with 3/8 in. diameter mild steel rods embedded in the longitudinal joints. The alternative form, shown in Figs. 626 and 627 is reinforced with bars and stirrups.
In Figs. 526 and 527, is reinforced with two 1/4 in. diameter mild steel bars or tension reinforcement embedded in the continuous longitudinal joint, together with 1/2 in. diameter stirrups, bedded in every third course. The stirrups are bent steel rods, which are provided to resist shear stresses.

Damp-Proof Courses: One of the chief requirements in building is that the structure shall always be dry. A damp building is very bad from every point of view. Damp is not only dangerous to the building structure, but to health too. Damp in the presence of warmth and darkness, breeds germs of tuberculosis, malaria, etc. When dampness rises into brickwork, certain salts dissolved in it, also rise with it, and appear in the form of white deposits on the surface of the wall, which cure the exposed surface of brickwork to disintegrate and fall to powder. Dampness also causes dry rot in timber, which is the very common form of decay in timber. Hence every building should be carefully protected from dampness. Though the high temperature of the Indian climate prevents dampness to a considerable extent, yet in closely built-up areas, wet situations, and localities of heavy rainfall, walls are liable to be affected by it. The following precautions should be taken to prevent dampness :—

1. The exposed wall should be of sufficient thickness. If of brick, it should be at least 13 in. thick.
2. The bricks should be hard, well burnt and free from defects such as cracks, flaws, lump of limestone, etc. They should not absorb more than 3 of their own weight when soaked in water for 24 hours.
3. The wall should be built in cement mortar composed of 1 part Portland cement and 3 parts sand, and a systematic bond adopted throughout the work. There should be no hollows inside the body of the wall, and care should be exercised to get a uniform joint so that unequal settlement, if any, may be prevented.
4. Cornices and string courses should be provided. Window sills and coping of plinth and string courses should be sloped on top and throated on the under-side to throw the rain-water off the face of walls.
5. The exposed surface should be covered with water-proofed
cement plaster. The later is cement plaster (1:3) in which some water-proofing compound is mixed.

(6) Hollow walls are more reliable than solid walls in preventing dampness, and they should, therefore, be constructed wherever possible.

Causes of dampness:—There are various causes of dampness in walls, the chief of which are given below with their remedies:

(1) Moisture rising up the walls from the adjacent ground. This may be remedied by providing air drains 1 and damp-proof courses (see Figs. 628 and 629), or by damp-proof courses alone (see Figs. 630 to 613). Sub-soil drainage may also be provided (see Fig. 633).

(2) Rain beating against the walls which may absorb the water to such an extent as to show dampness on the internal faces. This may be remedied by providing an impervious coating, such as water-proofed cement plaster. Alternately, the exposed face of the wall may be protected and dampness prevented by erecting "tatilies or thatties" of hay or bamboo matting, temporarily, during wet season. The bamboo matting needs to be painted with tar on the external surface, which makes it repel water, and also prolongs its life.

1 An air drain is a narrow dry space (9 in to 12 in. width), which is provided on the outer face of wall below the ground level. It is formed by a thin outer wall resting on the concrete bed of the foundation, as shown in Fig. 628 and carried up to a little above the ground level (usually 6 in.) to prevent surface water entering the drain. Openings are also provided at regular interval with grating. The narrow space is covered at top by thin stone or R. C. C. slabs, due provision being made for examination of the drain and keeping it clear. Damp-proof courses are also provided horizontally and vertically as shown. An air drain with wall ties is shown in Fig. 629.

2 In districts bordering on the West Coasts of India, which are exposed to heavy rains of the south-west monsoon, the local practice is to cover the external walls on the south and west sides of the building with hay or bamboo tatilies right up to the top, to prevent rain beating against the walls.
Fig. 628
AIR DRAIN

Fig. 629
AIR DRAIN WITH WALL TIES
Another method consists of constructing a 4½ in. thick brick wall on the outer side of the walls exposed to heavy rain, leaving a cavity of 1 in. between, and filling the cavity with hot asphalt or...
some good water-proofed cement plaster. The outer surface of the new wall should be covered with a thick coat of water-proofed cement plaster.

(3) Water descending into the walls from a leaking roof, or rain passing down from the top of walls. This may be remedied by projecting caves with proper gutters (see the chapter on "roofs"), or, if the roof be terraced, having an upper damp-proof course.

**Damp-proof courses:** A damp-proof course is a continuous layer of an impervious material which is provided to prevent the damp from rising from the ground and getting into the building. Its function is to maintain a dry and sanitary condition of the interior. It should be laid on all walls just above the ground and below the floor level. It should be laid at least 6 in. above the ground level, otherwise soil may be deposited against the external face of the wall at a greater height than the impervious layer and thus water may be transmitted from it to the wall above the damp-proof course. Damp-proof courses are used both horizontally and vertically. Horizontal damp-proof courses are used to prevent the dampness from rising from the ground and getting into the walls, while vertical damp-proof courses are employed to prevent the dampness in walls of basements. Horizontal and vertical damp-proof courses are shown in Figs. 628 to 633.

Damp-proof courses are made of various materials, of which the following is a short list:

1. Asphalt or Natural Asphalt heated, and spread upon the wall in % in. layers. Asphalt forms an excellent damp-proof course, it being impervious and indestructible; further it does not fracture, if, on account of unequal settlement, cracks are caused in the brickwork.

2. 1/4 in. sheets of bituminous or asphalted felt, prepared in rolls (of 24 yds. long) and of widths to suit brick walls. In laying the sheet in position, a thin layer of mortar is trowelled on the brickwork and the damp-proof course is bedded on it. It should be lapped at least 4 in. where joints occur and lapped full width at all angles and crossings. It should be pointed in cement mortar.

3. Sheets of lead (which weigh 4 to 8 lbs. per sq. ft.) spread upon the wall, and lapped at the joints in a similar manner to asphalted felt. The joints may also be sealed. The sheets should
be embedded in lime mortar and not in cement mortar. 

(4) A combination sheet consisting of lead foil interleaved between two thicknesses of asphalted felt, giving greater durability to the material. "Ledkore" is a good example of this. Ledkore is a combination of lead and asphalted felt. It is easily laid, efficient, durable, and economical.

(5) Sheets of copper spread on the wall and lapped or jointed as described for lead sheets, and embedded in lime or cement mortar. The copper should weigh at least 1 lb. per sq. ft. Copper is another excellent damp-proof course.

(6) Two courses of sound slates set in cement mortar composed of 1 part of Portland cement and 3 parts sand. Some patented water-proofer, such as Pudlo Cementone, Dempo, or Cico, may be added with cement plaster. The slates must extend the full thickness of the wall, and be neatly pointed in cement mortar. It is an effective damp-proof course, but it is liable to be broken if unequal settlement occurs.

(7) A thick coat of water-proofed cement plaster.

CHAPTER VI.

QUESTIONS FOR REVISION.

1. Explain with sketches any three of the following:
   
   (a) Damp-proof course (University of Baroda, 1952 and University of Bombay, 1954).
   
   (b) Reinforced brickwork (Gujarat University, 1954 and University of Poona, 1956).
   
   (c) Reinforced brickwork for partition wall (University of Bombay, 1954).

2. What do you understand by reinforced brickwork? Draw a sketch showing a slab of reinforced brickwork (Gujarat University, 1953).

3. What is circular brickwork? Describe the method of setting out brickwork by Trammel method. How will you prevent them? Mention six types of materials generally used for damp-proof courses.

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1 Some mortars particularly cement mortars, act upon lead and destroy it; such should therefore not be used as a bedding material for lead damp-proof courses.
PART II
CHAPTER VII

SCAFFOLDING, SHORING AND UNDERPINNING

Scaffolding:- A scaffolding or scaffold is a temporary structure, which is used in building operations to support platforms for workmen, structural materials and appliances required during construction. The scaffolding is erected either on one or both sides of the walls. Ordinary works may be done by scaffolding on one side. But for all first-class works the scaffolding must be provided on both sides of the walls.

There are two varieties of scaffolding in common use, viz., (1) The Bricklayer's scaffolding and (2) The Mason's scaffolding.

(1) Bricklayer's Scaffolding:- This is the ordinary and cheap type of scaffolding and is also known as the single scaffolding. A typical scaffolding as used for wall construction is shown in Figs. 634 and 635. A bricklayer's scaffolding consists of vertical members called standards, horizontal members called ledgers, cross members called putlogs, diagonal members called braces, and working platforms. Most of the members (excluding platforms) of the scaffolding are usually made of bamboos and poles. The scaffolding should be strong enough for the purpose. The standards, usually 4 in. diameter and 25 feet long, are driven into the ground at 5 ft. to 8 ft. apart and about 4 feet away from the wall to be constructed. The feet of the standards should be well bedded. Where it is not possible to fix the standards in the ground, they may be placed in tubs or barrels filled with sand or earth and made heavy against any movement or slipping. The standards are then firmly connected to each other by ledgers placed at right angles and spaced at a vertical distance of 4 to 5 feet (towards the building side). The putlogs, about 3" by 3" by 6' and spaced at 4 feet centre to centre, are supported on the ledgers on one side, and in holes in the wall on the other side, formed for the purpose by leaving out a header in laying. The putlogs support the timber planks (about 9 in. by 1½ in. by 12 ft.) forming the working platform.
Sometimes toe boards are provided for protection at the level of the working platform. The standards, the ledgers and the putlogs are fastened to one another by ropes. Sometimes nails and
bolts are also used for strengthening the scaffold. For longitudinal stability of the scaffolding, cross or diagonal braces are used. As the work proceeds, the platform is raised higher and higher and the standards are lengthened by adding extra pieces, if necessary. The scaffolding will be removed after the pointing or plastering and white-washing on the external wall surface is finished. After removing the putlogs, the holes will be filled solid immediately.

(2) Mason's scaffolding or Double Scaffolding:—This type of scaffolding is stronger than the bricklayer's scaffolding and is used for constructing stone masonry walls. In Mason's scaffolding two rows of standards are used, one close to the wall within 6 in. of the face and other at 4 to 5 ft. away from the face of the wall. The putlogs are supported at both ends on ledgers. This is more convenient as it is not possible nor advisable to leave holes in stone masonry walls at regular intervals. Thus the scaffolding is completely independent of the wall. Sometimes, in addition to the diagonal braces, inclined supports called shoring are provided to prevent the scaffolding from slipping away from the wall. The platforms are provided as in bricklayer's scaffolding. The scaffold must be made strong to carry the load of bigger blocks of stone and their movements while keeping in position. A typical mason's scaffolding is shown in Fig. 636.

In addition to the two principal types of scaffolding described above, the following are the other types of scaffolding which are also used:—

(3) Ladder scaffolding:—This is an improved method of a double scaffolding, and is shown in Fig. 637. This type of scaffolding can be easily assembled. This is very suitable for light work such as exterior paintings and decorations. Nowadays several patent ladder scaffolding are available in the market. The assemblage is secured by means of bolts and screws. The working platforms are supported on brackets, bolted to the inner row of standards. Sometimes the ladder scaffolding is secured by additional cross pieces tied to windows.

(4) Cantilever or Needle Scaffolding:—This type of scaffolding is used where it is not possible to fix the standards into the
ground in the usual manner. An example of a cantilever or needle scaffolding is shown in Fig. 638. The scaffolding is supported by a series of cantilevers or needle beams passing through window openings or through holes left or made in the walls. The inner end of the needle beam is projected to a reasonable distance and is strutted firmly between the floors. On the outside, the end of the beam is propped by a strut against the sill of a window or by any other suitable means. The needle scaffolding is also used to execute repairs or decorative work at higher level in a building.

5) Suspended Scaffolding:—This is another type of scaffolding, which is very suitable where steel frame construction is
adopted. In this type, the standards do not rest on the ground. The scaffolding is hung generally from the roofs by means of wire ropes and a travelling cradle is provided for workmen and materials at its lower end, which can be mechanically raised or lowered as required. This is a cheap type of scaffolding and is suitable only for carrying out light construction work.

(6) Steel Scaffolding—Although the ordinary type of timber scaffolding is economical, it can be used to moderate heights only. Steel scaffolding can be used to any height of walls of buildings. Steel scaffolding may consist of a single or double row of tubular uprights with tubular horizontals and cross pieces with special couplings and set-screws for junctions and joints. The tubes used are usually 1½ in. diameter, the metal being No. 6 gauge or about 1/8 in. thick, and are available in lengths of 6 ft. and above. The initial cost of the steel scaffolding is considerably higher than that of timber scaffolding, but it lasts much longer, is low in maintenance cost, is neat in appearance and increases the safety of the workmen. Steel scaffolding can be erected in position and dismantled with great rapidity and ease. Moreover, it is not necessary to leave holes in the wall for resting part of the scaffolding as required for the cross pieces called putlogs in the ordinary scaffolding.

Special forms of scaffolds are built for the construction of domes, tall chimneys, etc. The scaffolding should never be heavily loaded as it is only a temporary structure.

The structural materials and other appliances required during construction are carried to the required level on the scaffolding by inclined gangways, made roughly with poles and bamboos. The gangway should not be steeper than 1 vertical to 1 horizontal.

Thinking that the scaffolding is only a temporary structure, very often sufficient attention is not paid to its structural requirements. Such carelessness is very dangerous in every point of view to workmen. These structural defects will sometimes cause dangerous accidents. Hence only sound and strong materials should be used for scaffolding, and the erection work should be carried out in a perfect workmanlike manner so that the entire temporary structure possesses requisite stability and ensures the
safety of workmen. The uprights or standards should be made to rest on a firm ground, and they should be capable of withstanding the various stresses. Proper lapping should be provided whenever the length of a standard has to be extended by joining another. The width of the working platform should be at least 2 ft. and it should be provided at every vertical interval of about 5 ft. The working platform should be made of one or more planks, and the planks should not overlap, but only butt against each other to prevent tripping.

Gantries:—The scaffoldings described above can be used for works where the materials used in the work can be easily handled by the masons. But where the blocks of stone or material used for the construction are too large, and require a lifting tackle, the ordinary scaffoldings are unsuitable, and gantries are required.

The term gantry is used to indicate a timber or steel staging for carrying a travelling crane for handling heavy materials. The gantry is usually made of squared timbers in the same manner as the mason’s scaffolding, but with only one row of standards on either side of the wall. On the top of the standards, longitudinal timber pieces called runners are provided upon which a line of rails are fixed to carry a travelling platform. Rails are also provided on the top of the travelling platform, and the travelling platform in its turn carries a lifting tackle which moves on these rails, in a direction perpendicular to the length of the gantry.

The standards are placed from 10 to 20 feet apart depending on the size and the weight to be supported. The gantry should be stiffened with the aid of struts placed against the standards to prevent lateral movement.

Shoring:—The term shoring is used to indicate temporary support to unsafe structures, the stability of which has been endangered due to the unequal settlement of the foundation, or due to the removal of adjacent buildings or due to the defective or bad workmanship. Shorings may be classified into three classes, viz., (1) Raking or inclined shores (2) Flying or horizontal shores and (3) Dead or vertical shores.

(1) Raking or inclined shores:—These are used to support the unstable part of a structure. A raking shore consists of at least inclined members called rakers, needles, cleats, braces and
wall plates. Most of the members are usually made of wood. An example of a raking shore is shown in Figs. 639 to 642.

Figs. 639 to 642
Raking Shore. (Note that the upper ends of rakers are at the junction of each floor where supports are required most.)
One end of the rakers rests on the ground and the other end abuts against the wall of the building to be supported. A wall plate about 3 in. by 9 in. is placed against the wall, and secured to it by square needles which penetrate into the wall for a depth of 4\(\frac{1}{2}\) in. to 6 in. These needles prevent the wall plate from sliding against the wall. A wooden cleat is nailed immediately above the needle to increase the resistance of the same. The various rakers or baulks of a raking shore are rigidly interconnected by timber braces, usually 1 in. thick and 6 in. wide, nailed on the sides of the rakers, and the braces are usually placed immediately below the needles, as shown in the figure. The feet of the rakers are tied together by braces and hoop iron and they are made to rest on a timber sole plate firmly bedded into the solid ground. The rakers are secured to the sole plate by dog spikes (see Fig. 641).

In the case of multi-storeyed buildings, one raker is usually placed at the junction of each floor with the wall. The top most raker is called the rider raker. The rakers should be placed inclined on the ground at an angle of 45° in order to make the shoring quite effective.

![Fig. 643 Flying Shore](image)
(2) Flying shores:—These are used for supporting temporarily the walls of the two adjacent buildings, which may tend to collapse or damage due to the removal of the intermediate building designed to be re-built. A flying shore consists of at least wall plates, struts, straining pieces, horizontal struts, and cleats. A flying shore in position is shown in Fig. 643. It will be seen from the figure that the flying shores temporarily take up the position of the dismantled building. For erecting a flying shore the positions of the wall plates and the intersections of the needles and cleats are first carefully fixed, and then the horizontal and inclined struts and straining pieces are placed in their correct position.

(3) Dead shores (Fig. 644 and 645):—These are used for supporting temporarily the walls in connection with the rebuild-
ing or deepening of the foundations; or to provide large open­
ings in walls for doors, windows or shop fronts at lower levels.

To provide dead shores to a building, the door and window
openings are first strutted squarely to resist any deformation, and
then the floors inside the building are strutted by vertical timber
posts or struts of 6 in. by 6 in. to 10 in. by 10 in. At the top
and bottom of these vertical struts or posts timber heads and
sole pieces are provided to distribute the load effectively.

Wedges are also used below the foot of the strut for tightening
up the same. Holes are then made in the wall by crow bars at
points above the required opening, at a distance of 3 to 5 feet
apart, and through these holes timber or steel beams called
needles are inserted and projected at right angles on each side
of the wall. The ends of the needle beams are then supported
by heavy props. The props are made to rest on a timber sole
piece, firmly bedded on the ground. A pair of folding wedges
is generally used below the props for tightening up the needle
beam against the wall which it has to support. The needles
and props should be sufficiently strong to carry the weight of
the wall above. Sometimes raking shores are provided to the
wall above the portion to be removed for additional safety.

Underpinning:—Underpinning is a term which is used to
strengthen the foundations of an existing building having shallow
footings, when a building with deep foundations has to be con­
structed adjoining to it. Underpinning is sometimes resorted to
for rebuilding parts of walls above the ground level. During
underpinning, the existing buildings should be temporarily
supported by means of raking shores until the new foundations
or walls or both are constructed permanently. Underpinning
is usually provided by two methods, viz., (1) Pit Method, and
(2) Pile Method.

(1) Underpinning by Pit method:—In the pit method, the
excavation is carried down to the level of the proposed new
foundation, and the whole length of the wall is divided into
various sections, generally four or five feet in length, and each
time a section is excavated. The excavated portion is then filled
with cement concrete consisting of 1 part Portland cement, 2
parts sand and 4 parts broken stone. Rapid hardening cement
may also be used instead of Portland cement. A satisfactory
The connection between the old work and new work may be obtained by employing vertical mild steel bars of circular section. In practice, alternate sections are taken up in the first stage, and finally the intermediate ones are taken up for excavation and filling. The earth filling in each section is done as soon as the section in question is completed. In Fig. 646 is shown the method generally adopted for supporting a wall for underpinning. The needle beam rests on the crib supports, and jacks are used under the supports.

Fig. 646—Showing the Pit Method of underpinning.
Fig. 647—Showing the method of strengthening wall foundations by concrete encasing.
Underpinning by pile method: Sometimes the pit method described above cannot be used in water-logged areas. In such cases, precast R.C. piles or steel piles are driven to the required depth by a suitable means. On the top of these piles, R.C.C. caps are provided, just below the level of the wall to be underpinned, and the remaining gap is filled with 1:2:4 cement concrete. The pile method is very suitable for great depths and for heavy loads.

The foundations of piers and columns may also be strengthened by providing underpinning as described above.

The foundations of existing walls and piers are sometimes strengthened without removing or reconstructing them and thereby eliminating the process of underpinning. This is done by simply encasing their lower portions with cement concrete (1:2:4), as shown in Fig. 647. Mild steel rods of circular sections are passed through the wall, and also along the wall. Rolled steel joists are sometimes used with steel rods. The method of construction is easy and can be used without much technical knowledge. This method has been successfully adopted for many important buildings in India.

CHAPTER VII.

QUESTIONS FOR REVISION.

1. What are scaffoldings? Explain with sketches different types of scaffoldings generally used for works. (Karnatak University, 1955.)


3. Write short notes on the following:
   (1) Scaffolding. (Gujarat University, 1952)
   (2) Gantry with travellers. (University of Baroda, 1954)
   (3) Shoring.

4. Describe and illustrate with sketches the work of underpinning a three feet brick wall in brick-work to a depth of 6 feet below ground level. Specify suitable brick and mortar for this work and discuss method of pinning up the new work to the old. (University of Sind, 1950)
5 A wide door has to be provided in the blank wall of a shop. Explain the method by which you would carry out the work, indicating clearly the shoring that you would provide to support the roof on either side of the wall. (University of Poona, 1956).

6 The face wall of the upper storey of a building is badly cracked and its replacement has become inevitable. Explain, drawing neat sketches, the method of carrying out the work.
(University of Sind, 1950)
CHAPTER VIII

LINTELS AND ARCHES

Lintels:—Lintels are horizontal members which are placed over the openings such as door or window openings to support the structure above the openings. Lintels are usually rectangular in shape and they afford facilities for fixing the door and window frames, wherever they are used. Lintels may be made either of wood, stone, brick, reinforced brickwork, reinforced concrete or rolled steel sections embedded in cement concrete. The lintels must be sufficiently strong to resist failure due to the forces of compression, tension and shear.

1) Wood lintels:—In India, it is very common to use wood lintels for bridging across the openings and to support the work above. Wood lintels are generally made of sound and hard timber such as teak, and hence they are costly. Wooden lintels are liable to be destroyed by fire and decay. The size of the lintels largely depends upon the thickness of the wall, the span and the weight to be supported. The depth is usually about 1/12 of the span with a minimum of 3 in., and the width is equal to the full thickness of the wall. The ends of the lintels have a 6 in. wall-hold and are bedded on mortar so as to ensure a level and firm bearing. Single sections of wood or built-up sections of two or more pieces held together by bolts at suitable intervals, are used for the purpose. Built-up lintels are generally used for larger spans. Wooden lintels are generally assisted by a rough brick arch as a precautionary measure in the event of the timber being damaged or destroyed. The space between the lintel and the arch is filled with a brick core. A wooden lintel used in conjunction with a rough relieving arch is shown in Fig. 680.

2) Stone lintels:—Stone lintels should be used only in exceptional cases as stone is unsuitable to withstand transverse stresses. They should never be used for openings above 3 feet in span unless relieved of the weight above by a discharging arch,
otherwise they would require to be abnormally deep. As a general rule, the thickness of a stone lintel should be \( \frac{1}{4} \) in. per foot length of the span of the opening with a minimum of 9 in. Stone lintels also cost a good deal for quarrying, transporting to the working site, and dressing.

(3) Brick lintels (Figs. 648 and 649)—A brick lintel is composed of bricks which are normally laid on end and occasionally on edge. The depth of the brick lintels depends upon the size of the opening and the appearance required: their depth is usually \( 4\frac{1}{2} \) in. or 9 in. The brick lintel is constructed on a temporary wood support known as turning piece. Brick lintels are weak in construction and in strength and hence they cannot be used for supporting heavy loads above. They should, therefore, be used to span small openings only, and the span should not be more than 3 feet. The bricks should be hard, well-burnt and free from defects such as lumps, cracks, flaws, etc. Cement mortar composed of 1 part Portland cement and 8 parts sand should be used, and pressed bricks having a frog on each bed are better than wire-cut bricks. The term jogged brick lintel is used to this type when bricks having frogs are used, the joggle
or notch being made by the widened joint at each frog. The joggles resist the shearing action to which the lintel is subjected.

It is common practice for small spans to bed brick lintels directly upon the heads of the door and window frames; such frames should be set back 1 in. from the external face of the wall.

(4) Reinforced brick lintels.—These are described on page 17

(5) Reinforced concrete lintels.—In Modern practice reinforced concrete lintels are extensively used as they are cheap and convenient. They are fire-proof, durable and strong. The relieving arches may be eliminated by using these R.C.C. lintels. Concrete alone is unsuitable for lintels as it is comparatively weak in tension, and hence the lintel is commonly strengthened by using mild steel bars or some other form of steel reinforcement. A suitable mix of concrete consists of 1 part Portland, 2 parts sand and 4 parts broken stone of 1 in. gauge. The R.C.C. lintels may be either precast or cast in situ. The former are cast in wooden moulds (with 1½ to 1½ in. thick bottom and sides) which are removed when the concrete has set. The precast method is very often employed as the lintels can be made well in advance to allow them being sufficiently cured for fixing when required and the construction of the walling above them may be continued immediately after fixing. This method is also economical, as the same moulds may be used several times, and less skill is required for fixing the precast lintels. Precast lintels are very convenient for small spans up to 6 feet. For larger spans the lintels should be cast in situ unless special lifting tackle or cranes are available. In the case of precast lintels, the top should be carefully marked with tar or paint soon after the concrete is poured into the moulds; if they are mistakenly laid in a reversed position disastrous results will occur.

The number and size of the reinforcement depend upon the span, width and load to be supported. Up to 4 ft. span, one 8/8 in. diameter steel bar per 6 in. or part width of wall is usually quite sufficient. Thus, for a wall of 13½ in. of brick, or 18 in. of stone, three rods, bent as shown in Figs. 650 and 651, may be placed in the mould, two placed 1½ to 2 in. inside from the faces, and one in the centre. For spans of 4 to 6 ft. width three
\[\begin{align*}
\frac{1}{2}\text{ in. diameter steel bars, bent as shown in Figs. 650 and 651 are used. Above 6 feet span, the steel bars are assembled like those shown in Figs. 650 and 651.}
\end{align*}\]

Fig. 650 3/8 in. diameter steel bars for concrete lintels up to 4 ft. span. The ends of the bars are hooked as shown in order to increase the bond or grip between them and the concrete.

Fig. 651 R. C. C. lintel for spans up to 4 ft. for a beam, with two rods at top, and all surrounded by vertical stirrups, as shown in Figs. 652 to 654. The reinforcement is correctly placed in the moulds and the concrete is poured in, care being taken in packing it round the reinforcement. A thickness of 4 to 8 in. is normally sufficient for lintels up to 6 ft. span. An R. C. C. lintel carrying a chajja or canopy is shown in Fig. 655.

(6) Lintels of rolled steel sections embedded in cement concrete:—These are very costly and are generally used over wide openings, especially when they have to support heavy loads.
of solid walls in positions such as shop fronts, bay-windows, etc. They are sometimes called bressummers. These lintels are also used where there is no space for an arch above. They are usually composed of three I-beam sections which are held together at proper distances apart by cross-bolts and are well embedded in cement concrete. Cast iron or steel distance tubes are sometimes introduced between the adjacent rolled steel sections, as shown in Fig. 656. At the bottom of the steel sections a strip of metal lathing or wire netting is provided to increase the bond or grip between them and the concrete.

![Fig. 655](image1)

![Fig. 656](image2)

**Fig. 655** Showing an R.C.C. lintel carrying a chajja or canopy.
**Fig. 656** A lintel of rolled steel section embeded in cement concrete.

**Arches:** An arch is a structure comprising a number of tapered or wedge-shaped blocks, which are jointed together with mortar. The blocks uphold themselves by mutual pressure, and the entire arch is maintained in equilibrium by means of th.
resistance of supports. Arches are usually built about the form of some curve, and are used in buildings over openings in walls as those for doors and windows to support the loads above. The following points should be noted in designing and constructing arches:

(1) The supports such as abutments or piers (see below) should be sufficiently heavy and strong, and they should not move or fail under the moment due to the arch thrust.

(2) Only first class blocks should be used in the work. For larger spans, the arches should be strengthened by steel reinforcement.

(3) The thickness of the arch and its curve should be so designed that the line of resistance at any section falls within the middle-third of the arch. This assists in preventing the tensile stresses in the arch.

(4) The safe resistance of the material of an arch should not be exceeded.

(5) All the bed joints should be perpendicular to the line of least resistance. Normally they are made normal to the curve of the arch, in which position they are nearly perpendicular to the line of least resistance.

(6) The temporary support (called centering) used for the construction of arches should not be removed either during construction or before the mortar is set. The centering must be eased slightly two days before its removal so that the voussoirs may close in and press the mortar, and the centering must be completely removed before any masonry is constructed on the top of the arch.

Technical terms:— Most of the technical terms generally used in connection with arches are illustrated in Fig. 657 and the following is a brief description of them:
Fig. 657 Showing various parts of an arch.

1. Voussoirs.—These are the tapered or wedge-shaped bricks or blocks of stone or precast blocks, forming the courses of an arch.

2. Key.—This is the uppermost or central voussoir of an arch. It is sometimes emphasized by making it larger and projecting it above and below the outlines of an arch. Although it is common to insert a keystone or key-brick in the centre of many types of arches, it is neither a theoretical nor structural necessity. Anyone who chooses to do so can build an arch without a key, the question is merely one of taste.

3. Springers.—These are the extreme or lowest voussoirs of an arch, which are placed immediately adjacent to the skewbacks. See Fig. 658.

4. Springing points.—These are the points from which the curve of an arch commences or springs.

5. Springing line.—This is the horizontal line joining the two springing points. See Fig. 658.
6. **Abutments.** These are the outermost supports of an arch, from which the arch springs. The abutments are designed to resist the inclined thrust from one or more arches, and are therefore made of greater weight than ordinary piers.

7. **Piers.** These are the intermediate supports of a series of arches or an arcade.

8. **Arcade.** This is a series of arches, adjoining each other, supporting a wall and being supported by piers.

9. **Skew-backs.** These are the inclined or splayed surfaces of the abutments prepared to receive the arch and from which the arch springs. See Fig. 658. Skew-backs are not required to some types of arches.

10. **Ring, Rim, or Ring course.** The circular course or courses comprising the arch.

11. **Extrados or Back.** This is the upper or convex side of an arch.
12. **Intrados, soffit or bottom.** This is the under or concave side of an arch.

13. **Crown.** It is the highest point of the extrados of an arch.

14. **Haunch.** It is the name given to the lower half of the arch, from the skew-back or springer, midway to the crown.

15. **Jamb.** These are the sides of the abutments or piers below the springing line.

16. **Impost.** It is a projection at the upper part of an abutment or pier, which is sometimes finished with a moulded cap.

17. **Span.** It is the horizontal distance between the springing points.

18. **Rise.** It is the vertical distance between the springing line and the highest point of the intrados.

19. **Centre.** It is the geometrical centre point, from which the lines or arcs forming the extrados and intrados are described or struck.

20. **Depth or Height.** It is the perpendicular or normal distance between the extrados and intrados.

21. **Spandril.** It is the name given to the irregular triangular space between the extrados and a horizontal line drawn through the crown.

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![Fig. 659](image1) ![Fig. 660](image2)

**Fig. 659**  **Fig. 660**

Two different forms of flat stone arches.
Classification of arches*: Arches are classified according to (a) their shape, and (b) the materials and workmanship employed in their construction.

(a) Classification of arches according to their shape: Arches are generally named from the outline of their soffit or underside. The common types of arches are: (1) Flat arch, (2) Semi-circular arch, (3) Segmental.

* As already mentioned on page 18, arches are made of tapered or wedge-shaped blocks (except monolithic arches of concrete), and such arches are called "voûte arches". The voussoirs may consist of either (1) ordinary or standard uncut bricks, (2) axed bricks, (3) purpose-made bricks or (4) rubber bricks. These bricks are briefly described hereunder:

(1) Ordinary or standard uncut bricks:—When such bricks are used in the formation of arches, the bed joints are not of uniform thickness. An arch constructed of these bricks is relatively weak in bonding and strength, and is quite unsuitable to support heavy loads. These bricks are used in the construction of plain or rough brick arches.

(2) Axed bricks:—These are standard or ordinary bricks which have been roughly cut to the required shape by a bolster and dressed off with an axe. They are used in the construction of axed brick arches.

(3) Rubber bricks, Rubbers, Cutters or Malmus:—These are soft bricks which may be sawn and rubbed to the required shape. They may be obtained in various sizes, and are used in the construction of gauged brick arches.

(4) Purpose-made bricks:—These are special bricks, which have been moulded to the required shape. They are used for first class work.
(1) Flat, straight, square or camber arch.—A flat arch is shown in Fig. 658. The extrados is horizontal and the intrados is given a slight camber or curvature by providing a rise of $\frac{1}{8}$ in. per foot of span in order to prevent it from being hollow when the arch settles. The angle of the skewbacks is usually 60 degrees. The depth of the arches is generally equal to three or four courses of bricks, and all the bed joints are laid radial from the corresponding centre. Flat arches are not very strong and hence they should be limited to spans of from 4 to 5 ft. unless they are strengthened by steel reinforcement.

Three different forms of flat stone arches are shown in Figs. 659 to 661.

![Illustration of flat arches](Fig. 661)

Showing two different methods of securing stone voussoirs.

(2) Semi-circular arch.—Different varieties of semi-circular arch is shown in Figs. 662 to 665 and in Fig. 657. It is con-
structured on a centre, which is at the centre of the springing line. In this type of arch skew backs are generally omitted.

Fig. 662
Two different forms of semi-circular rough brick arches.

(3) Segmental arch:—Two varieties of segmental arch are shown in Figs. 666 and 667. The bed joints of the voussoirs radiate from the centre which is below the springing line. Cross joints may be omitted if desired. The method of getting the outline of a segmental arch is as follows:—Take as example an opening 8 ft. wide, with a rise in the centre of 2 ft. (see Fig. 668). Mark the points A, B, C in the required curve, the point C being in the centre. Join the points AC and BC. Bisect the lines AC and BC by the ordinary geometrical method by the lines DE and FG at right angles to AC and BC respectively. Produce the lines DE and FG indefinitely so that they may meet at O. The point O is the centre of the circle of which ABC is the required segment. The depth of segmental arches may be 9 in., 13\(\frac{1}{2}\) in., or any multiple of half-bricks according to the class of work, width of opening, etc.
Figs. 663 to 665 Three different types of semi-circular stone arches.
Fig. 666
Segmental brick arch.

Fig. 667
Segmental stone arch.
A few other types of arches are briefly described below:

**One centred arch**—This type of arch has only one centre from which the bed joints of the voussoirs normally radiate. Flat, semi-circular, segmental, stilted, horse-shoe, and circular, or wheel or bull's eye are examples of one centred arches.

![Fig. 668](image)

**Fig. 668**
Showing the method of setting out segmental arch.

![Fig. 669](image)
Fig. 669
Stilted arch.

![Fig. 670](image)
Fig. 670
Horse-shoe arch.
The first three examples of arches are shown in Figs. 657 to 667 and the remaining are shown in Figs. 669 to 671.

Fig. 671
Circular, Wheel, or Bull's eye arch.

Two centred arches:—The curves of these arches are struck from two centres. Equilateral, lancet or acute and obtuse or drop arches are good examples of two centred arches, and they are shown in Figs. 672 to 674.

Three-centred or Elliptical arch:—Three centred arch is a common term, and is derived from the fact that three different centre points are used for striking the arcs. It would popularly be called an elliptical arch, but although very much like one, it is not truly elliptical. The object of using three centres instead of a semi-ellipse is because the arch joints in the former case are very easy to set out, while in the latter case every joint would have to bisect the angle formed by lines drawn from the two foci. To find the points for striking the small arcs divide the span into six equal parts, the radius of the small arc being one part. Then open the compasses to the distance between these centres, and strike arcs intersecting below, giving the centre for the large arc, which will have a rise of a fraction over one.
fourth of the span. See Fig. 675. An elliptical arch is not structurally sound. It is sometimes preferred to the segmental arch where a comparatively large span is required and the height is restricted.
Fig. 675
Setting out a semi-elliptical arch by three centres.

Fig. 676
Three-centred drop arch.
Another form of three-centred arch called **three-centred drop-arch** is shown in Fig. 676. The method of getting the one line of the arch is clearly shown in the figure.

Four-centred arch: A four-centred arch is also known as the Tudor arch, and is illustrated in Fig. 677. In this type, two centres are on the springing line and the other two below the springing line. The method of setting out the arch curve is shown in the figure.

Five-centred arch: A five-centred arch is shown in Fig. 678. For setting out a five-centred arch, draw the springing line of the arch, and divide it into five equal parts, as shown. With a radius equal to the span describe arcs intersecting at E. Join E2 and E8, and produce them indefinitely. With C and D as centres...
and CD or DC (equal to three divisions) as radius draw arcs intersecting at F. Join FC and FD, and produce them indefinitely.

Fig. 678

Setting out five-centred arch.

The small circles show the centres for describing the five curves in the arch. Complete the arch as shown in the figure. A five-centred arch is more or less like a semi-elliptical arch. Thus a semi-elliptical arch may be easily formed either by three-centres or by five-centres.

French or Dutch arch: This type is sometimes used for inside openings of narrow span. It is a relatively weak form of construction, and is not suitable for large spans. This type is illustrated in Fig. 679.
Relieving arch: This type of arch is also known as the discharging arch. A relieving arch is usually constructed over a lintel as shown in Fig. 679 or over a flat arch as shown in Fig. 680 for the purpose of carrying the weight of the wall above the same, and thereby relieve the latter of superincumbent weight. The ends of relieving arches should be prolonged to abut
properly on the solid wall, keeping clear of lintels,\textsuperscript{3} insertion of door or window frames, or portions liable to be points of weakness. In modern practice R. C. C. lintels designed to support the walls etc., are largely used instead of relieving arches.

**Inverted arch:** An inverted arch is so called on account of its inverted position, since the crown of the arch is below the springing, and the centre is above the springing. The inclination of the skewback is usually 60 degrees, and the intersection of the two skewback lines produced gives the centre for striking the arch. An inverted arch is chiefly used for distributing the load of the piers uniformly over the entire length of the foundation.

![Relieving arch over a flat arch.](image)

\[1\] Very often it is found that students make the mistake of springing the arch from points on top of the lintel. In the event of the wood lintel rotting or being destroyed by fire or by some other means, the arch and the masonry work above it would collapse if the arch does not spring from the ends of the lintel.
Fig. 682 Venetian arch. Fig. 683 Florentine arch.
(87)

See Fig. 22 and also the details given under the head "Inverted arch foundation".

Pointed arch: This is also known as the Gothic arch, as the pointed arch is characteristic of this style of architecture. There are five forms of pointed arch, viz., equilateral, Tudor, drop, lancet and Venetian. The first four types have already been briefly described above, and the remaining type, viz., Venetian arch, is briefly described below:

A Venetian arch is deeper at the crown than at the springing line and the centres of the arch are on the springing line. The method of setting out is shown in Fig. 682.

Florentine arch: This type of arch is shown in Fig. 683. The arch is deeper at the crown than at the springing. The intrados consists of a semi-circular curve, and the extrados consists of two segmental curves, as shown in the figure. Sometimes the extrados is semi-elliptical.

Arch built with orders: This type of arch has an excellent appearance, and is used to both door and window openings in very thick walls. The arch consists of a number of rings similar

Figs. 684

Semi-circular arch built with orders.
to an ordinary arch, but the width or thickness of each ring is
diminished from the outer to the inner ring. The arch is thus
recessed or stepped by a series of rings known as orders. The
orders may rest at the springing of the arch, or they may be
continued to the sill. A semi-circular arch built with orders
is shown in Figs. 684 and 685.

(b) Classification of arches according to the materials and
workmanship employed in their construction:—Under this cate-
gory, we have the following types of arches:—

1. Stone arches
   (a) Rubble arches
   (b) Ashlar arches.

2. Brick arches
   (a) Rough brick arches
   (b) Axed or rough-cut brick arches.
   (c) Gauged brick arches.
   (d) Purpose-made brick arches.

3. Concrete arches.
   (a) Concrete block arches
   (b) Monolithic concrete arches.

A brief description of these arches is given below:—

(1) Stone arches:—There are two kinds of stone arches,
   viz., (a) Rubble arches, and (b) Ashlar arches.

(a) Rubble arches:—These arches are sometimes used for
   inferior work. They consist of rubble stones roughly hammer,
dressed to the required size and shape and laid in cement mortar.
In this type, all the stones need not be of the same size. Rubble
arches are a relatively weak form of construction, and hence
they should be limited to spans of 3 to 4 feet. A rubble arch is shown in Fig. 686.

Fig. 686.
Rubble relieving arch over a woop lintel.

(b) Ashlar arches:—These are constructed with properly cut and dressed wedge-shaped stones of the full thickness of the arch and laid in lime or cement mortar. The large voussoirs in ashlar arches are usually provided with cement joggles to prevent any sliding on their beds. Flat stone arches are sometimes strengthened by rebated or joggled joints, as shown in Fig. 661. To find out the number and size of voussoirs and the keystone of stone arch, the full-sized arch is first set out on a level platform, and the sizes of each voussoir and the keystone are carefully worked out by slight adjustment. Templates are then made, and the stones are dressed to these templates.

Ashlar arches have a good appearance, and are used for superior work. Different types of ashlar arches are shown in Figs. 659 to 661, 663 to 665 and 667.

2. Brick arches:—Brick arches are classified into four varieties, according to the quality of workmanship and the bricks used, viz., (a) Rough brick arches, (b) Axed or rough-cut brick arches, (c) Gauged arches, and (d) Purpose-made brick arches.
(a) Rough brick arches:—These are built with ordinary or standard uncut bricks, and consequently the joints are wider at the extrados than at intrados. The bricks should not be laid as stretchers on the face of the arch (see Fig. 662 right side) in order to prevent the thick end of the mortar joint becoming too large. They are generally constructed in half-brick rings (see Fig. 662, left side) and the joints are wedge-shaped. They are usually built over wood lintels or flat arches; they are then generally known as discharging or relieving arches. Rough brick arches are used where the appearance is not of primary importance and where much strength is not required. Though rough brick arches are cheap, they lack in strength and are suitable only for concealed work.

(b) Axed or rough-cut brick arches:—These are built with ordinary or standard bricks roughly cut to wedge shape by means of a bricklayer’s axe. The appearance of these arches is not satisfactory and are unsuitable for exposed work. They are generally used in cases where the face will be finished with a coat of plaster.

(c) Gauged arches:—These arches are constructed with bricks accurately cut and neatly dressed to a wedge shape. Thus the joints in a gauged arch are very fine, thin and truly radial. For high class work, special bricks known as rubbers (see the footnote given on page 23) are used, which can be cut and worked to the required forms. These bricks are cut with a saw, and the surfaces of the bricks are finished by rubbing them with a stone or with a file. To obtain fine and thin bed joints, pure slaked lime as putty is used throughout the work.

(d) Purpose-made brick arches:—These consist of purpose-made bricks, which are laid in putty lime (pure slaked lime) to get fine and thin joints. These are frequently employed in good-class work.

3” Gauge means measure, and a characteristic of gauged work is exactness.
Concrete arches may be classified into two classes, viz., (a) Concrete block arches, and (b) Monolithic concrete arches.

(a) Concrete block arches:—These consist of precast cement concrete blocks laid in cement mortar. Steel reinforcement is not normally used in this type of construction. The blocks are cast in accurately made moulds, and water-cured for at least 15 days. The blocks are then ready for use. The mixture used for the concrete depends on the strength required but for ordinary work the concrete is usually composed of 1 part Portland cement, 2 parts sand and 4 parts coarse aggregate such as gravel or broken stone. The details of construction of concrete block arches are similar to those of stone and brick arches, and hence it is not necessary to repeat the same here. Concrete block arches have been successfully used in our country for many important buildings and bridges.

(b) Monolithic concrete arches:—These are generally cast in situ, and are normally employed for arched culverts and bridges. They may be constructed in plain cement concrete provided the maximum tension on any section is kept within the safe limit. For large spans reinforced concrete arches are employed. The reinforcement varies from 0.5 to 1.5 per cent, and is distributed equally along the extrados and intrados of the arch. As the arch acts more or less like a curved column, the reinforcement of extrados and intrados is well bound together. Well graded and correctly proportioned cement concrete is used for the purpose. Form work is provided to support fresh concrete until it hardens sufficiently to support its own weight and the load above. The entire work should be kept wet for at least 15 days.

Method of construction of arches with small units such as bricks or stone blocks:—The construction of an arch is commenced at its springings and carried up uniformly towards the crown, where the key block is wedged in finally. From this it is evident that the voussoir blocks require some kind of temporary support to keep them in position during construction.
This temporary support is known as centre or centering which is usually made of timber. Being a temporary structure, it must be economical in material and capable of quick construction. A well designed centering should be sufficiently strong and rigid enough to support the load to be imposed without distortion. It must also be capable of being removed easily after the arch is set.

The construction of arches differs widely according to the shape, span, width of soffit and the material of which the arches are to be constructed. In practice any suitable timber which is readily available is converted to the required shape and is used for centering. Thus there is a great variation to the sizes and the arrangement of the members. In its simplest form, a centering consists of a pair of solid ribs cut from planks of the required thickness and width. The upper surface of these ribs is made to the shape of the intrados of the arch to be supported. On the top of the ribs narrow battens called lags or laggings are nailed across, as shown in Fig. 687 for supporting the blocks of the arch. Note both open and close lagging shown in the figure. The former is generally used for rough and axed brick arches, while the latter is adopted for gauged and purpose-made brick arches. The distance apart of the lagging when open varies from $\frac{1}{2}$ to 1 in., but this distance may be increased for stone arches. The thickness of the rib is usually 1 to $\frac{3}{4}$ in. The length of the laggings, and the distance apart of the two ribs to which they are nailed, depend upon the thickness of the walls. The length of the lagging may be half an inch less than the thickness of the wall. At the bottom ends of the ribs, wooden cross members called bearing pieces or bearers are nailed to rest the centering on supports. A pair of folding wedges is provided between the bearing piece and the head of the post for vertical adjustment such as the slight raising or lowering of the center into correct position prior to the construction of the arch, and for

1 Sometimes the centering is made of mild steel trusses for large spans. Centering made of mild steel trusses is very suitable where a considerable number of similar arches are to be constructed.
its subsequent easing and striking with the minimum vibration. The operation of slightly lowering the centre is termed "easing the centre".

An arch centering, suitably designed for camber arches and segmental arches is shown in Figs. 687 and 688.

Figs. 687 & 688

Arch centering for small arches.

In Figs. 689 to 691 are shown two forms of centerings suitable for semi-circular arches. These centerings are suitable for spans up to 20 feet, and they are composed of wooden built-up ribs shaped to the intrados of the arch, and covered at the top by loggings nailed across them. The ribs are built up in two thicknesses, nailed together and overlapped, as shown. The ribs are usually spaced from 2 to 6 feet apart.
Figs. 689 to 691 Centerings for a semi-circular arches.
The lagging pieces, which must be at least 1 in. thick, may be laid with some spaces, usually ½ to 1 in., for rough and axed arches, for gauged and purpose-made brick arches, they are laid close together, with the surface made smooth and quite regular. The distance between the laggings may be increased for stone arches. The centerings rest on the supports, and each support consists of two posts or props to which is nailed a bearing piece at the top and a similar wooden member called sleeper plate or sleeper at the bottom. A pair of folding wedges is inserted between the bearer and the head of the post to facilitate the easing of the centering. Ties and struts are provided to impart rigidity to the centering. It should be remembered that a centering may have to take up, in some cases, the weight of men and materials as well.

A centering suitable for semi-elliptical arches is illustrated in Fig. 692.
Centerings for small arches are made in a very simple way. A thick plank \(^1\) (equal in length to the span of the arch and as wide as the wall) is supported horizontally on two or more posts or props \(^2\) as required, and bricks are laid in mud on this plank roughly to the shape of the intrados of the arch to be supported. A plaster of mud is then applied on the top of this brickwork to obtain a uniform surface required for the soffit. The laying of the voussoir blocks is then started from both the springing points.

Striking or Removing Centerings:—Although there is some difference of opinion as to the period \(^3\) after which the centering should be removed, it is generally agreed that the centering must be eased slightly two days before striking so that the voussoirs may close in and compress the mortar; and that this should be done before any masonry is built on the top of the arch. Further, the centering must be removed completely before masonry is constructed over the arch. If the centering is struck or removed after masonry is constructed over the arch it is likely that the removal of the centering may cause a small settlement of the arch, and this settlement will cause cracks in the masonry on the arch and in due course disfigure the same.

Thickness of arches:—To determine the thickness of arches, any one of the following formulae may be used:—

1. Semi-circular arch,

\[
T = \sqrt{0.20 \times \text{R}} \text{ feet}
\]

---

1 Two or more number of planks may be provided if the width of the wall is great.
2 The plank or planks may also be supported on temporary brick piers.
3 This period generally varies from one to six weeks after keeping according to the size of the arch and the skill bestowed on the centering.
2. Semi-circular arches in series,
   \[ T = \sqrt{0.25 \times R} \text{ feet.} \]

3. Segmental arch,
   \[ T = \sqrt{0.12 \times R} \text{ feet.} \]

4. Segmental arches in series,
   \[ T = \sqrt{0.17 \times R} \text{ feet.} \]

5. Highway arched bridges,
   \[ T = \sqrt{0.01 \times \text{span} \left( \frac{\text{span}}{\text{rise}} + 3 \right)} + 0.15 \]

In the above formula, \( T \) = thickness of the arch in feet and \( R \) = radius of arch in feet.

The radius \( R \) of the intrados of an arch may be determined by adopting the following formula:

\[ R = \left( \frac{\text{Span}}{2} \right)^2 \times \frac{\text{Rise}}{2} + \text{Rise}, \text{ feet} \]

Example:— The span of a brick arch is 6 feet, and its rise is 1 ft. Determine the thickness of the arch.

Radius of the intrados (\( R \))

\[ = \left( \frac{6}{2} \right)^2 \times \frac{1}{2} \text{ plus Rise} \]

\[ = \left( \frac{9}{2} \right)^2 \times \frac{1}{2} \text{ plus 1} \]

\[ = \frac{9}{2} \times \frac{1}{2} = \frac{10}{2} = 5 \text{ feet.} \]
If a coefficient of 0·12 is taken for this arch, then the thickness of the arch is given by the formula:

\[ T = \sqrt{0.12 \times \text{radius}} \]

\[ = \sqrt{0.12 \times 5} \]

\[ = \sqrt{0.60} \]

\[ = 0.77 \text{ ft. or 9.24 in. (nearly)}. \]

CHAPTER VIII

QUESTIONS FOR REVISION.

1. What are the various materials and methods of construction adopted for spanning an opening in a wall? (Gujarat University 1954)

2. Write short notes on:
   (i) Laying R. C. C. lintel over a window (University of Poona 1951, University of Sind 1920)
   (ii) Flat arch (University of Sind 1950 and Gujarat University 1952 and 53)
   (iii) Relieving arch (Karnatak University 1954)

3. Draw neat sketches to show centering for a brick semicircular arch over a window 4 ft. wide. What are joggle joints? (Karnatak University 1954)

4. (a) What is centering and its requirements?
   (b) Distinguish between types of ribs with sketches.
   (c) Sketch in detail centering for a span of 6 ft. clear. (Karnatak University 1958)
5. Explain the following terms and illustrate your answer with sketches:—Skewback, Voussoir and Keystone.  
(University of Sind 1950)

6. Write short notes, with sketches:—
(a) Centering for arches  (University of Poona 1956)
(b) Lintels  (Gujarat University 1952)
(c) Gauged arch  (Karnatak University 1952)
(d) Receding order in arches  (Karnatak University 1952)

7. Cracks are noticed in a segmental stone arch spanning a 5 ft. wide entrance to a building. Suggest the various causes which may be responsible for this occurrence.  
(University of Poona 1956)
CHAPTER IX

JOINTS IN CARPENTRY

Structural timber as obtained from timber depots is rough and unwrought. It requires to be cut, planed and framed for adoption in building work. This art or act is known as "Carpentry and Joinery", and the timber which is thus dressed and finally placed in position in buildings is known as "wrought and put up". Although the terms "Carpentry and Joinery" are usually grouped together, there are several differences between them. Carpentry embraces those forms of construction in wood which are subjected to stresses on account of the loads which they support or the pressures which they resist. Such construction may be permanent in character, as partitions, lintels, floors and roofs, or it may be temporary in nature, as shoring, scaffolding, timbering for trenches, centering for arches and form work to support reinforced concrete floors, etc., during construction. Thus carpentry is mostly constructional, the timber is used in the rough, and in comparison with its size and value the labour expended upon it is very small, and most of the work is done on the building site. Joinery is the art of preparing and framing pieces of timber together to form the internal fittings and finishings of houses and it comprises the construction and fixing of doors and windows with their frames or linings, stairs, panelling, cupboards and floor boards. Joinery increases the appearance of a building to a large scale, but the labour is a large item compared with the volume of the timber used, and most of the work is carried out in the workshop. In India, carpentry and joinery, are not treated as two separate trades, and they are carried out by one and the same class of men. Hence the word "carpentry" is usually used in this country for both kinds of work; as a matter of fact, the word "carpenter" is only used, and the word "joiner" is rarely or never used.

Terms used in joinery:—The following terms are generally used in joinery work:
1. **Sawing**—Sawing is cutting of wood by means of saws.

2. **Chamfering**—This is the process of taking off the edges or rises of a piece of wood, thus forming a level. The exposed edges of wood are usually chamfered or rounded. When two chamfered edges are placed together, a V-joint is formed. When the chamfer is not continued to the entire length of a piece of timber it is called a **stopped chamfer**. See Figs. 693 and 694.

![Chamfer and Stopped Chamfer](image)

3. **Planing**—Planing is taking shaving off wood. The stuff thus prepared is called dressed or wrought, and when brought to a level surface, it is said to be out of winding.

4. **Shooting**—Dressing the edges of the boards straight and square with face is termed shooting.

5. **Plough grooving**—It is the operation of cutting grooves parallel to the grain of the wood for decorative work. When a groove is made across the grain of the wood, it is termed trenching or cross grooving.

6. **Rebating**—Rebating is the process of cutting away a rectangular portion from the edge of a timber piece of sufficient depth for another piece similarly cut to fit in.

7. **Housing**—Housing is the term given to the sinking of the edge of one piece of stuff into another.
8. Mitring:—This is the process of joining two boards at an angle. Various forms of mitred joints are described later.

9. Bead:—This is the name given to the semi-circular projection formed on edges or surfaces of wood.

10. Grounds:—These are pieces of wood which are nailed either to wooden blocks, or plugs in cross joints of walls to obtain a firm base or hold to which linings of walls or ornamental moulds can be screwed. They are cut with their surfaces flush with the plaster. Grounds are only used to first class work.

11. Veneer and Veneering:—Veneer is a thin sheet of wood, usually not exceeding 1/16 in. in thickness. It is generally prepared from rare or costly woods having a beautiful colour or grain, and is used for decorative work. Veneering is the operation of covering the entire or part of the exposed surface of woodwork with veneer, to improve the appearance. The inner woodwork is intended to satisfy the structural needs whereas the veneered facing is intended for decorative purpose. Veneer may be laid on work in large sheets, or it may be cut into shaped pieces and laid to various designs.

**Principles to be followed in the design of joints:**—The general principles to be followed in the design of joints as suggested by Professor Rankine are given below:

1. To cut the joints and arrange the fastenings so as to weaken the pieces of timber, that they connect, as little as possible.

2. To place each abutting surface in a joint as nearly as possible perpendicular to the pressure which it has to transmit.

3. To proportion the area of each abutting surface to the pressure which it has to bear, so that the timber may be safe against injury under the heaviest load which occurs in practice, and to form and fit every pair of such surfaces accurately, in order to distribute the stress uniformly.

4. To proportion the fastenings so that they may be of equal strength with the pieces which they connect.
5. To place the fastenings in each piece of timber so that there shall be sufficient resistance to the giving way of the joint by the fastenings shearing or crushing their way through the timber.

Joints play an important part in the work of a carpenter, and hence they should be well designed by observing the above principles of Prof. Rankine. The essential requirements of joints are tightness and delicacy. In nearly all cases simple joints are more effective than complicated ones. The latter are not only difficult to form and fit, but are very liable to be affected by the shrinkage of the timber.

Classification of joints—Joints may be largely classified into six kinds. They are—

1. Lengthening joints.
2. Widening joints.
4. Framing joints.
5. Angle or corner joints.
6. Oblique shouldered joints.

1. Lengthening joints.—These are used for lengthening ties, struts, and members subjected to bending. Very often the lengths of available timber sections are insufficient, and in such cases these joints are required to extend them to suit the required purpose. These include lap or lapped joint, fish joint, scarfed joint, and tabled joint.

1. Lap or Lapped joint.—This is the simplest means of uniting two pieces of timber. The end of one piece of timber is made to lap over that of the other, and the whole is secured by W. L straps, as shown in Fig. 695. Bolts should

![Fig. 695](lap_joint_w_l_stirrup_straps.png)

Lap joint with W. L. stirrup straps.
be used instead of straps if the joint has to withstand tensile stresses in addition (see Fig. 696).

Fig. 696
Lap joint with mild steel bolts.

(2) Fished joint — Three varieties of fished joints are shown in Figs. 697 to 700. The joints shown in Figs. 697 to 699 are suitable for compressional stresses and the joint shown in Fig. 670 is suitable for tensile as well as compressive stresses. The timbers are cut square and butted. Metal or wood plates called fish plates are provided on two opposite faces and the whole bolted together, as shown. The bolts should be placed zig-zag in plan so as not to weaken the timber by more than one bolt-hole at any section. (See Fig. 698). A fished joint is quite efficient and simple, specially where strength is of primary importance and appearance is the secondary consideration.

(3) Scarfed or spliced joint:— In all forms of scarfed joint the simplest are the best, as they are the easiest to fit accurately together. Various forms of scarfed joint are shown in Figs. 701 to 705.
The joint shown in Fig. 701 is the simplest scarfed joint, and is suitable for compression. The bolts are put in chequerwise as shown, so that the fish plates and timbers are not cut through by more than one-bolt-hole at any section. The ends of the fish plates are bent and let into the timber as shown.

Another common form of scarfed joint is shown in Figs. 702, and is used to resist compressive stresses.

Figs. 701 and 702

Figs. 703 to 705
Scarfed or spliced joints.
The joint shown in Fig. 703 is used to resist tensile stresses. Two hard wood wedges are used to tighten the joint.

A horizontal beam supported at its ends carrying a vertical load is subjected to a stress which is compressive at the top and tensile at the bottom. In Figs. 704 and 705 are shown two forms simple scarfed joints which are suitable for such a member. The joint shown in Fig. 704 is also known as the tabled and splayed scarf joint.

Tabled joint:—Three forms of tabled joint are shown in Fig. 706 to 708, and are suitable for both tension and compression. The use of fish plates and bolts may be avoided if the timbers are not subjected to longitudinal stresses; but it is worthwhile to remember that the strength of such joint is less than half the strength of the pieces.

Figs. 706 to 708
Tabled joints

2. Widening or side joints:—These joints are used for connecting planks or boards edge to edge. These joints are some times called boarding joints, and include the following joints:—

(1) Butt, square or plain joint (Fig. 709):—This joint is formed by simply planing the edges of the boards at right angles to the face or side and placing them in contact. This joint is not suitable for good work.
(2) Rebated joint (See Fig. 710):—This joint is made by cutting a rectangular slip in the thickness and along the edge of each board or plank, and overlapping the cut portions. This joint prevents dust passing through.

(3) Rebated and filleted joint:—To form this joint, the boards are butted together with the rebated portions turned down; into the slit, formed on the underside of the rebated portions of the boards as shown in Fig. 711, is slipped a piece of wood called fillet. This joint is used in factories, stores and similar places where floors undergo heavy wear.

(4) Tongued and grooved or Feathered and grooved joint:—This joint is formed by making a narrow projecting tongue or feather just below the middle along the edge of one board, and fitting it into a groove cut along the edge of the other. The tongue is sometimes rounded off so as to facilitate the laying of the boards and prevent it being dangered during the process. This is a dust-proof joint and is employed more frequently than any other for good work. This joint is illustrated in Fig. 712.

(5) Rebated, tongued and grooved joint:—This is a combination of the joints indicated by the name, and is illustrated in Fig. 713. This is a good dust-proof but expensive joint.

(6) Splayed, rebated, tongued and grooved joint:—This is a stronger joint than the rebated, tongued and grooved joint, and is shown in Fig. 714. This is a very good but expensive joint and is used for superior work.

(7) Ploughed and tongued or Ploughed and slip-feathered joint:—In this type of joint grooves are formed or ploughed along the square edges of the boards to receive hard wood tongues or slip-feathers. This joint is not often employed. This joint is shown in Fig. 715.

(8) Dovetail slip-feather joint: This joint is formed by cutting a trapezoidal or dovetail shaped groove along the edge of each board and inserting a strip of hard wood called slip-feather or tongue through the opening formed by the grooves (see Fig. 716). This joint is also known as the Keyed joint.
(9) Dowelled joint: Small hard wood or iron dowels are fixed along the edge of one board to fit into holes made in

- Butt, square, or plain joint
- Rebated joint
- Rebated and filleted joint
- Tongued and grooved joint
- Rebated, tongued, and grooved joint
- Splayed, rebated, tongued, and grooved joint
- Ploughed and tongued joint
- Dovetail slip-feather joint
- Dowelled joint
- Matched and beaded joint
- Matched and vee-jointed

Figs. 709 to 719

Widening or side joints.
the other (see Fig. 717). The surfaces of the joints may be glued to prevent any slight separation.

(10) Matched joint: In Figs. 718 is shown an ordinary form of matched joint. The matched joint has a tongued and grooved arrangement, and the tongued edge of each board is beaded. This bead serves the double purpose of destroying the monotony of the surface, and of hiding any slight shrinkage that may take place in the boards. Instead of being beaded the edges are frequently chamfered as in Fig. 719 to serve the same purpose, and this arrangement is known as Vee-jointing. The process of laying boards with matched joints is called match boarding, and the boards used for the work are known as match boards. The match boards should not be more than 4 in. in width, should be nailed on one edge only, in order that no joint shall open too much, and that the whole shall be free to shrink.

End or Heading joints: These joints are used for lengthening the floor boards, which may be square, splayed, rebated or forked. The square heading joint usually secured by two nails, one on each side of joint as shown in Fig. 720. The splayed or bevelled heading joint is very commonly adopted, and is illustrated in Fig. 721. The rebated heading joint is shown in Fig. 722, and is usually used for good work.

The forked heading joint is shown in Fig. 722. It is made with a series of truncated triangular forks, which fit into each other inclined to the length about 10 degrees, as shown. This is an expensive joint and is suitable for superior work. All the heading joints should be formed on joists. The appearance of the work is spoilt if the heading joints form one continuous line over the same joist. They should be laid on alternate joints to break joints.

Glue is prepared from the hooves and sinews of cattle and horses. The glue is broken up, allowed to soak for about 24 hours, placed in a pot, sufficient water is added to cover the glue which is then boiled for about 15 minutes, when it is ready for use. Instead of boiling, the glue-pot may be placed in the sun for about 2 hours.
3. Bearing joints—The following are the various types of bearing joints commonly used.

![Diagram of bearing joints]

**Fig. 720 to 723**

End or Heading joints.

1. Notched joint:—This joint is very often used for fixing joists to wall plates in a timber floor. There are two forms of notched joint, viz., single notched joint and double notched joint. A single notched joint is shown in Fig. 724, the lower edge of the joist being cut to fit over the wall plate. A double notched joint is shown in Fig. 725, and is formed by cutting both joist and wall plate to the required depth. The shoulders formed in a notched joint prevent the joists from lateral movement.

A dovetail notched joint is illustrated in Fig. 726.

Tredgold's notched joint:—This type of joint is very suitable for joining wall plates at right angles, and is illustrated in Fig. 727. This joint is, however, rarely in practice.

2. Cogged, Corked or Caulked joint:—Two forms of cogged joint viz., single cogged joint and double cogged joint
are shown in Fig. 728 and 729. In double cogged joint notches are cut in the lower piece of timber on either side.

![Diagram of different types of joints]

Figs. 724 to 731
Bearing joints.

an uncut portion in the middle. The uncut portion is called.
3. Figs. 732 to 741 Bearing joints.
a cog. The upper piece of timber contains a small notch only wide enough to receive the cog of the lower piece.

In single coggged joint only one notch is cut in the lower timber piece to receive the upper piece containing notch as shown. Very often the joists are coggged on to the wall plate. A coggged joint has some advantages over a notched joint. The upper timber piece is kept at its full thickness at the point of support and is therefore stronger than when notched. The cog gives the upper piece a hold on the lower, even when its end does not project beyond the latter.

(3) Housed Joint.—When the entire end or thickness of one piece of timber fits for a short distance into a notch cut into another piece, a housed joint is formed (see Fig. 730 and 731). Three other forms of housed joint, viz., square housed joint, bevelled housed joint and dovetail housed joint, are shown in Figs. 732 to 734; the first two joints are also known as half-depth joints.

(4) Halved Joint.—A simple halved joint is shown in Figs. 735 and 736. In this joint, half of the thickness of each timber piece is cut out, and the remaining portion of one just fits into the remaining portion of the other, the upper and under surfaces of the pieces being flush. This is an ordinary method of joining wall plates or other timbers at an angle, where there is no room to let the ends project so as to cross one another.

Fig. 737 shows a bevelled halved joint. In this the surfaces of the cheeks are splayed or bevelled as shown. Various other forms of halved joints are illustrated in Figs. 738 to 741 with their distinctive names.

(5) Dovetail Joint.—This joint is formed by cutting dovetail or wedge-shaped alternate piece out of each timber piece and fitting the projections of the one into the notches cut into the other. This joint is used for curbs of skylights, corners of boxes, drawers, cisterns etc. A single common dovetail joint is shown in Fig. 742. The strongest form of angle or common dovetail joint is shown in Figs. 743 and 744, which can only be used, however, when there is no objection to the end grain of the timber being visible. Another form of dovetail joint, called lapped dovetail joint, is shown in Fig. 745, and is so arranged
that the joint is not visible on one side. The joint shown in Fig. 746 is known as the mitred or secret dovetail joint; this

Figs. 742 to 748
Bearing joints
joint is not so strong as either of the others, but is employed when it is required to completely hide the joint.

(6) Mortise (or Mortise) and tenon joint.—This type of joint is more commonly used than any other kind of joint in carpentry, and is used for fixing two pieces of wood at right angles to each other. An ordinary or close mortise and tenon joint is formed by cutting a projection called a tenon in one piece of timber and fitting it into a corresponding hole called a mortise in another. The pieces are held together and the joint is strengthened by driving a pair of hard wood wedges. This joint is illustrated in Fig. 747, in which the tenon is formed by dividing the end of the vertical piece into three and cutting out rectangular pieces on both sides, each equal to the part left in the middle. A corresponding rectangular hole, called a mortise is cut out in another piece to receive the tenon. The sides of the mortise are termed the cheeks, and the surfaces, on which the shoulders of the tenon rest, are known as the abutment cheeks. The springing of the tenon from the beam is termed its root.

The mortise and tenon must be suitably proportioned if failure of the joint is to be avoided, and the following rules should be followed:

(a) The thickness of tenon should equal one-third that of member.

(b) The width of tenon should not exceed five times this thickness or a maximum of 5 in. whichever is the less.

In Fig. 748 is shown a mortise and tenon joint with cross tongues. In this joint a hard wood cross-tongue is provided on each shoulder in addition to the tenon. This method of strengthening the joint may be adopted where the tenon cannot be formed of the proportions given above.

In order to give additional strength to the mortise and tenon joint, the end of the timber piece bearing the tenon is very often sunk or housed into the other piece for a short distance. This arrangement is called a housed tenon joint or mortised and housed joint. See Fig. 749 and 750.
The mortise and tenon joint is sometimes secured by what is known as the fox or foxtail-wedging in cases where the joint cannot be wedged from the outside. It is very suitable for superior work, where the appearance of the end of the tenon on the edge of the framing would be considered objectionable. The foxtail-wedging is carried out thus—The mortise is sunk to within \(\frac{3}{4}\) to 1 in. of the back of the mortised member and is made...
slightly dovetail-shaped. Two or more saw-cuts are then made in the end of the tenon, and into each of these a wood wedge is inserted. Finally, the tenon is glued and forced home. See Fig. 751 and 752.

(7) Joggle, stub or Stump tenon:—This is similar to mortise and tenon joint, but the tenon is short and does not extend to the full thickness of the mortised piece. This joint is very commonly employed for fixing the studs of a timber partition to the horizontal sill of the frame. See Fig. 578.

(8) Dowelled or Draw pinned mortice and tenon joint:—
In this joint, the mortice is made on the end of one timber piece which receives the tenon formed in another piece. A hole is then bored through the tenon and the cheeks or sides of the mortice to which is inserted a dowel to draw the shoulders of the joint together and the side of the tenon against the inner end of the mortice. This joint is also known as the open mortice joint, and is illustrated in Fig. 753.

(9) Dovetailed tenon joint:—This type of joint is used when the timber pieces are to be connected and taken apart occasionally. In this joint, one edge of the tenon is cut obliquely and the mortise is made a little wider than the width of the tenon. The joint is secured by driving a hard wood key or wedge as shown in Fig. 754. The wedge is used to tighten the joint and also keep the timber pieces together. When the tenon is not extended to the full thickness of the mortice piece as shown in Fig. 755, it is called a stopped dovetail joint.

(10) Chase mortise joint:—Wherever it is required to fix timber pieces between the main timbers, which are already laid in position and immovable, this joint is adopted. This joint is very often used for fixing ceiling joints between binders, etc. Two forms of this joint are shown in fig. 756 and 757.

(11) Tusk tenon joint:—This is a strong form of joint and is very commonly employed in timber floor construction. In figs. 738 to 761 are shown the various details of a tusk tenon joint. The projecting portion below the tenon is known as the tusk, and the slanting or bevelled portion above the tenon is called the horn or haunch. The tusk transmits most of the weight to the joist, and the horn or haunch strengthens the tenon. The joint is secure-
ed by means of a hard wood wedge as shown. Various parts of this joint must be carefully proportioned if failure of the joint is to be avoided. The usual proportions are shown in the figures. The tenon must be placed in the centre of the depth of the pieces to be connected.

TUSK TENON JOINT
Figs. 756 to 761
Bearing joints.

(12) Double tenon joint:— This joint, which consists of
Double tenons as shown in Fig. 762 is very often employed between large sized timber pieces, it being more effective than a single tenon in bringing the shoulders of the tenon tight up against the adjacent timber piece. The combined thickness of a pair of single tenons should be equal to that of a single tenon.

(13) Bridle joint.—This is a sort of converse of the mortise and tenon joint, and is illustrated in Figs. 763 and 764. In this joint, a kind of mortise is cut in the end of one timber piece to fit the bridle or projection left upon another piece, as shown. This is an expensive but good form of joint, and may be preferred to the mortise and tenon joint, as any bad workmanship can be easily detected.
Figs. 763 to 770 Carpentry joints.
Figs. 771 to 778
Showing the joints used in door shutters
4. Framing joints:—These joints are used for frames of doors and windows. These joints are similar to the bearing joints, but slightly modified to suit the special requirements. Though they are not required to withstand any great stresses, they must be made strong enough for the purpose. Various forms of framing joints used for doors are shown in Figs. 771 to 778.

5. Angle or Corner joints:—These joints are used to connect ends and edges. In Fig. 779 is shown a simplest form of joint, called butt joint, for connecting together two boards meeting at an angle. Figs. 780 to 783 show variations of the same joint. In cases where it is undesirable to show the end grain of the wood, mitred joints are employed. Various kind of mitred joints are illustrated in Figs. 784 to 789. Three forms of dovetailed angle joints are illustrated in Figs. 742 to 746. A few other forms of angle joints are shown in Figs. 790 to 793. Angle joints are very often secured by nailing, and glue is used in the making of such joints.

6. Oblique shouldered joints:—These include oblique tenon, birds mouth, bridle, mitre, and halving and dovetailing.

   (1) Oblique tenon joint:—For joining the timbers at an angle other than a right angle, oblique tenon joint is used. This joint is very often used in timber roofs and timber partitions. Frequently oblique tenon joints are strengthened by means of W.I. straps or mild steel bolts and washers. An oblique tenon joint is shown in Figs. 765 and 766, which is generally used for the junction of a principal rafter and a tie-beam.

† A frame is usually constructed by joining timber pieces (about 3 in. in width and 2 in. in thickness) together with a special form of mortise and tenon joint to enclose a number of square, rectangular or other shaped spaces. Generally the timber pieces have grooves on their inside edges, into which boards called panels are fitted. The vertical members that are grooved or mortised are called styles; all other vertical members between the styles are termed muntins, and the horizontal members are known as the rails.
Figs. 779 to 793
Angle or corner joints.
(2) Birdsmouth joint:—This joint is effected by cutting an angular notch in one piece of timber and fitting it obliquely on another, as shown in Figs. 767 to 770.

The remaining joints have already been described above.

Fastenings:—The following fastenings are generally used in carpentry:

1 Wire nails:—These are usually made of steel or wrought iron. These nails are either circular or oval in section and are usually known as French nails. They are tough and strong, and the separations made in the stem increase the ability to grip the fibres of the wood into which they are driven. Oval wire nails are used for general purposes while circular nails are used for temporary, or unimportant work. These nails are obtainable in sizes varying from 1 in. to 6 in.

2 Cut clasp nails:—These are flat nails cut from mild steel or W. I. plates about 3 in. or less in length.

3 Spikes:—These are W. I. nails above 4 in. in length, and are largely used in fixing timbers together.

4 Floor brads:—These are tapering nails of parallel thickness with heads projecting only on one side. These are used mainly for securing floor boards. The projecting head should be driven in the direction of the grain of the timber. The length varies from 1 in. to 3 in.

5 Clout nails:—These are nails with large, flat, circular heads.

6 Lath nails:—A form of iron clout with a tapering shank, square in section, the sides of the shank being rough.

7 Trenails:—Hard wood pins of large diameter are called trenails. They are largely used in ship building or in positions where iron fastenings would be liable to rust.

8 Screws:—There are many forms of screws, and the shape of the head generally determines the name, such as round-headed, flat headed etc. They are made of steel, wrought iron and brass.
Figs. 794 to 808
Fastenings.
Screws are sometimes called wood screws, as the thread is effective in cutting into wood. Screws are usually fixed by means of a screw-driver. Usually a hole of a smaller diameter than that of screw is made by means of a boring tool prior to inserting the screw. Always it is a better practice to use screws instead of nails though they require a little more time for fixing, and the former have some advantages over the latter, viz., (1) they can be fixed without vibrations, (2) they can be easily removed when required, and (3) they give a stronger job on account of their greater holding power.

9. Coach screws:—These are similar to ordinary screws, except that their heads are square or hexagonal so that they can be turned by a spanner. They are frequently used for connecting metal plates, straps and angles to wood. They are from $\frac{1}{4}$ to 8 in. long and $\frac{3}{16}$ to 1 in. in diameter.

10. Hand-rail screws or double-nutted screws:—These screws have a thread at each end, a square nut at one end, and at the other end a circular nut slotted on edge. The pieces to be joined are bored to receive the screw. These screws are commonly used for securing heading joints.

11. Bolts, nuts and washers:—Bolts and nuts are used for securing members such as wood and steel roof trusses and similar framed structures, built up wood lintels and beams, steel beams, etc. When bolts are used to fasten wood members, washers are introduced between the timber and the heads and nuts as shown in the figure. The bolts are fixed in positions by means of a spanner. A bolt essentially consists of a head and shank, and the end of the shank is in the form of a screw to which a nut is inserted for tightening up the bolt. Bolts vary in size from $\frac{1}{4}$ to 6 in. diameter, but $\frac{1}{2}$ to 1 in. bolts are largely used in building construction. The length of the bolts also varies according to the diameter of the bolts. Bolts, nuts and washers are made of mild steel, wrought iron and brass.

12. Dogs:—These are pieces of flat or round wrought iron bent at ends. The ends of the dogs are specially pointed so that they may be driven into the wood easily. The bent heads are hammered in to secure timbers together. Dogs are chiefly used for shoring, rough stagings and temporary structures.
Figs. 809 to 827
Carpenter's tools.
13. **Wedges:** These are wedge-shaped or tapered pieces of hard wood and are used to secure joints together as in the mortice and tenon joint. When the wedges are used in pairs (which draw up more equally), they are called folding wedges. Wedges are sometimes called the keys.

14. **Straps:** These are made of mild steel and wrought iron. These are used to enclose timbers together and keep them in positions, and are fixed by bolts.

15. **Sockets:** These are usually made of wrought iron, and are used to enclose the ends of timbers to protect the ends from splitting. When the sockets are used at the feet of members, as on wooden piles, they are called shoes.

Most of the above fastenings are illustrated in Figs. 704 to 808.

**Tools used in carpentry:** The tools commonly used in carpentry may be classified into those required for: (1) Marking and setting out, (2) Cutting and planing (or shaving), (3) Boring, (4) Impelling and Miscellaneous. Most of these tools are shown in Figs. 809 to 827.

1. **Marking and setting out tools:** These comprise try square, rule, striking or marking knife, bevel, spirit level, compass and gauges. Bevel is used for setting out angles other than right angles. Gauges are tools used to mark one or more lines on the wood which are parallel to the edge.

2. **Cutting and planing tools:** These tools include faws, chisels, planes, axes, adzes and gauges. Gouges are curved chisels which produce circular cuts.

3. **Boring tools:** These include the bradawl, gimlet, auger and brace and bits. **Gimlet** is a small tool, which is useful for boring holes to mark the position and facilitate the insertion of screws. Bradawl has a sharpened end, and is used for making small holes. **Auger** has steel stem, about 2 ft. long, and is used for deep borings up to 2 in. diameter. **Brace** is a handle or stock to which is attached a cutter or bit used for boring holes; hand pressure on the head of the brace assists the boring action of the cutter whilst the brace (gripped by the handle) is revolved. The sweep of the brace is made of steel, and the head and handle are made of wood.
(70)

Fig. 728 to 69
Carpenter's tools.
(4) Impelling tools—These tools comprise mallets, hammers, screw-drivers and nail punches. Mallets are used for driving chisels and knocking framing together. Hammers are used for general purposes, especially for driving nails. As is implied screwdrivers are used for fixing screws. Nail punches are used to punch the heads of nails below the surface of the wood.

(5) Miscellaneous.—These include oil stone, rasps, cramps, pincers, pliers, and plumb-rule. Rasps are made of steel and are chiefly used to remove bumps on curved surfaces. Cramps are used to cramp up framings, etc., during the gluing and wedging process. The plumb-rule is illustrated on page. For large work electric saws, planers, screw-drivers, drills and sanders may be used.

CHAPTER IX

QUESTIONS FOR REV.SION

1. Write short notes on the following:
   (a) Scraf joint (Guajrat University, 1953).
   (b) Mortice and tenon joint (Karnatak University, 1954).
   (c) Dovetail joint in carpentry (Bombay University, 1951).

2. Describe the various joints used in carpentry with sketches wherever necessary.

3. Show by neat sketches the details of the following joints in the case of a door:
   (a) Top rail and stile, (b) Frieze rail and stile, (c) Bottom rail and stile, (d) Diminished middle rail and stile.

4. Draw in isometric projection the following joints in carpentry:
5. In designing joints in carpentry, give five principles to be considered. Give the names of five joints in carpentry arranged under each of the following three classifications:—
(a) Lengthening joints. (b) Bearing joints. (c) Oblique Shouldered joints.

6. Explain the principle of the design of the tusk-tenon joint and describe where it is best to use it.

Sketch the joint with the members separated, and figure the dimensions in ratio to the depth of thickness of the members.

7. Describe with sketches the main principles in designing carpentry joints.
CHAPTER X.

DOORS AND WINDOWS.

Doors:— Doors are used for free movement of men in and out of a house, and they should be of a minimum number for each room as more cause obstruction. A door consists of a frame, and either one or two shutters hung to the frame by means of metal hinges. Doors with two leaves or shutters are known as hung-folding or double-leafed (or double-shuttered), and those with one leaf or shutter are called single-leafed or single-shuttered. Double leafed doors are used for wider openings, and single leafed doors are used for small openings. As a rule, single-leafed doors are used in partitions. Sometimes doors are provided with shutters on the two sides of the frame in first class buildings. In such cases, the inner shutters are usually fully glazed, and the outer shutters are fully panelled.

Doors (and windows) are usually made of wood and mild steel, though for glazed portions of shutters glass invariably used. In modern practice R.C.C. frames are also used for doors (and windows).

Sizes of doors:— There are no specific rules for determining the sizes of doors, and hence the sizes vary considerably. The size of a door (or a window) is normally expressed by the overall dimensions of its frame which corresponds with the opening formed in the wall for the purpose. In India, the overall dimensions of a door are usually determined by making the height equal to the width plus 3 to 4 ft. In ordinary buildings, the minimum height of a door is 6 ft. 6 in. without a fanlight and 8 ft. with a fanlight, whereas the maximum is usually not more than 7'–6" without a fanlight, and 9'–0" with a fanlight. The minimum width of a door is 3 ft., whereas the maximum is usually not more than 4 ft. 6 in. In partitions, the width of the door is very often 2 ft. 6 in. or 3 ft. 9 in.
Door frame and its fixing in wall:—A door frame usually consists of four wooden members, i.e., two uprights or posts which are secured at the top and bottom to two cross-pieces called head and sill respectively. See Figs. 861 and 862. The head and sill are mortised to take the tenon formed at the ends of the two vertical posts of the frame. A draw pin is used to hold the shoulders of the tenon tightly home. The head and the sill usually project from 4 to 9 in. beyond the posts, and these projections, called horns, are built into the wall to secure the frame. A 1/2 to 5/8 in deep recess or rebate, equal in width to the thickness of the shutter, is made round the frame to receive the shutter. The outer edge of the frame is either chamfered or moulded as desired. The sizes of these members vary, but 4 in. by 3 in. and 4 1/2 in. by 3 in. are common. The door frame is also made of steel or R.C.C.
Sometimes the bottom sill of a door frame is omitted as it causes an obstruction to the movement of the occupants, does not permit of easy cleaning and washing of floors. When the sill is omitted, the vertical posts are fixed into the floor below by means of wrought iron dowels, as shown in Fig. 863.

![Fig. 863](image)

Use of dowels in fixing door frame.

The door frame is fixed in the wall by means of wrought iron hold fasts or wooden horns about 12 in. long as shown in Fig. 861. The details of a hold fast are shown in Fig. 862. Always it is a better practice to embed the hold-fast or horns in cement concrete in a wall. The door (and window) frame is usually fixed inside the wall by leaving a space of 3 to 4 in. from one face; this space is called the reveal. On the other side of the frame more space is left which is known as the jamb. The jamb may be left square or built splayed. See Figs.

Classification of doors:— The following types of doors are normally used in buildings:—

1. Ledged and battened doors.
2. Ledged, battened and braced doors.
3. Framed, ledged, braced and battened doors.
4. Framed and panelled doors.
5. Glazed or sash doors.
6. Louvred or Venetian doors.
1. Ledge and battened door:—This is the simplest form of door, and is frequently used for narrow openings and in positions where the appearance is not important. The door consists of vertical boards or battens which are secured to horizontal pieces called ledges. Usually the ledges are three in number, viz., top ledge, middle or lock ledge and bottom ledge. The outer edges of the ledges are usually chamfered (see Fig. 693). The thickness of the ledges is usually 1\(\frac{1}{2}\) in., and the middle and bottom ledges are sometimes wider than the top ledge. The battens are usually 4 to 6 in. wide and \(\frac{1}{2}\) to 1\(\frac{1}{2}\) in. thick. Those in narrow widths give a more satisfactory appearance if the width of the door is small, and the shrinkage which occurs is correspondingly reduced. The battens are secured by means of tongued and grooved joint and are either V-jointed or beaded, as shown in Figs. 864 to 867. These joints are very

![Figs. 864 to 867](image)

Joints for battens.

effective in making the appearance of the door less objectionable when shrinkage takes place and joints open. The battens are sometimes only tongued and grooved, and in cheap work they are butt or square jointed as shown in Fig. 709. The door is fitted between the rebates of the frame and a clearance of 1/16 in. is usually allowed between the edges of the door and the frame for expansion. If the door does not fit accurately, any irregularities are noted and the door taken down and corrected where necessary. The door is hung with T-hinges or cross-garnets fixed on the ledges, or by narrow butt hinges fixed on the edge of boarding. This type of door is not either strong or good in
appearance, and hence it is only used for out-buildings in temporary purposes. A ledged and battened door is shown in Figs. 868 to 872.
2. **Ledged, battened and braced door**— The ledged and battened door has a tendency to droop at the outer edge. To prevent this drooping and also to increase the rigidity of the door, pieces of wood called **braces** are fixed diagonally between the ledges and are so arranged as to act as struts from the hinge towards the lock side (i.e., the brace are made to incline

Figs. 873 to 876
Various views of a ledged, braced and braced door.
upwards from the hanging edge) of the door. The braces are usually housed and not tenoned into the ledges of the door. The outer edges of the braces are chamfered. The width of the braces is usually 4 to 6 in., and the thickness is about 1½ in. A door of this description is called a ledged, battened and braced door, and is hung to the frame similar to a ledged and battened door. This is used for similar purposes as described for the ledged and battened door, but on account of its greater strength, it may be employed for larger openings. Various views of a ledged, battened and braced doors are shown in Figs. 873 to 876.

3. Framed, ledged braced and battened door (Figs. 877 to 879) — This is a good and strong type of door, and is largely used for external work. This type of door has a framework consisting of stiles or styles, ledges or rails, battens and braces. The framework consists of three rails, viz., top rail or head, middle or lock rail and bottom rail. The top rail is morticed and tenoned into two vertical timber pieces called stiles; and the middle and bottom rails are morticed and tenoned into the stiles. The battens are usually tongued and grooved and are V-jointed (see Figs. 864 to 867). The upper ends of the battens are let into the top rail or head, the side battens are tongued into the stiles and the lower ends of the battens completely cover the bottom rail, as shown. The braces are either housed into the rails at about 2 in. from the styles, or are taken into the corners and tenoned into the stiles, as shown. Though the latter arrangement is not as strong as the former, it is very often adopted on account of its better appearance. The braces are usually made to incline upwards from the hanging edge in order to get the full advantage of them. The outer edges of the braces and rails are stop-chamfered, beaded or moulded as shown. T-hinges or butt hinges are generally used for hanging this type of door.
4. Framed and panelled doors:—A panelled door usually consists of styles, rails, muntins or mullions and panels, and these parts are shown in Fig. 880. Various designs of panelled doors are shown in Figs. 881 to 891. From the figures it will be seen that (a) the stiles are continuous from top to
bottom. (b) the top, frieze, muntins or mullions are joined to the stiles and (c) the muntins or mullions are joined to the rails. The thickness of the frame for the shutters varies from 1\(\frac{1}{2}\) in. to 2 in., depending on the size of the door, the situation, the thickness of the panels, etc. The thickness of the panels is usually \(\frac{1}{2}\) in. The number of panels in any single door is generally limited to six. Grooves are made on all the inside faces of the frame to receive panels. Framed and panelled door is usually on butt hinges.
5. Glazed or sash doors:—These are wholly or partly glazed and are extensively used for hospitals, colleges, offices etc., to supplement the lighting provided by windows, or to make the interior of one room visible from another. Several designs of glazed or sash doors are shown in Figs. 892 to 897. The glass panes are set in the rebates of the framework of sash.
bars, and they are usually secured by nails and putty, or by beads tacked to the frame. Note the old-fashioned diminished still doors shown in Figs. 889 to 897. About one-third of the height of the door at the bottom is panelled, and the upper portion is glazed. In order to provide the maximum area of glass, the width of the upper portions of the styles which receive it is decreased as shown. These decreased stiles are called diminishing stiles or gun-stock stiles. Glazed doors are specially suited to light lobbies, halls, corridors, staircase landings, etc.

6. Louvred or Venetian doors:—These doors admit a free passage of air and light, securing at the same time privacy and safety. But they easily collect dust and hence they are difficult to clean. Venetian doors are largely used in Colleges, work-shops, residential buildings, etc. In louvred doors, the spaces between the rails are filled in by a series of wooden leaves (called louveres) overlying each other, each leaf being loosely pinned in the stiles, so as to allow of an upward and downward motion to a certain extent; the leaves in each space are connected by a vertical piece of timber, so that the whole may open or shut together.
Figs. 892 to 897 Various designs of glazed or sash doors. The doors shown in Figs. 895 to 897 are called diminished stile doors.
In order to make the louvres effective and economical, they should be fixed at an angle of 45 degrees or more to the horizontal. A common venetian door is illustrated in Fig. 898.

Combinations of 4, 5 and 6 are also possible; thus a door may be (a) panelled and glazed (Fig. 899), or (b) panelled and venetianed, or (c) panelled, glazed and venetianed (Fig. 900). See also Figs. 895 to 897.

7. Flush doors:— These doors have a better appearance and now they are extensively used. Flush doors are manufactured in standard sizes to facilitate mass production. Two varieties of flush doors are in common use, viz., framed flush door and solid or laminated flush door.
Fig. 901 and 902
Frame 1 Flush door,

Fig. 903 and 904
Solid or laminated flush door.
A framed flush door (Figs. 901 and 902) consists of a skeleton or hollow wood frame comprising stiles, top, bottom and intermediate rails, and this frame is covered on both sides by sheets of plywood. Sometimes the hollow wood frame is filled with granulated cork or any light material instead of being left hollow. The top and bottom rails are tenoned to the stiles, and the thin intermediate rails (which are usually in. square in section) are stub-tenoned to the sides. The joints of the framing are invariably glued and cramped, and the sheets of plywood are glued to the framing under great pressure. To ensure a thorough circulation of air within the framing, ventilation holes are provided as shown. Lock blocks are provided for the insertion of a mortise lock. Most of the mass-produced flush doors are of this type, chiefly because of the great economy in the amount of material which results.

A solid or laminated flush door (see Figs. 903 and 904) consists of a core of strips of wood glued together under great pressure and faced on each side by plywood sheets. These sheets of plywood are also glued under great pressure to the laminated core. The laminated core usually consists of 3/8 in. wide strips of wood, which are arranged with the grain alternating; this arrangement assists in reducing the shrinkage and distortion. In good class doors hard wood pieces, called edging slips are fixed on all edges. These edging slips prevent the core and the edges of the plywood being damaged. A laminated flush door is normally heavy and requires much material.

The plywood facings for good class flush doors are usually 1/4 in. thick, and for cheap doors they are only 3/16 in. thick. The finished thickness of both types of flush doors

Plywood is a compound wood made up of three or more layers or plies or veneers, glued together under great pressure, and arranged so that the grain of one layer is at right angles to the grain of an adjacent layer or layers. A plywood sheet usually consists of an odd number of layers, i. e., 3 Ply, 5 Ply, 7 Ply, 9 Ply, etc. The number of layers or plies may be increased as desired. Plywood is also known as laminated wood or reconstructed wood.
are usually 1\(\frac{1}{4}\) in. Flush doors do not catch dust and are easy to clean, and may be given an excellent appearance by using proper plywood for the facings. The plywood facings are often left in their natural colours, the decorative effect depending upon the grain and texture of the woods. See Figs. 905 to 910.

External views of flush doors
8. Revolving doors:—Revolving doors afford an

Figs. 911 and 912.
Plan of a revolving door. A revolving door
entrance on one side and exit on the other side simultaneously. They are provided where there is a constant foot traffic of people entering and going out of an entrance in a public building such as a bank, hotel, (an) office, hospital, theatre, etc. These doors are also used in hill stations to avoid strong wind blowing in. They considerably assist in excluding the draught of cold or hot air through them, and are therefore very suitable for air-conditioned buildings. These doors serve the purpose of keeping the openings automatically closed when they are not in use, and in this respect they are more advantageous and also convenient than the self-closing spring swing doors.

A revolving door consists of four shutters, which are arranged diagonally on the sides of a centrally placed pivot. A circular space of entrance is also provided into which these four shutters revolve. Panelled, glazed or partly glazed and partly panelled shutters may be used. Vertical, protruding rubber pieces are fixed on all the edges of the four shutters, and these rubber pieces rub against the circular surface of the entrance to exclude draught. A revolving door is illustrated in Figs. 911 and 912. The radiating wings can be folded when there is a great rush of traffic.

9. Collapsible doors:—These doors do not require hinges for opening and closing the shutters, and are extensively used for residential buildings, public buildings, sheds, stores, godowns, gangways, etc. They are fabricated from rolled steel channels and flats and are provided with rollers at bottom to roll on rails when they open or collapse. Two forms of collapsible doors are shown in Figs. 913 and 914.
10. Rolling steel doors:—These doors can be rolled up at the top easily and cause no obstruction either in the opening or in the floor space. Rolling steel doors are generally used for the main entrance of shops, show-rooms.

![Diagram of a casement window with fan-light](image)

**Elevation of a casement window with fan-light**

**Plan of casement**

Fig. Nos. 940 and 941.

A casement window with fan-light
Garages, etc. The doors are made of thin steel plates tied by wire into a framed shutter and fixed over a central hollow rod 6 to 9 in. diameter. Inside the hollow face are springs to maintain it in position wherever it is left. The shutter slides in grooves in the side walls. The rolling of shutter is usually done in 3 turns. Rolling doors are usually from 6 to 12 ft. wide and 9 to 12 ft. high. These doors are sufficiently strong and may be safely used in exposed places.

Fan-lights or transoms--lights or Ventilators (Fig. 940):—These are openings placed on the top of doors or windows, and are intended for light and ventilation when the doors or windows are closed. The horizontal member separating the door (or the window) and fan-light is called a transom, each end of which is tenoned to the frame. Fanlights or ventilators may also be provided in walls at a height above the top of doors or windows.

Location of doors:—Doors should be so located that they allow the maximum use of the accommodation in a room, and at the same time maintain sufficient privacy without inconvenience, or trouble. As a rule, the doors should be located near the end of a room, but they should not be placed in the centre of a room, particularly in residential buildings.

Windows:—Windows are provided for admission of light and free circulation of air into the building. As a rule, maximum number of windows should be provided in the external wall area. The minimum area of a window or windows shall be one-tenth of the floor area of the room, and at least half of this area shall be made to open for ventilation. For schools, factories and hospitals, the area of the windows should be at least one-fifth of the floor area.
There is but little difference between the framing and fixing of doors and windows, and much of what has been said regarding the former applies to the latter. Windows are usually double-leaved and the frame is provided with a centre style, rebated like the remainder of the frame against which the shutters butt, and to which they are fastened by two or more butt hinges (according to their size and weight).

An elevation, section and plan of an ordinary form of window are shown in Figs. 915 to 917. In Fig. 918 is shown a vertical section of a louvred or venetian window.

The size and shape of windows depend upon the object of the room in which they are to be provided. The
position of windows depends on the orientation of a building. The sills of windows are usually placed from 2 ft. 6 in. to 3 ft. 6 in. above the floor level. Tops of doors and windows are generally on the same level. In India, window frames are provided with iron bars, netting, or both for purposes of safety. They are also provided with wrought iron ornamental grille work (see Fig. 919).
Sometimes windows are provided with shajjas or sunshades for protection against the sun and rain (see Fig. 653). The window sills are usually weathered and slotted to throw the rain-water off the face of the wall. A water or weather bar, usually of wrought iron, is placed vertically between the cut stone sill and the wooden sill of the window frame to prevent the access of rain water at this point (see Figs. 932 and 933). This is effected thus. A groove is formed in the stone sill and the water bar, which is the full length of the sill, is partially inserted and bedded in cement mortar. Then a corresponding groove is cut in the wood sill which is filled with a mixture of whit lead ground in linseed oil and the window frame is firmly bedded on the mortar spread to receive it with the projecting bar engaging in the groove. The bottom of the window opening is sometimes finished with a window board. The board is usually about 1½ in. thick, and is tongued into the wooden sill of the window frame. It is made wide enough to project beyond the surface of the plaster for about 1 in., shown in Fig. 932, and the projecting edge is either rounded or moulded.

The window frames may be fixed into the opening as the masonry work proceeds, or they may be fixed later. In the former case, the ends of the heads and sills project to form horns, which are embedded into the masonry work and help to secure the frame. In the latter case, the frames are secured by means of hard wood wedges, which are driven tightly between the frame and the wall.

Special types of windows:—Windows have acquired different names according to their shapes or position in buildings. Most of these doors are briefly described hereunder:

1. Dormer window:—This is a vertical window which is built on the sloping surface of a roof. The dormer
is used for admitting light into a room, and is shown in Fig. 920.

2. **Corner window**—This type of window is placed in the corner of a building, and is illustrated in Fig. 921.

3. **Gable window**—This is placed in the gable ends of a roof.

4. **Bay window**—This type of window projects outside so as to form a projection called a bay in a room (see Fig. 922). Such a window gives an increased area.
of opening for admitting light and air, and also an extra space inside a room.

5. Lanterns or Lantern lights:—These are windows fixed in flat roof for admitting light to passages or inner apartments to which normal light cannot be secured by means of windows. Such windows project above the normal surface of the roof. In Fig. 923 is shown a section of a lantern in which a metal frame and sash bars are used.

![Fig. No. 923. A lantern or lantern light](image)

6. Clerestorey window:—This type of window is usually fixed near the top of the main roof, and opens above the adjoining verandah or lean-to roof. The clerestorey window is arranged by swinging it on two horizontal pivots in the side styles as shown in Figs. 924 and 925 so that it is opened and shut by means of two cords, one from the top rail and the other from the bottom, the upper part opening inwards and the lower part outwards. The window may be easily made water-tight because a rebate forming an effective stop can be cut in the inner side of the top part and the outer side of the bottom part of the frame. This method is not suitable for large windows on account of the strain from the mode of hang-
7. **Circular window**—For a circular window working on a central axis, the rebate on the one-half of the frame, is also opposite to that on the other half, the rebate being, of course, cut to suit the direction of the opening. It is opened and shut by means of two cords. This type of window is very common in factories, barracks and lofty rooms.

8. **Sky-light**—A sky-light is usually fixed on the sloping surface of a roof parallel to its inclination, for
light and ventilation. The details of a typical sky-light are shown in Fig 927. For fixing a sky-light, the rafters of the roof are trimmed, leaving between them a space to suit the size of the sky-light. On the four sides of the opening, 9 to 11 in. deep and 1\(\frac{3}{4}\) to 2 in. thick wooden curbs or linings are provided to form a solid frame called curb frame. Over the curb frame is fixed a sash for fixing the sky-light glass, and the edge of the glass is projected about 1\(\frac{3}{4}\) in. beyond the lower edge of the bottom rail and is held by copper clips. The projecting top of the frame is throated, and lead flashings are provided for diverting the rain-water from the tiles above the sky-light towards the sides. Steel sky-lights are now manufactured, and are available in the market.

In Mangalore or Allahabad tiled roofs, the purpose of a skylight can be well served by substituting glass tiles of the Mangalore or Allahabad pattern in the required portion. This is much simpler and cheaper.
9. **Sash or glazed windows**—Sash is a special type of frame of a lighter section designed for carrying the glass panes, and consists of two vertical stiles, a top rail and a bottom rail. A sash may be divided by both horizontal and vertical bars or horizontal bars only. These are called sash bars or glazing bars or astragals. The sashes may be fixed, made to slide up or down or sidewise, hung at the top, bottom, or sides, or be pivoted on the central axis. If the sashes are hung to solid rebated frames and open like doors, the sashes are called casements, and the windows are usually specified as casement windows. The casement windows may open inwards and outwards and are hung with butt hinges or extension hinges to solid rebated frames. If the sashes slide vertically and are balanced by weights, the windows are called sash and frame windows or double-hinge sash windows. Boxed or cased frame is adopted for sashes sliding vertical.

The sashes are framed together by means of the mortise and tenon joint. The best joint for connecting sash bars is shown in Fig. 928, and this method is called **halving**. Alternatively, the vertical bar is mortised to receive the other on which short tenons are left, and
which is scribed or cut, to fit the first. This method is known as franking the sash bars, and is shown in Fig. 929.

The sashes are rebated for glazing; these rebates are from \( \frac{1}{8} \) to \( \frac{1}{4} \) in. wide by about \( \frac{1}{4} \) in. deep. The glass is secured by either putty or small fillets glazing beads.

If a sash or glazed window has only one sash, the frame consists of two vertical posts, stiles or jambs, a head and a sill. If it has two sashes, the additional vertical wooden member is called a mullion. An elevation, plan and section of a sash window, called casement window, are shown in Figs. 930 to 932 respectively, the alternative shapes for the sash bars being shown in Figs. 934 to 939. An enlarged vertical section of the window is shown in Fig. 933. Another elevation and plan of a casement window are shown in Figs. 940 and 941.

Fig. Nos. 931 to 939.

*Fig. 934, Rustic or bevelled sash bar; Fig. 935, Gothic sash bar; Fig. 936, Gothic and fillet sash bar; Fig. 937, Ovoid and fillet bar; Fig. 938, Lamb's tongue sash bar; Fig. 939, Lamb's tongue and fillet sash bar.*

Hardware or ironmongery includes hinges and fittings such as bolts and locks; it also includes door knobs and handles (sometimes called *door furniture*). Hardware for casements consists of butt or extension hinges, casement fasteners and casement stays.
10. Metal windows—In modern practice metal windows are extensively used for all kinds of buildings, particularly for schools, hospitals and public buildings. Bronze and mild steel are the metals chiefly used in the manufacture of these windows. Undoubtedly bronze windows are the best, as they are rust-proof and are finished with a good surface of a pleasing colour which, if kept clean, improves with age. But they are relatively expensive, and hence are not largely used. At present there is a big demand for steel windows in lieu of wood casements. Two ordinary forms of metal windows are illustrated in Figs. 942 and 943. The metal frame may be fixed direct to a wood frame.
to the wall as shown in Figs. 944 and 945, or it may be

**Fig. No. 944 and 945.**
Details of fixing metal windows to plain brickwork.
fixed to a wood frame as shown in Figs. 946 and 947. The
frame is usually bedded in cement or bituminous mastic and this must be well done to prevent the entrance of rain water. The frame and sash are usually of $\frac{3}{8}$ in. thick and their sections are identical in size and shape. They are of Z-section, 1 in. deep with $\frac{1}{2}$ in. wide flanges, as shown. The horizontal and vertical members of the frame and sash are welded solidly at the corners. Sashes are made with and without $\frac{1}{4}$ in. by $\frac{1}{4}$ in. by $\frac{1}{4}$ in. sash bars of T-section, the sash bars being threaded and locked at the intersections. Metal windows are usually hung with extension hinges, which are shown on page 118.

Putty (whiting ground in raw linseed oil) is used for glazing the metal windows. Ordinary putty will run, and hence sufficient quantity of gold size must be added with it to enable it to set. Springs may also be used in addition to putty. Metal clips are sometimes used to retain temporarily the panes of glass until the putty has set.

Most of the metal windows quickly corrode unless they are suitably treated. Spraying them with zinc is one of several rust-proofing processes which has been employed on a large scale. Unlike windows made of wood, metal
windows are not, of course, affected by atmospheric influences, and are very durable.

A few other forms of metal windows with or without fan-lights are illustrated in Figs. 948 to 952. These windows have outward opening casements, and are glazed from the outside. They may also be glazed inside and made to open inwards instead of outwards.

Fixtures and fastenings for doors and windows:
The following fixtures and fastenings are generally used for doors and windows, and most of these are shown in Figs. 953 to 980.

1. Hinges—Many types of hinges are now manufactured for doors and windows and the following types are in common use:—

(a) T-hinge or cross garnel:—This is a wrought iron strap pivoted to a metal plate, and the thickness of the strap varies from \( \frac{1}{8} \) to \( \frac{1}{2} \) in., and its length from 10 to 24 in. The straps or long arms of the hinges are fixed to folding shutters whereas the plates of the hinges are screwed to the door posts. This type of hinge is mainly used on planked shutters such as ledged and battened shutters, ledged, battened and braced shutters, etc.

(b) Strap hinge:—This type of hinge is sometimes used instead of a T-hinge, but it is especially suitable for heavy doors, such as stable doors, gates, etc.

(c) Butt hinges:—These are most commonly used on doors and windows. They are screwed to the edges of the doors or windows and to the frames. The flanges or wings of the hinges are made of either cast iron, malleable iron or steel, and the wings have countersunk holes to receive the heads of the screws used to secure the wings to the door or window and frame. The length varies from \( \frac{1}{4} \) to 6 in.
Fig. Nos. 953 to 973.
Various Hinges etc.
Fig. Nos. 964 to 966.
Various hinges, various fastenings and locks.
(d) Skew butt hinges or Rising or Lifting butt hinges—These hinges are sometimes used instead of ordinary butt hinges. These hinges cause the door to rise \( \frac{1}{2} \) in. (and thus clear a carpet or mat) on being opened, on account of the helical knuckle joints. The top edge of the door and the rebate on the soffit of the casing must be splayed to permit this vertical movement. These hinges also allow the door to close automatically.

(e) Back flap hinges—These hinges are used where the shutters to be are thin, and consequently no room on the edges for butt hinges.

(f) Counterflap hinge—This type of hinge is formed in three parts and having two centres. This arrangement allows the two flanges or leaves to be folded back to back.

(g) Parliamentary hinge—This is as shown in the figure, and is used for hanging doors.

(h) Pin hinge—This type of hinge is used for hanging heavy doors. The centre pin may be withdrawn; this renders it convenient to fit the two halves of the hinge without lifting or raising the heavy door each time it is offered up during fitting.

(i) Extension or cleaning hinge—This is an improvement upon the butt hinge for hanging casements; the upper and lower fittings are shown. Another form of extension hinge suitable for metal windows is shown near the bottom fitting. These are made of steel, wrought iron, bronze or gunmetal. They are often sherardized, a process of rendering the metal rust-proof by the application of powdered zinc.
2. Fastenings and locks: The following types of fastenings and locks are in common use:

(a) **Barrel bolt and tower bolt**: These are used for fixing to the back faces of external doors. The plate is screwed to the inside of the door and the bolt engages in a metal socket or staple fixed on the door frame. These bolts are usually from 3 to 15 in. long, and are made of either iron, brass or bronze.

(b) **Flush bolt**: This is as shown in the figure, and is not so conspicuous as the barrel or tower bolt type. The bolt is let into the door either upon a face or an edge of a door, and flush with the surface. This type of bolt is used where the projecting tower bolt would be objectionable.

(c) **Espagnolette bolt**: This is an extension bolt which is generally used for securing casement windows. It consists of two long bolts, one of which secures the top and the other the bottom of the sash. Both bolts act simultaneously by turning the handle or lever in the centre. The bolt is made of iron, steel or bronze.

(d) **Aldrop bolt**: This is fixed on external doors where a padlock is to be used. This bolt is usually made of iron.

(e) **HASP and staple**: These are usually of iron, and are fixed on external doors where a padlock is to be used. The staple is screwed to the door post and the hasp is secured by two small bolts to the door.

(f) **Hook and eye**: These are made of iron, and can be effectively used for keeping the window or door shutter open. The hook is fixed to the sill of the door or window frame, and the eye is fixed to the bottom rail.
(g) Norfolk latch: This is also known as the Thumb latch or Suffolk latch and is sometimes used to secure doors. It is usually of malleable iron, although for good class work it is of bronze. A Norfolk latch consists of a back plate with handle and pivoted sneck and a keeper through which a beam or fall bar passes to engage in a stop. The length of the fall bar is about 7 in., and that of the back plate is about 9 in.

(h) Casement fastener:—This is shown on page 119 and is made of iron or bronze. This type is also known as a cockspur fastener.

(i) Casement stay:—This form is called a peg stay, and is made of iron, gunmetal or bronze. The stay consists of a metal bar bored at about 2 in. centres, which is pivoted to a small plate that is screwed to the inside face of the bottom rail; there is in addition a pin or peg plate which is screwed to the top of the wood sill. The object of the stay is to maintain the sash when in the open position, and this it does when the pin is engaged in one of the holes.

(j) Handles:—These are of several types such as bow, knob or lever pattern. Three types of handles are shown on page 119.

(k) Padlock:—This is used for securing doors in temporary and common work.

(l) Mortice lock:—This type is employed for doors 2 in. and above in thickness. It is fixed in a mortise formed on the edge of the door and is only visible on the edge of the door.

(m) Rim lock:—This type is used for thin doors and are screwed on to the face and the edge of the door.
(n) **Cupboard lock**—This type is used for securing doors in temporary or inferior work.

**Panels**—These are suitably worked boards which are used for the shutters of doors and windows. The chief varieties of panels are:

1. **Square sunk or flat panel**—This is the simplest type of panel and is illustrated in Fig. 981. From the figure it will be seen that the thickness of the panel is same throughout. **Flush panel and solid panel** are the other two varieties of flat panel and are shown in Figs. 982 and 983. Very often a **bead** is formed on the vertical edges of the panel, and this panel is called a **bead butt panel** (see Fig. 984). If in addition a similar bead is stuck on the horizontal edges of the panel the panel is called a **bead flush panel**. Sometimes the corner of the frame is slightly rounded by sand-papering and is called **pencil-rounded**.

![Diagram of different panel types](image-url)
2. Raised panel—If the central portion of the panel is thicker than the edges or margin, it is called a raised panel. Several forms of raised panels are shown in Figs. 985 to 987.

3. Moulded panel—A simple moulded panel is illustrated in Fig. 988. Mouldings of various designs are provided along the edges of panels and at the junctions of panels and stiles.

Flat panels catch less dust, and require less labour to make. Elaborate mouldings must be avoided as they harbour dust and are difficult to clean. They are also expensive to produce.

Panels are also made of laminated wood such as plywood and laminboard. These panels are not liable to shrink and are light in weight in addition to their strength and durability.

Moulding—Moulding is the forming of the surface of the wood into various square and curved contours, and two types of mouldings viz., stuck moulding and planted moulding are generally used. The following is a brief description of these mouldings.

(a) Solid or Stuck mouldings:—The mouldings are stuck or worked on the edges of the framing. The joints at the angles of stuck mouldings are scribed to give 45 degrees mitres or intersections. Scribing is the shaping of a moulding which is required to fit against a similar but continuous moulding. A simple form of stuck moulding is shown in Fig. 989.

(b) Planted mouldings: These are separate mouldings which are planted round the panels adjacent to
the framing. The mouldings are nailed to the framing as shown in Fig. 882 and the nails must not pass through the panels in order to protect the latter from shrinkage or cracks. Provision should also be made for the free movement of the panels and there should be a space of 1/16 in. between each edge of the panel and the groove. Planted moulds are formed with mortered joints at the angles, each adjacent end of the moulding being cut at an angle of 45 degrees.

Planted mouldings which finish level with the face of the framing are called flush mouldings (Fig. 990), and those which project beyond the face of the framing are called bolection mouldings (Fig. 991).

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(125)
CHAPTER X

QUESTIONS FOR REVISION

1. Draw a dimensioned sketch of a fully panelled door 8' - 0" wide and 10' - 0" high, for a town-hall building. Mention the various parts with their sizes including fixtures and fastenings.
   (Gujarat University, 1953)

2. Explain with sketches:
   (a) Sky-light. (Gujarat University, 1953 and University of Sind, 1950).
   (b) Difference between ledged and braced door and a panelled door. (University of Baroda, 1952).
   (c) Louvred window. (University of Baroda, 1952).

3. Give a dimensioned sketch of a revolving door 5 ft. wide and 7 ft. high. How is it constructed and fixed in an opening? Narrate its advantages and disadvantages.
   (Gujarat University, 1953).

4. Name and describe the functions of the various fixtures as provided for high class building doors.
   (University of Baroda, 1952).

5. Draw to a scale in your answer book one horizontal section through jamb and mullion, and one vertical section through head, transem and sill of a steel window, 5' x 3' in size, fixed in a sub-frame. The frame is set back 4\(\frac{1}{8}\) inches from the face of the wall. Figure on the approximate dimensions of all members.
   (University of Bombay, 1954)
6. Draw a neat dimensioned sketch of a window, for a residential building, with all details of panels and frames. The shutters are half-panelled and half-glazed. 

(Karnatak University, 1955)

7. By means of a diagrammatic sketch show the size, number and location of the openings for ventilation to be provided in a three bed private ward hospital. Assume a suitable size for the room. What type of window do you propose for the room? Explain its construction with the help of sketches.

(University of Poona, 1956)

8. (a) Explain the following:—
   (i) sunk panel, (ii) frieze rail, (iii) rolling shutter, (iv) dormer window.

(b) Draw an oblique mortise and tenon joint.

(Karnatak University, 1954)

9. Write short notes on the following:—
   (a) Hold-fasts and horns.

   (b) Horn

   (University of Baroda, 1952)

   (c) Revolving door. 

   (University of Sind, 1950)

10. Sketch a partly panelled and partly glazed door for an opening 4 ft. wide and 8 ft. high. Mention various parts and their sizes.

   (Gujarat University, 1952)

11. Draw to a scale of 1 in. to a foot a section of wood casement sash and frame.

12. Draw full size section of window sill, window board, water bar and stone sill.
CHAPTER XI.

STAIRS AND STAIRCASES

General:—Stairs are steps arranged suitably in a series for the purpose of giving access to different floors of a building. A flight is formed by a series of steps, and there may be two or more flights, separated by flat platforms called landings, between two floors. A step usually consists of a tread and a riser supported by strings (see below). A step of uniform width and rectangular in plan is called a fler. A stair, together with the part of the building accommodating it, is known as the staircase.

Location of stairs:—As a stair is the only means of communication between the floors, the position to be allotted to a stair in a building requires careful consideration depending upon the purpose of use in each case. In a residential building the staircase should be near the front entrance, and in a public building the position of the staircase should be obvious from the main entrance. Where two stairways are required, they should not be too near each other, and if there are more than two, they should be well separated and placed so as to afford the easiest and quickest service possible to the building as a whole. The distribution of stairways is particularly important in the design of large factory buildings. Stairways should never be located around or adjacent to elevator shafts without solid walls between them.

 Dwelling houses, both in the city and country, should have two stairs, the front or principal stair, for general use, and a back stair for the service of the house. The back stair also serves as an escape way in case of
emergency. The front stair is generally made to be seen, and the back stair is ordinarily out of sight. If regular sloping staircases (see below) are constructed both in the front and rear of the house a large portion of the floor area is used up, particularly in small buildings, making this arrangement rather expensive. A spiral stair (see below) at the back of the house on the other hand, saves much space, and its construction cost is also comparatively low. Always it is advisable to place the staircase against a wall for economy of space, provision of light and ventilation, and ease of construction. Special care must be taken to see that all staircases are well ventilated and properly lighted.

Stairs are open or closed when they are open or enclosed by walls.

Technical terms:—Most of the technical terms used in the design and construction of stairs are illustrated in Figs. 992 to 994, and the following is a brief description of them:

1. **Tread**.—It is the horizontal member which forms the upper surface of a step.

2. **Riser**.—It is the vertical front portion of a step which is connected to the tread.

3. **Rise**.—**Rise of a step** is the vertical distance between the upper surfaces of two successive treads, and the **rise of a flight** is the total height from floor to floor, or floor to landing, or landing to landing.

4. **Going**.—**Going or run of a step** is the horizontal distance between the faces of two consecutive risers, and the **going of a flight** is the horizontal distance between the face of the bottom riser of the flight and that of the top riser.

B.C.—9
5. **Nosing** — This is the front edge of a tread which projects beyond the face of the riser below it.

6. **Line of nosings** — The line of nosings is that drawn to touch the projecting edges or nosings of the treads of a flight, and is parallel to the slope of the stair.

7. **Flier** — It is the name given to a step of uniform width and rectangular in plan.
8. Flight:—A flight of stairs, technically, is a continuous set of steps extending from floor to floor, or floor to landing or landing to landing without a break, but in ordinary conversation it is generally taken to mean the entire height of stair from one floor to the next, including landings.

9. Landing: This is a horizontal platform which is provided between two flights to serve as a rest, and when required, to make effective provision for turning a stair. This term is also applied to the portion of the floor adjacent to the top of a stair. A landing may be a quarter-space landing or a half-space landing. A quarter-space landing (See Figs. 1024 to 1027) is one on which a quarter turn has to be made between the end of one flight and the beginning of the next. If the landing extends for the combined width of both flights and a complete turn is necessary, it is called a half-space landing (See Figs. 1020 to 1023).

10. Pitch or slope: This is the angle between the line of nosings and the floor or landing.

11. Scotia: A scotia or scotia block or scotia mould is sometimes used to provide an additional finish to the nosing of a tread. A scotia board is cut from a relatively wide board and used at nosings of treads forming bull-nosed and similar rounded bottom steps.

12. Strings or stringers: These are inclined members which support the steps. For each flight two strings are usually provided, i.e., one on each side. There are two principal types of strings, viz., (a) closed or housed strings and (b) cut, open or notched strings.

(a) A closed or housed string (See Figs. 992 and 993) has top and bottom edges parallel and on its inner
face grooves are cut to receive the ends of the treads and risers; these grooves are called *housings*; and the steps are said to be housed into the strings. The amount of housing varies from \( \frac{1}{8} \) to \( \frac{1}{4} \) in. usually \( \frac{1}{8} \) in.

The grooves, trenches or housings are sloped at the lower side of the tread and the inner side of the riser and are of sufficient width to permit of the insertion of wedges, which should be of hardwood. These wedges, after being dipped in glue, are driven in from the back. The tread wedges thus bring the treads tightly against the upper cuts of the housings, and the riser wedges cause the faces of the risers to fit tight against the outer vertical housing.

(b) **A cut, open or notched string (See Fig 994):**—has its lower edge parallel to the pitch of the stair and its upper edge is cut or notched to receive the ends of the treads and risers.

The strings which are fixed to walls are called *wall or inner strings* and are usually closed or housed string; those on the outside are known as *outer strings* and may be of either the closed or open type.

If the stairs are very wide, one or more inclined members, usually 4 in. by 2 in. or 4 in by 3 in., are provided at intermediate positions to support the steps in addition the strings. These are called *rough strings, carriers, bearers, carriage-pieces, rough carriages or spring-trees*.

13. **Soffit or planter:**—It is the under surface of a stair which is usually neatly finished with a ceiling of planks or plaster. See Fig. 992.

14. **Spandrel or Spandril:**—This is the triangular surface between an outer string and the floor, and is usually plastered or panelled.
15 Step.—A step is the combination of a tread and a riser supported by strings. The following types of step are generally employed:—

Bull-nosed step.—This is situated at the bottom of flight, projects beyond the face of a newel or newels (see below) and has one or both ends rounded. See Figs. 995 and 996.

Fig. Nos. 995 to 1002
Showing the special types of steps generally employed in stairways.
Curtails, round or scroll step:—This is the lowest step of a flight with its one or both ends finished semi-circular or spiral in plan. See Figs. 997 and 998.

Splayed step:—This type of step has one or both ends splayed as shown in Figs. 999 to 1001.

Commode step:—A commode step has a curved riser and tread. See Fig. 1002.

Flier:—This type of step is extensively used; it is of uniform width and rectangular on plan.

Winders (See Figs. 1026 and 1027):—These are tapering steps which are used for changing the direction of a stair. They are usually triangular in plan and radiate from a point which is usually situated at the centre of a newel (see below). The central winder of series is called the Kite winder. Winders should be used only in exceptional cases.

Dancing or balancing steps:—These are winders which do not radiate from a common centre. See Fig. 1002.

16. Balusters:—These are short vertical members which support the handrail and protect the open side or sides of a stair. See Figs. 1003 to 1011 and 1021 to 1037.

17. Balustrade or Banister:—An open balustrade consists of balusters, handrail, string and newels (see Figs. 1020 to 1037).

A solid balustrade (see Fig. 1039) consists of panelling in lieu of balusters. The term balustrade properly applies to massive work in stone or its imitation, but now it is much used by architects and engineers for the lighter work in wood and iron employed in modern stair construction. The balustrade offers an exceptional opportunity for decorative work.
18. Handrails (See Figs. 1003 to 1013):—These are provided to afford assistance and a safeguard to persons while going over a staircase. The handrails are fixed at the top of balustrades or at a convenient height to walls. They should be of a satisfactory size and shape to enable them to be easily grasped by the hand. Usually a handrail runs between two newels and is supported by balusters.

Fig. 1003 to 1013
Showing the various forms of handrails

Fig. 1011 shows the details of a laminboard solid balustrade, and Figs. 1012 and 1013 show the details of wall handrails.

Even if a stairway is entirely enclosed by walls on both sides, the handrail is an important part of the modern stair construction. Without it the danger of injury to
people using the stairway would be greatly increased. Two
forms of common wall handrail are shown in Figs. 1012
and 1013. The former is very common wall handrail and
is securely plugged to the wall; the latter wall handrail is
circular in section and is screwed to a continuous stainless
steel bar which is set-screwed to metal brackets, secured
at approximately 3 ft. intervals to plugs. Both forms
of handrails are usually made of hardwood.

19. Newels or Newel posts.—These are principal or
more important posts supporting a handrail. Newels are
used at the beginning and end of a balustrade, and also at
turning points on landings. The upper moulded end is
called a cap and the projecting lower end is known as a
drop.

20. Head-room (Fig. 1014).—The vertical dis-
tance between the line of nosings and the soffit or land-

![Fig. No. 1014.]

Showing head-room in a staircase.
ing of a flight immediately above it is called head-room. The head-room should not be less than 7 feet.

21. Walking line:—A person ascending or descending a stair usually travels along a line which is normally about 1 ft. 6 in. from the centre of the handrail or newel. This line of travel is called the walking line.

22. Stair:—A stair may be a step, a series of steps, or a continuity of steps from floor to floor, or the word in its singular form may apply to all the stairs in one continuous stairway. In many ways, the singular and plural form of the word can be used interchangeably.

23. Staircase:—As already stated, a stair, together with the part of the building accommodating it, is called

1. For the determination of head-room required in stairways, the procedure illustrated in Fig. 1015 is quite commonly used in America. Mark a reference line parallel with the steps at a height measured vertically 1 ft. 6 in., above the line through the stair- nosings. A clearance of 2 ft. 6 in. as shown with respect to the reference line is considered the minimum allowed. Determination of the height at which the railing is to be attached is also shown in the figure. This method is quite suitable to our country also.
the staircase. In common usage, it is almost synonymous with the word stair, but improperly so.

24. Stairway:—This is the opening or space occupied by the stair.

25. Well or well-hole:—This is the name given to the space between the outer strings of the various flights of a stair called an open well stair. See Fig. 1002.

26. Margin:—This is the portion of a closed string between its upper edge and the line of nosings. See Fig. 993.

Essential requirements of a well-designed stair:—A well-designed stair should comply with the following requirements.

1. Location of stair:—A stair should be located in buildings in a position where there is both light and ventilation, especially at turnings. It should be constructed in such a position that it can be conveniently approached from lower rooms and afford a ready access to the upper rooms. Doors should be placed at least 1 ft. from the head and foot of a stair. Special care must be taken to provide sufficient light to a solid balustraded stair as it offers a greater obstruction to light than one with balusters. If possible, two-way switches must be provided at the head and foot of the stair.

2. Materials:—It should be constructed of sound materials and workmanship. It should preferably be constructed of materials which possess fire-resisting qualities.

3. Proportions of going and rise:—The ascent and descent of a stair should be relatively easy, and the proportions of going and rise should conform to one of the rules given below. The pitch must not be more than 45 degrees if undue tiresomeness is to be avoided, and it
should not be less than 25 degrees in order to prevent a tedious ascent and the occupation of excessive space.

The following three rules are generally used to obtain a satisfactory ratio between the going and rise of a step:

(i) \((\text{Going in inches}) + (2 \times \text{Rise in inches})\) = approximately 24,

(ii) \((\text{Going in inches}) \times \text{Rise in inches}\) = approximately 66,

(iii) With a 12 in. going and a 5\(\frac{1}{2}\) in. rise as a basic ratio, for every inch deducted from the going half an inch is added to the rise, i.e., (a) 12 in. going and 5\(\frac{1}{2}\) in. rise, (b) 11 in. going and 6 in. rise, (c) 10 in. going and 6\(\frac{1}{2}\) in. rise, (d) 9 in. going and 7\(\frac{1}{2}\) in. rise, etc.

Rule (iii) agrees with rule (i) in so far as the going plus twice rise equals 23 in. in each case. But this does not agree with rule (ii) when the going is less than 11 in. Stairs designed in accordance with one of the rules have been found adequate, safe and practical. People are used to such steps and therefore can use them with the greatest degree of convenience. But under any circumstances, the going should not be less than 9 in. In residential buildings 10 in. by 6\(\frac{1}{2}\) in. (i.e., 10 in. going by 6\(\frac{1}{2}\) in. rise), and in public buildings 11 in. by 6 in. are the usual dimensions. In factories, the going must not be more than 10 in. and the rise not more than 7\(\frac{1}{2}\) in. A satisfactory proportion for theatre stairs is an 11 in. going and a 6 in. rise. The customary rise employed varies from 5\(\frac{1}{2}\) to 7\(\frac{1}{2}\) in. and the run or going from 9 to 12 in. A rise greater than 7\(\frac{1}{2}\) in. is

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1. Other rules in use are: sum of riser and tread to be 17\(\frac{1}{2}\) to 18 in.; product of riser and tread to be 70 to 75. The latter rule agrees with the New York Building Law. But the New York Building Law limits the height of riser to 7\(\frac{1}{2}\) in. and the width of tread, without nosing, to 6\(\frac{3}{4}\) in.
objectionable and results in making a stairway too steep for comfort and safety.

It may be worth while to note that the value of going in the above rules does not include the nosing of the step, and the projection of the tread beyond the face of the riser should not exceed the thickness of the tread, as an excessive projection may cause a person to trip when ascending.

4. Tread and riser:—The height of risers should be exactly the same from one floor to the next, even if it figures out an odd fraction of an inch to make it so, and there is no exception to this requirement. The treads should have a uniform width, except where winders are used. In high buildings where the heights of storeys vary the height of the riser will ordinarily vary when the height varies. In such a case, the change in the height of the riser should be made as little as possible. Generally speaking, variation in the size of steps should be avoided, if accidents are to be avoided (see Fig. 1016).

Fig. No. 1016

Showing variation in the size of steps. It should be avoided if accidents are to be avoided.
5. **Width of stair**—The width of a stair should not be less than 3 ft. The width of landings should be at least equal to that of the steps.

6. **Head-room**—Adequate head-room (or unobstructed vertical height) must be provided. It should not be less than 7 feet if accidents are to be avoided. (See Fig. 1017).

![Fig. No. 1017](126x126)

Showing low head-room in a staircase. It causes accidents.

7. **Length of flight**—A flight should not contain more than 12 steps or less than 3 steps, to give comfort and safety. Stairways are usually designed with short straight flights, with one or two intermediate platforms or landings. Long uninterrupted flights without landings from one floor to that of another are objectionable and dangerous.

8. **Landings**—Adequate number of landings should be provided at intermediate positions. Always preference should be given to half-space landings. If quarter-space landings have to be used, a regular flight of not less than 5 steps should be introduced between two consecutive
quarter-space landings. As a rule, landings should not be less in width than the width of the stair in which they occur. It is very desirable to have at least one landing in every ordinary storey.

Winders—Winders are always a source of danger, especially to young children and aged persons, and they should, therefore, as far as possible, be avoided in a stair (see Fig. 1018). But often this is not possible when the going is greatly restricted, and winders may then have to be used either at the bottom or at the top of a flight; in cramped positions there may be no alternative to the provision of winders at both the head and foot of a flight. When winders have to be used, they should be placed near the lower end of the flight; for, if one happens to slip from a winding step, while descending, the fall will
be from a small height. Only three winders should be used in a quarter-space landing, for purposes of convenience and safety.

10. Handrails:—The handrails should be of suitable size and shape in order that they may be easily grasped by the hand, and they should be fixed at a convenient height. Care should be taken to avoid sharp arrises on a moulded handrail in order to prevent injury to a person's hand, especially during a rapid descent of a stair.

The height of a raking handrail, i.e., parallel to the pitch, should be 2 ft. 7 1/8 in. measured vertically from the line of nosings to the top of the handrail or 2 ft. measured normally from the line of nosings, and that of a horizontal handrail should be 3 ft. Designing of stairs:—The various points given under the head "Essential requirements of a well-designed stair" should be kept in mind when designing a stair. The type of stair decided upon largely depends on the size and shape of stairway. The number of steps to be decided upon is governed to a large extent by the total value of going available. If the height from floor is fixed and the going is not limited, the number of steps is determined in the following manner:

Let the rise be 6 1/2 in. (which as stated above, is satisfactory for a dwelling stair). Then the number of risers equals the height divided by 6 1/2. Thus, if the height from floor to floor is 10 ft., the number of steps

\[
\frac{10 \times 12}{6 \frac{1}{2}} = \frac{120 \times 2}{13} = 18 \frac{6}{13}
\]

Adopting this figure, the exact rise is

\[
\frac{10 \times 12}{18 \frac{6}{13}} = \frac{10 \times 12 \times 13}{240} = 6 \frac{1}{2} \text{ in.}
\]
We know that (Going in inches) + (2 × Rise in inches) = approximately 24. The going will then = 24 - 2 × 6\(\frac{1}{2}\) = 11 in. Here it is necessary to remember that the number of treads is one less than that of the risers, as the surface of the upper floor forms the tread for the top step.

If the going is so restricted that the minimum going of 9 in. can only be used, then the number of steps equals 10 × 12 ÷ \(\frac{24 \text{ in.} - 9 \text{ in.}}{2}\) = \(\frac{120}{7\frac{1}{2}}\) = 16. Adopting this figure, the rise of each step is \(\frac{10 \times 12}{16}\) = 7\(\frac{1}{2}\) in.

This will be satisfactory, as it conforms to the rule (Going in inches) + (2 Rise in inches) = approximately 24, i.e., 9 in. + (2 × 7\(\frac{1}{2}\) in.) = 9 in. + 15 in. = 24.

Classification of stairs:—Stairs are classified as follows:

1. Straight flight stairs.
2. Dog-legged stairs.
3. Open well stairs or Open newel stairs.
5. Geometrical stairs.
7. Bifurcated stairs.

1. Straight flight stairs:—A straight flight stair (or simply a straight stair) is one in which all the steps are parallel to one another, and rise in the same direction, so that a person ascending them moves forward in a straight line. A straight stair may consist of a single flight only or two or more flights in its length which are separated by landings. A plan and section of a straight flight stair are shown in Figs. 1019 and 1020 respectively.
2. Dog-legged stairs:—A dog-legged stair is so called from its being bent or crooked suddenly round, in fancied resemblance to a dog's leg. It is a convenient form when the going is restricted and sufficient space equal to the combined width of two flights only is available. In this...
type of stair the successive flights rise in opposite directions. The flights of the stair may be separated by (a) a half-space landing, (b) a quarter-space landing and (c) two sets of winders and no landing. These methods are given in order of merit. The last method should be avoided as far as possible as it makes the stair too steep and dangerous near the newel post. This method also involves constructional difficulties. A dog-legged staircase with half-space landing is shown in Figs. 1021 and 1021A.

3. Open well stairs or Open newel stairs:—An open well stair or an open newel stair is very similar to a dog-legged stair, but in this type there is a rectangular well-hole, or opening, between the backward and forward flights (see Figs. 1022 and 1023). The width of stair would, therefore, be twice the width of the stair plus the width of the well-hole or opening. At the head and foot of each flight of the stair are placed newels which form a conspicuous feature for the stair to be called 'Newel stair.' It is a convenient form of stair, and the well-hole allows of top lighting. If the space for a stair is restricted, a short flight of 3 to 5 steps is introduced on the narrow side of the well with two quarter-space landings on either side. Always an open well stair gives satisfactory results and hence it should be tried to provide an open well stair though it requires a little more space than a dog-legged stair. This extra-space (i.e., extra width) required for the open well stair need not be more than 6 in.

4. Newel stairs:—This is another name for dog-legged stairs, because the newels form a conspicuous part of the structure. A newel is usually placed at the foot and head of each flight of the stair. Three forms of newel stairs are shown in Figs. 1024 to 1029.
5. Geometrical stairs (Figs. 1030 to 1035):—A geometrical stair is one in which there is an opening or well-hole between the backward and forward flights. In this type of stair both the strings and handrails are continuous and are set out in accordance with geometrical
principles. Such a stair requires a little more width, but only about the same length of space as a dog-legged stair. The change of direction is obtained by winders radiating from the centre of curvature of the curve between the flights. It will be seen from Fig. 1030 that the winders have a certain amount of width even at the inner verge, and they are, therefore, more convenient to use than those in a newel stair. A newel may, for reasons of design, be introduced at the bottom and top of such a stair, but is not an essential part of the construction. Geometrical stairs may be either circular, octagonal or elliptical on plan.

6. Circular or winding stairs:—Circular stairs are constructed of winders, and there are two forms of circular stairs, viz. (a) circular-newel stairs or spiral stairs and (b) Circular geometrical stairs.

(a) Circular-newel stairs or Spiral stairs:—In this type of stair, all steps radiate from a central newel post (see Figs. 1058 and 1059). Iron or R. C. C. spiral stair is very common and is especially used for service purposes. The iron spiral stair is not usually enclosed in a staircase, and is very suitable for back-door entrances as it occupies only a small room. Although spiral stairs are mainly used for service purposes, they are also adopted for access to mezzanine floors in shops and offices and to projecting balconies in meeting halls.

(b) Circular geometrical stairs:—A circular geometrical stair is somewhat similar to a spiral stair, but occurs usually in R. C. C. stone, or iron, and has a circular opening or well-hole in place of the newel post. See Figs. 1056 and 1057.

7. Bifurcated stairs:—This type of stair is very common in public buildings in which it appears as a prominent feature. In this type of stair, the bottom wide
flight is divided at a landing into two narrower flights which branch off to the right and left. A plan and elevation of a bifurcated stair are shown in Figs. 1038 and 1039 respectively.

The classification of stairs also includes the *quarter-turn stairs* and *half-turn stairs*. The former type of stair changes its direction either to the right or left, the turn being effected either by a quarter-space landing or by winders (see Figs. 1024 to 1027 and 1034 to 1037). The latter type of stair has its direction reversed either by a half-space landing as shown in Figs. 1021 to 1023, 1028 and 1033), or a quarter-space landing and winders, or two quarter-space landings and a short flight of 3 to 5 steps or completely by winders as shown in Figs. 1030 and 1031.
Ladder stairs:—Deep stairs are called *ladder stairs*, and are made of steel, iron or wood and are usually 15 to 24 in. wide. They are used in a small space, for low heights and used only occasionally, such as mezzanine floors in shops and offices. They are given a rise of 10 in., and a tread of 5 in., and the angle of inclination is from 70 to 76 degrees. They are fixed in position or are left as removable. The removable type is provided with an iron bracket at the top for holding and prevention from slipping of the lower end.

Materials used in the construction of stairs:— Stairs are built up of various materials such as wood, stone, steel, wrought iron, cast iron, reinforced concrete or reinforced brickwork. Sometimes two or more of the above materials are used in the same stair. Most of the building laws require stairs to be constructed entirely of incombustible material, except in framed buildings and in non-fire proof buildings of moderate size. All such stairs are usually supported by iron strings, or they are made of R, C, C. If they are supported by iron strings, the treads should be made of solid steel or cast-iron plates. Marble or other stone should not be used for finish treads without such plates under them because in case of fire the stone treads are likely to crack or break from heat. In the most economical construction of this character, the treads and risers are now made of stamped steel plates in various forms, some of which are arranged to carry marble or cement treads.

Wooden stairs:—In dwelling houses stairs are usually made of wood. Wooden stairs are lighter in weight than those of any other material, and are easily made, cheap, quick to lay and repair and last moderately long. They are made of any size according to requirements, say from 2 ft. 9 in. to 8 ft. wide. The flight of stairs is built
independently outside as one unit and fitted into position. The only objection to wooden stairs is that they are liable to be attacked by fire. If, however, the wooden stair is entirely made of teak-wood or any other hardwood of at least 2 in. finished thickness, it is sufficiently fire-resisting to enable the occupants to escape from the upper floors within a reasonable time.

The steps of a wooden stair are formed of hardwood boards, and they consist of treads and risers. The thickness of treads varies from 1½ in. to 2 in., and that of risers from 1 in. to 1½ in. But the treads are usually 1½ in. thick, and risers are 1 in. thick. The tread is made to project slightly beyond the face of the riser so as to give an architectural effect to the step. This projection is called the nosing, which is usually half-rounded or moulded (see Figs. 1040 and 1041). The nosing, as already stated, should not project more than the thickness of the tread.

Fig. Nos. 1040 and 1041.
Showing the joints between treads and risers.
Fig. 1040 shows a good method of connecting the treads to the risers, both edges of the latter being tongued into the grooved treads and screwed as shown. Another good method of jointing treads and risers is shown in Fig. 1041, where the treads are tongued at their inner edges into the risers. Sometimes a specially moulded scotia block is used to provide an additional finish to the nosing of a tread as shown in Fig. 993. The scotia block also adds to the strength of the tread at nosing, when the latter has a longer projection. A small groove is cut at the underside of the nosing in which the scotia block fits. Inclined risers are sometimes used as an alternative to the more usual vertical form already mentioned. These inclined risers give an appearance to the stair, especially if a simple form of nosing is employed. Sometimes small triangular wooden blocks, called glue blocks, are provided to give additional strength to the steps. The glue blocks are glued in at the inner angles formed between the treads and risers, and are spaced at 3 or 4 in. apart. See Figs 1040 and 1041.

The steps of a wooden stair are supported at each end by inclined wooden members called strings or stringers, and the strings are supported on newels, trimming joist, or pitching pieces. The thickness of the strings usually varies from 1½ to 2½ in. and its depth from 10 to 16 in. As already stated, strings are of two kinds, viz., (a) Housed or closed strings and (b) cut strings. These kinds of strings are described to sufficient length later. Against walls, closed or housed strings are nearly always used, and in this position they are called wall strings. The wall strings are securely plugged to the walls and the upper ends are supported on a trimmer beam. A 2 to 3 in. wide margin is provided and the upper edge of the string is often rounded and rebated to provide a simple but effective
finish between it and the plaster. The outer strings are secured to newels (usually 4 in. by 4 in.) placed at the foot and head of each flight. The strength of the stair depends a good deal upon the rigidity of these newels and the method of jointing the strings to them. The thickness of strings is usually from 1 \(\frac{1}{2}\) to 2 \(\frac{1}{2}\) inches. Stairs wider than 3 feet require one or more intermediate supports against bending of treads. These supports are given by inclined wooden pieces called **bearers** or **rough strings**. These bearers are usually 4 in. by 3 in. or 4 in. by 2 in., and are placed slightly below the underside edges of steps. In order to give maximum support to the bearer, 1 in. thick short pieces of wood (generally pieces of floor board), called **rough brackets**, and shaped as shown in Fig. 992, are nailed to the sides with their upper edges cut square and brought tightly up to the underside of the treads to which they are nailed; these brackets are fixed alternately to the bearer. The strings are usually designed to carry a load of 300 lbs. per step or 100 lbs. per sq. ft. whichever is greater.

For forming a half-space landing, a trimmer or trimmer beam (usually 7 in. by 3 in.) is fixed across the width of the staircase. It supports the bridging or landing joists which are tenoned or housed into the trimmer at one end, and are supported on the wall at the other. The bridging joists are usually 4 in. by 2 in. The newels are normally continued through the floor and well nailed or bolted to thick joists. If this is not possible, the newels are continued to the floor to which they are nailed. See Figs. 1043 to 1046.

For forming a quarter-space landing, a wooden piece called a **pitching piece** is built at one end into the wall, and at the other end it is housed into the newel, which may either be hanging or supported on the floor. In the
In the former case, the pitching piece is designed as a cantilever and is strengthened by a bracket on the underside. The pitching piece supports the bridging joists for the landing. See Fig. 1042.

Winders are usually supported by means of bearers, built into the wall at one end, and framed into the newel at the other. The back of the bearer is flush with that of the riser immediately over it. Cross bearers, to support the treads, are framed between the risers and the bearers behind them. See Fig. 1042.

Fig. No. 1042
Showing the Framework for winders on the left-hand side, and that the framework for quarter-space landing on the right side in a wooden stair

The handrail should be made of hardwood and of suitable size and design. The handrail is supported from the string by wooden balusters. Various forms of handrail are shown in Figs. 1003 to 1013. The balusters are usually spaced at 3 to 4 in. apart, and may be either housed (as shown in Fig. 1003) or tenoned (as shown in Fig. 1005) into handrails. In cheap work, they are cut...
to the pitch of the handrails and strings and simply nailed to them.

Bronze or similar metal balustrades or metal grilles are sometimes used for wooden stairs. Solid balustrades are also employed, and for the construction of these the use of lamin-board is likely to increase. Fig. 1011 shows the details of a lamin-board solid balustrade. The lamin-board may be housed into the newels and string. See Fig. 1038.

The underside of the flight may be covered with \( \frac{1}{2} \) in. lath and plaster or with \( \frac{1}{2} \) in ceiling planks, as a finishing for the soffit (See Fig. 992). The inner empty spaces of the stair are sometimes filled in with coke breeze blocks.

![Diagram of a stairway showing details of construction.](image)

*Fig. 1043 & 1044
Wooden straight flight stair.*
Such a stair is not as noisy as the usual hollow wooden stair.

A straight flight stair and a dog-legged stair, entirely made of wood, are shown in Figs. 1043 to 1046.
2. **Stone stairs**: Compared to wooden stairs, stone stairs are harder, more durable, less likely to decay, more fire-resisting and simpler in construction. But the steps of stone stairs are heavy, and require substantial walls for their support; moreover, they become smooth under the friction of continued wear, and then are slippery and dangerous. Stone stairs are generally used for external stairs. The stone selected for steps must be hard, strong and durable, and it should not readily wear to a smooth and slippery surface. Certain varieties of sandstone best satisfy these requirements and they should, therefore, be used for stone stairs.

Stone steps are generally of solid blocks, and are worked on the tread and riser. In superior buildings the soffit also is worked and the nosing may be moulded. Stone steps supported at both ends are of most simple construction.

The main types of stone steps are:

1. **Square steps**: These steps are rectangular in section, and hence they are also called, 'rectangular steps.' Stone steps, may in some forms of staircase, be supported at both ends by walls; in other cases only one end of each step is built into the wall, the other end being free; these latter are called *hanging or cantilever steps*.

As already stated, steps supported at both ends are of most simple construction (see Figs. 1047-1049). The steps are rectangular in section, and have a rebate cut at their lower corner into which fit the square upper edges of the steps below (see Fig. 1049). The minimum *lap* of the upper step on the lower one is 1 ½ in. The steps are about 12 inches longer than the width of the stair, so that a length of 6 inches at each end is built into
The adjacent walls. **Hanging steps** are fixed at one end only; the outer end projects, and is without support other than that afforded by the steps below it. The fixed end of these steps should be let into the wall about 9 inches, and very solidly and firmly built in. Square steps are cheaper than spandrel steps as the labour in cutting and dressing the stone to a triangular shape is saved.

Figs. 1047 to 1051

**Figs. 1047 & 1048**—Show a straight flight stair composed of square steps supported at each end by being built into the side walls.

**Fig. 1049**—Shows an enlarged section with three steps.

**Figs. 1050 & 1051**—Spandrel steps.
(2) Spandril steps:—These steps are employed when a regular flight of stairs has to be constructed between the floors. A spandril step is approximately triangular in section and has its one end square which is built into the wall. Spandril steps are rebated to fit one over the other, the rebate being arranged at right angles to the soffit as shown in Fig. 1050. This arrangement avoids acute angles at the edges, and ensures a direct thrust; it also makes the steps lighter and is considered to have a neater appearance than square steps. The distance from the internal angle between the tread and the riser should not be less than 2 in. for stairs up to 3 ft. 6 in. wide, and for every additional foot width, this distance should be increased by \( \frac{1}{2} \) in. The steps are very often given a returned nosing as shown in Fig. 1051. Stone slabs are used for landings, and the thickness of the slabs varies from 3 to 6 in. Spandril steps may also be supported at both their ends by means of a wall or a steel section.

Details of the balusters and handrails are shown in Figs. 1052 and 1053.
3. Metal Stairs:—Metal stairs are not commonly used in residential buildings, but they are frequently employed in factories, mills, workshops, godowns, etc., where greater stability and fire-proof qualities are required. The chief metals used in the construction of these stairs are iron, mild steel and bronze. They are manufactured in workshops and erected in place. A metal stair in its simplest form consists of cast iron or rolled steel strings to which are fixed metal treads by means of angles at their ends below. The risers are usually omitted. The angles supporting the treads may be fixed to the string by means of rivets, or they may be welded. Sometimes marble or other good stone treads are laid on metal treads in cement. This improves the appearance of the stair. Concrete treads are also cast on metal treads, and a metal nosing is provided in addition for protecting the edge of the step. Metal balusters with pipe handrail are generally provided for metal stairs. Metal stairs are obtained in stock patterns for different dimensions and span, from the manufacturers.

Cast-iron spiral stairs are very commonly used for service purposes in public as well as residential buildings. In powerhouses and pumping stations this type of stair has a very wide application. The castings for the steps are threaded on a wrought iron vertical central rod.

Reinforced concrete stairs:—Reinforced concrete on account of its fire-proofness, permanency and adaptability, has become a very common material for use in the construction of stairs. It has also superseded to a great extent the use of steel, iron and stone in the construction of stairs in many types of buildings.

R. C. C. stairs are usually cast in situ but occasionally pre-cast steps are used. The steps can be cast to any
required shape, and can be easily rendered non-slip R.C.C. stairs suitably finished, have an attractive appearance and may be cleaned easily by any suitable means.

R. C. C. stairs are particularly adaptable to buildings made of R. C. C. construction, and are often more economical than iron stairs. Moreover, in a building of R.C.C. construction, stairways of the same material can be designed so that they will become an integral part of the structure. Further, almost any combination of constructions desired is practicable with this material (R. C. C.). For purposes of better appearance, stairs constructed entirely of reinforced concrete are often covered or veneered with marble, tiles, terrazzo or other suitable material.

A suitable mix for the concrete consists of 1 part of Portland cement, 2 parts of clean graded sand up to 3/16 in. size and 3 parts of broken stone 1/4 in. to 3/16 in. size. Five gallons of water per cwt. of cement are satisfactory.

R. C. C. stairs are made in three different ways:

(i) Two (inclined) R. C. C. beams (for strings) are built to support the R. C. C. steps. The reinforcements of the two parts are inter-joined. See Figs. 1054-1055.
(ii) One R. C. C. (inclined) slab of the full width of the stair is built to support the steps. Or the steps are as it were built in the slab. The reinforcements are connected. See Fig. 1056.

(iii) R. C. C. steps cantilevered out from a wall.

![Fig. 1056.](image)

Shows a vertical section through an R. C. C. stairway suitable for an industrial building. The inclined concrete stair slab is designed as a one-way slab supported on and cast integrally with beams as shown. The landing construction may be suspended by hangers from the floor above, supported on concrete struts from the floor below, or may bear on the enclosing walls. A live load of 100 lbs. per sq. ft. is satisfactory for stair design. Reinforcing bars extending from the inclined slab into the landing slabs should not be bent at re-entrant angles but should be lapped as shown.
The inclined beam or the inclined slab spans from floor to floor, or from floor to intermediate platform, or from landing to landing.

In all the three cases the longitudinal reinforcement spaced 4 to 6 in. centre to centre (abbreviated C to C), are continuous in the bottom and in the upper slab. The crosswise bars, spaced at 6 to 8 in. centre to centre, also carry the links to reinforce the steps. A 12 in. bearing is usually provided for cantilevered steps. Various details of R. C. C. stairs are given in Figs. 1054 to 1056. In this connection it is necessary to note that the sizes given in these figures vary according to the width of the stair and load to be supported, and are determined by calculation.

The edges of concrete steps are likely to be knocked off, and if broken, are very difficult to repair. Hence they are very often protected by means of a brass, iron or steel corner piece, or a G. I. pipe as shown in Fig. 1057. A flagstone with a projecting nose may also be fixed as shown. The flagstone must be well bedded on cement mortar.

The balustrade or railing most commonly used consists of a G. I. pipe rail with balusters at proper intervals to insure rigidity. The balusters are usually secured in pockets provided by wood plugs placed prior to pouring of concrete, or by means of expansion bolts. Sometimes dovetailed mortices are formed in the steps to receive the ends (preferably pegged to give a key) of the balusters; molten lead is then poured in, well caulked (consolidated
when cool with a blunt chisel) and covered flush with cement mortar (see Figs. 1052 and 1053).

Closed concrete railing are frequently used where open railings (described above) are undesirable. This form of railing consists of an R. C. C. slab 3 to 4 in. thick with provision for a wood handrail secured to the top. A plaster band of 4 in. wide may also be formed at the top of the balustrade to form the handrail. The handrail is generally placed on an average of about 2 ft. 6 in. above the tread on a line vertical with the face of riser (see Fig. 1015).

Concrete steps for narrow stairs such as spiral stairs are very often pre-cast, i.e., are separately made in wooden moulds of the required shape. These when sufficiently set are removed from the moulds, and water-cured for at least 14 days. After curing period, the steps are stored under shade and allowed to dry. The steps are then used in the work.

A plan and elevation of a pre-cast reinforced concrete spiral stair are shown in Fig. 1058 and 1059, respectively.
It consists of pre-cast steps cantilevering out from a central reinforced concrete column which is cast in situ. Cross section of such an R.C.C. column is shown in Fig. 1060. A steel pipe is sometimes used in place of the R.C.C. column. The pipe is fitted up in short lengths of 3 to 4 ft. joined by means of threaded sockets and finally filled with concrete. During construction, steps are
suitably supported from below by means of brick cribbing or timber scaffolding, as shown in Fig. 1061. The cribbing or supports of the steps can be removed after the column has attained its full strength after 4 weeks.

Various details of a typical pre-cast step are shown in Fig. 1062 to 1068. The main reinforcement consists of 3/8 in. diameter round rods tied together by 3/16 in. diameter round stirrups. The top bar of each step is bent into a "V" shape with a circle at the apex. The other two bars have also their ends bent into circles. These bars are assembled by means of 3/16 in. diameter round stirrups, as shown.
Fig. Nos. 1062 to 1068.

Details of a typical precast step suitable for an R.C.C. spiral stair.

Brick stairs and Reinforced brickwork stairs:—In India, plain brick stairs and reinforced brickwork stair are very rarely used. Hence they are not described here.
CHAPTER XI.

QUESTIONS FOR REVISION

1. Sketch a timber dog-legged staircase, 4 ft. wide, suitable for an office building. The height between floors is 10 ft. 6 in. Show details of the steps and the railing. (University of Poona. 1956).

2. Enumerate the different types of stairs. What are the essential requirements of properly designed stairs? Give a free-hand plan and sectional elevation of a dog-legged stair and name its parts. (University of Sind, 1950).

3. (a) Distinguish between dog-legged and open newel stairs.
   (b) What do you understand by the terms:—
      (i) flight, (ii) rise; (iii) tread?

   What are their magnitudes adopted in practice. (Karnatak University, 1952).

4. Draw a sketch of R. C. C. staircase. Height from floor to floor 11′ – 0″. Stair-case well 13′ – 6″ × 8′ × 0′. Show all important details connected with the staircase. (Gujarat University, 1952).

5. A staircase room for a library opens on the verandah on both floors of 17′ – 0″ height. The room is 24′ – 0″ × 24′ – 0″. Sketch a lay-out and section of an open newel staircase 8′ – 0″ wide, with 6′ risers. (Gujarat University, 1952).

6. An open newel staircase of R. C. C., 4′ – 9″ wide is to be provided for an office building. The space available for the staircase is 16′ – 0″ × 13′ – 0″ and it opens on verandahs on both floors. The height from floor to floor is 14′ – 0″,
Design the staircase and sketch a plan and a section showing placing of reinforcement.

(Gujarat University, 1953).

7. The staircase room of a public library is $24' \times 24'$. The height of floor is $15'$. The width of the staircase is to be $8'$. Design a suitable staircase and illustrate your proposal by drawing a plan and section.

(University of Baroda, 1953).

8. A staircase of fire-resisting materials is to be provided between two flats. It is to be placed at the rear, so as to approach the back balcony. The width of the hall is $7' - 6''$ and the height from floor to floor is $11' - 0''$. Design the layout and sketch a section through one flight, stating full dimensions and materials adopted.

(Gujarat University, 1954).

9. (a) What are the requirements of a good staircase?

(b) Sketch one flight up to landing, a wooden staircase $5'$ wide having 10 risers (rise = $7$ in.; tread = $11$ in.) with balustrade and open stringers. Show clearly how landing and stringers are to be supported. Dimension your sketch fully.

(Karnatak University, 1954).

10. Discuss briefly the following terms in connection of stairs:

(a) Rough stringer

(b) Open stringer

(c) Geometrical stair

(d) Going

(e) Newel post.

(Karnatak University, 1955).
CHAPTER XII.

ROOFS

Roofs:—Roofs are coverings which are provided over the tops of buildings for the purpose of keeping out rain, sun and wind, and also to protect them from the elements. A good roof is just as essential as a safe foundation. A well-designed foundation secures the building against destruction starting at the bottom; a good roof affords protection for the building itself and what the building contains, and prevents deterioration starting from the top. A faulty roof may be very difficult to remedy, involving generally a removal or the cost of a new roof, with probable changes in roof construction and inconvenience to occupants. Roofs must, therefore, be well-designed and constructed to meet the requirements of different climates, and the covering materials available. In experience it is found that pitched roofs or sloping roofs are very suitable to coastal regions where rainfall is heavy, and that flat roofs are suitable to plains where rainfall is meagre and heat is great.

Classification of roofs:—There are two main classes of roofs, viz., (a) Pitched roofs or Sloping roofs and (b) Flat or terrace roofs.

(a) Pitched roofs or sloping roofs:—Pitched roofs are those whose surface has a considerable slope. They are generally lighter than flat roofs and require less timber. The following terms are commonly used in the design and construction of roofs:—

(1) Roof truss:—A roof truss is a framework designed to support the roof covering or ceiling over rooms, thereby avoiding the use of interior columns.
(171)

(2) **Span**:—This is the clear horizontal distance between the internal faces of the walls supporting the roof. The effective span is the horizontal distance between the centre of the supports. See Fig. 1069.

(3) **Rise**:—This is the vertical height measured from the lowest to the highest points. See Fig. 1069.

(4) **Pitch of roof**:—The inclination of the sides of a roof to the horizontal plane is called the *pitch of a roof*. The inclination or pitch of the roof depends upon the climatic conditions and the material used for the roof covering. The higher the pitch, i.e., the steeper the roof slope, the stronger is the roof; but it has a larger area exposed to wind pressure, and such a roof requires more timber and covering material. In practice, the inclination of the roof is made as flat as possible for the purpose of economising the timber and covering material. The pitch of the roof is usually expressed in one of two ways, first the ratio of the rise to the span, secondly in degrees. The pitch of roof suitable for various roof coverings is given in Table No. 14.

**Setting off pitch**:—To set off the slope of a roof at one-third pitch draw the span AB (Fig. 1069), divide it into three equal parts, and at the centre of the span C set up the perpendicular CD equal to one part. Join AD. Then AD or BD will be the required pitch. This is the flattest part at which the roof covering materials should be laid.
(172)

TABLE NO. 14

Slopes of various roof for covering materials.

<table>
<thead>
<tr>
<th>Roof covering material</th>
<th>Angle with horizon</th>
<th>Pitch i.e. ratio of rise to span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangalore pattern tiles</td>
<td>33° 40'</td>
<td>4</td>
</tr>
<tr>
<td>Country tiles</td>
<td>45° 0'</td>
<td>4</td>
</tr>
<tr>
<td>Pan tiles</td>
<td>33° 40'</td>
<td>4</td>
</tr>
<tr>
<td>Thatch</td>
<td>45° 0'</td>
<td>4</td>
</tr>
<tr>
<td>Slates</td>
<td>26° 33'</td>
<td>4</td>
</tr>
<tr>
<td>Asphalt felt, corrugated asbestos and iron sheets</td>
<td>11° 18'</td>
<td>2 1/2</td>
</tr>
<tr>
<td>Stone slabs</td>
<td>33° 40'</td>
<td>4</td>
</tr>
<tr>
<td>Lead, Zinc, asphalt and copper</td>
<td>0° 45'</td>
<td>2 1/2</td>
</tr>
<tr>
<td>Asphalt, concrete or mud terrace</td>
<td>2° 0'</td>
<td>2 1/2</td>
</tr>
</tbody>
</table>

(5) Gabled roof:—A roof with a slope on either side may end either in gable or a hip. When the end of a roof is in the form of a vertical triangle (i.e., with no slope end wise), it is called a gabled roof (See Figs. 1070 to 1074).

Fig. Nos. 1070 to 1073

Sketch showing the gabled and hipped roofs.
(6) Hipped Roof:—When the end of a roof is finished in the form of a sloped triangle (i.e. when there is endwise slope as well), it is called a hipped roof (see Figs. 1070 to 1074). A hip is the line produced when two roof surfaces intersect to form an external angle which exceeds 180 degrees, and hipped end is a portion of roof between two hips.

One or both ends of a roof may be gabled or hipped; when hipped at both ends, it is called a pavilion roof.

(7) Valley:—A valley is the reverse of a hip. It is formed by the intersection of two roof surfaces having an external angle which is less than 180 degrees. See Fig. 1074.

(8) Common rafters:—These are inclined wooden members supporting the battens or boarding to support roof coverings. They run from a ridge to the eaves (see below). They are spaced at 12 in. to 18 in. centre to centre, depending upon the roof covering material. The usual sizes of common rafters for different spans are given in Table No. 15.

**Table No. 15**

Minimum sizes of common rafters spaced at 12 to 18 in. centre to centre.

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Unsupported length of rafter</th>
<th>Size of rafter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6 feet</td>
<td>3 in. by 2 in.</td>
</tr>
<tr>
<td>2</td>
<td>7 &quot;</td>
<td>3½ in. by 2 in.</td>
</tr>
<tr>
<td>3</td>
<td>8 &quot;</td>
<td>4 in. by 2 in.</td>
</tr>
<tr>
<td>4</td>
<td>9 &quot;</td>
<td>4½ in. by 2 in.</td>
</tr>
<tr>
<td>5</td>
<td>10 &quot;</td>
<td>5 in. by 2 in.</td>
</tr>
</tbody>
</table>

1 The approximate depth of 2 in. thick common rafters spaced at 12 to 18 in. for any span may be obtained from the following rule.
Depth (in inches) = $\frac{\text{Span}}{2}$ (in feet).

Thus for a span of 10 feet, the size of common rafter would be 5 in. by 2 in. The common rafters most commonly used are 2 in. thick and for good class work they are of teak wood.

9 Ridge, Ridge piece or Ridge board:—This is a wooden piece or board which runs horizontally at the highest point in the roof. The common rafters abut against the ridge piece and are fixed to it. Its size is usually 5 in. by 1½ in. or 7 in. by 1¾ in. A ridge line is the line of external angle or the apex formed by the tops of two sloping roofs meeting together. See Fig. 1074.

10 Eaves:—Eaves (meaning edge, and used in plural) of a roof are the bottom end of a pitched roof from which the rain-water from the roof surface drops down. In good class work, gutters are fixed along the eaves to collect and drain the rain-water.

11 Eaves board:—An eaves board or fascia board is the thin piece of wood fixed to the feet of the rafters at eaves. The ends of the lowermost roof covering material rest upon it and the eaves-gutter is also secured against it. The under portion of an overhanging eaves is called the soffit. An eaves board is usually 1 in. thick and 5 to 8 in. wide.

12 Barge boards:—These are wooden boards fixed on the gable side of a roof. They are secured to the ends of ridge, purlins and wall-plates (see below). They are usually 1 in. thick and 7 to 9 in. wide.

13 Verge:—This is the edge of a roof which runs from eaves to ridge at a gable. See Fig. 1074.
(14) **Purlins**—These are members either of wood or of steel, laid horizontally to support common rafters of a roof when the span is large. They are usually supported by walls, hip and valley rafters and roof trusses. The sizes of purlins generally vary from 5 in. by 3 in. to 6 in. by 4 in. Table No. 16 shows the sizes of purlins for different spans.

**TABLE No. 16**
Sizes of timber purlins for various spans. (These sizes comply with most bye-laws).

<table>
<thead>
<tr>
<th>Span</th>
<th>Maximum inclined distance apart.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 feet.</td>
</tr>
<tr>
<td>6 feet.</td>
<td>5½ in. x 3 in.</td>
</tr>
<tr>
<td>3 feet.</td>
<td>6 in. x 3 in.</td>
</tr>
<tr>
<td>10 &quot;</td>
<td>7 in. x 3 in.</td>
</tr>
<tr>
<td>12 &quot;</td>
<td>7 in. x 5 in.</td>
</tr>
<tr>
<td>14 &quot;</td>
<td>7 in. x 5 in.</td>
</tr>
<tr>
<td>16 &quot;</td>
<td>11 in. x 4 in.</td>
</tr>
</tbody>
</table>

*Note:* Purlins exceeding 16 ft. in length are not economical. In the absence of cross-walls or partitions, trusses are provided to limit the unsupported length of purlin to 16 feet.

(15) **Cleats**—These are pieces of wood, or angle iron or steel, which are nailed or screwed on the trusses to support the purlins. These are required to afford a direct support to the purlins and prevent them from sliding down. They are usually fixed to the principal rafters of a truss.

(16) **Hip rafters**—These are sloping rafters which run from a ridge to the corners of the walls to support
(176)

the roof. They receive the ends of purlins and ends of jack rafters. See Fig. 1074.

(17) Valley rafters:—These are sloping rafters which run towards the eaves for supporting valley gutters. They receive the ends of purlins and ends of jack rafters. See Fig. 1074.

(18) Jack rafters:—These are short common rafters which run from a hip to the eaves or from a ridge to a valley. A hip or valley is formed by the meeting of jack rafters. See Fig. 1074.

(19) Dragon beam, Dragon tie or Angle tie:—This is a wooden member which is laid diagonally under a hip rafter at its lower end across the corner of the walls. The dragon beam is fixed to the wall-plates on which it rests. It is intended to resist the outward thrust of the hip rafter on the wall. Its size is usually 3 to 4 in. square and of the required length.

(20) Wall-plates:—These are long wooden members which are embedded in masonry on top of walls nearly at the centre of their thickness. The feet of the common rafters are fixed to the wall-plates by means of simple notching, and nails are also used. The wall plates are usually lengthened by bevel-halved joint. The size of a wall-plate is usually 4 in. by 3 in., and is laid with 4 in. side horizontal.

(21) Post-plates or pole-plates:—These are continuous timber pieces which are fixed at the tops of posts to support the common rafters and at the same time to strengthen the ends of posts. Usually a Knee strap with bolts is provided to fix the common rafters to the post-plate and the latter to the posts (See Fig. 1073). The post-plates are usually 4 in. by 3 in.
(177)

(22) **Battens**—These are pieces of wood, which are directly nailed to the rafters or ceiling. The slates, tiles, etc., are laid directly over them. The battens are usually $\frac{1}{2}$ to 1 in. thick and 1 to 2 in. wide.

(23) **Boarding or Sarking**—This consists of boards which are nailed to the upper edges of common rafters, and to which tiles and other roofing materials are secured. The thickness of the boards is generally 1 in.

(24) **Template**—This is a square or rectangular block (usually 4 to 6 in thick), which is placed below a beam or a truss so as to spread the load over a larger area. It may be made of stone, wood, concrete or reinforced concrete.

(a) **Classification of pitched roofs**—Pitched roofs may be classified into three main classes. They are:
   - (i) Single roof,
   - (ii) Double roofs,
   - (iii) Triple-membered, trussed or framed roofs.

(i) **Single roofs**—These consist only of common rafters which are secured at the ridge and wall-plates. The various forms of this type are lean-to, double lean-to, couple, couple-close and collar roofs. These forms of roofs are briefly described hereunder.

**Lean-to roof**—This is the simplest form of pitched roof, and is also known as the shed or verandah roof. The lean-to roof is formed with one slope only and consists of common rafters usually inclined at 30 degrees against a wall. The upper ends of the common rafters are placed on a wooden wallplate or pitch-plate placed on brick, stone, iron or wooden corbels projecting from a wall, and the feet of the common rafters are notched and nailed to a wooden post-plate, jointed to the top of posts. Knee straps and bolts are used to get a connection.
between the rafters and posts, as shown in Fig. 1075. Sometimes the common rafters are made to enter the

main wall of the building about 6 in., and sloping slightly downwards, are fixed at their other ends to a wall and wall-plate.\(^1\) \textit{Recesses or battens} are nailed to the upper surface of the rafters at right angles to their direction and usually about 6 in. apart from centre to centre, and on the frame thus prepared the roof covering material is laid. The lean-to roof is limited to 8 feet span, and is used for out-houses against main buildings and for sheds and verandahs, but also for any other independent buildings as desired.

\textbf{Double lean-to, Pent\(^2\) or V-roof} — This type of roof consists of two lean-to roofs which slope towards each other, constituting a V-form over which a gutter is formed as shown in Fig. 1076 and 1077. The lower ends

\(^1\) A beam, called brestsummer may also be used instead of a wall-plate. \(^2\) Pent means pointed or closed in.
of the common rafters are made to rest on a wooden wall plate which is supported by a common wall. Sometimes the lower ends of the common rafters are secured to a beam which runs parallel to the main walls and if necessary, is supported at intervals by columns or pillars. This type of roof is now rarely used as it is expensive on account of the extra walling or columns required and because the gutter is a potential source of weakness.

Couple or Span roof:—In this type of roof, each pair or couple of common rafters is pitched against each other and supported at the upper ends at the ridge piece or ridge board. The lower ends of the common rafters are fixed to wall-plates embedded in masonry on the top of the walls as shown in Fig. 1078. This is not a good form of roof as it has a tendency to spread at the feet and thrust out the walls. The couple roof is, therefore only adopted when the span is not more than 12 ft. This type of roof is not recommended for good class work.

Couple-close or close couple roof:—This is a better form of roof and is very suitable for spans upon 16 feet under ordinary conditions of stress and loading. In this type of roof, each couple of rafters is closed by a horizontal tie (called tie beam) hence the name. This tie is connected to the feet of the common rafters and prevents them from spreading outwards. The tie may be a piece of wood or a steel rod in tension. Connection between the ties and the feet of the rafters is usually obtained by means of dovetail jointed joint, but in cheaper work the ties are just spiked to the rafters. Sometimes a plastered ceiling is formed on the underside of the ties; they are then called ceiling joists. For larger spans, the couple-close roof is supported by a central King rod or King-bolt suspended from the ridge. This arrangement prevents the tie-beam of the couple-close roof from sagging.
Collar or Collar-beam roof:—This is similar to the couple-close roof, except that the horizontal tie is now placed higher up the roof, and is called collar or collar-beam. The collar is usually fixed at one-third or one-half the vertical height from the wall to the ridge; but the lower it is placed the stronger is the roof. From this it is evident that the couple-close roof is stronger than the collar roof, but the latter has one advantage over the former in that it permits of an increase in the height of the room below. The collar and the common rafter are connected by a halved dovetail joint or halved and cogged joint, and the connection is secured by a bolt. This type of roof is used for spans up to 16 feet.

A common rule is to give for common rafters 1/6 in breadth and 1/3 in. depth for every foot of span, but the depth should not be less than 3 in.; hip rafters are generally given 1/4 in. breadth and 1/2 in. depth for every clear foot of span; collar beams are generally 2 in. wide and 3 or 4 in. deep.

(ii) Double roofs or Purlin roofs:—In this type of roof, additional members, called purlins, are introduced to support the common rafters at intermediate points. Purlins are required for roofs with spans of 17 feet and upwards, otherwise the size of common rafters would need to be increased to an uneconomical size, and such rafters will be very heavy and difficult to handle. The maximum span of the common rafters is usually taken as 8 feet, and this is reduced 6 feet when roofs have a small pitch and are covered with heavy roofing material. The introduction of purlins permits the use of comparatively small rafters which are easily handled. The purlins tie the rafters together, and greatly stiffen the rafters and the roof as a whole. Fished or scarfed joint is usually resorted to when a purlin is required to be
increased in length. All the single roofs shown in Figs. 1075 to 1080 may be altered to double or purlin roofs by the addition of one or more sets of purlins.

![Fig. No. 1079—Couple-close roof.]

![Fig. No. 1080—Collar roof.]

The sizes of purlins for various spans are given in Table No. 16.

(iii) Triple-membered, framed or trussed roofs:—It has already been stated that for larger spans common rafters require intermediate supports in the form of tie-beams, collar-beams or purlins to increase their rigidity, and that the tie-beams require King-rods or King-bolts to prevent them from sagging. These conditions are well satisfied by roof-trusses. These trusses transmit the roof loads in a vertical direction upon the walls, and each
member of a roof truss is subjected to direct stress either compression or tension.

A framed or trussed roof usually consists of common rafters, purlins and trusses. The common rafters distribute the weight of the roof covering material, snow (if any) and wind pressure to the purlins which transmit this load to the trusses, and the purlins in their turn transfer the weight to the walls. The outline of the truss must conform to the shape of the roof required, and a triangle is the strongest form of framed structure for it cannot be deformed if its members are sufficiently strong and properly connected together. The theory of trussing is given in the chapter on "Partitions".

The trussed roofs generally include King-post roof truss, Queen-post roof truss and Mansard roof truss, and they are briefly described below. The spacing of the trusses depends upon the load on the roof, and the position of the cross-walls or partitions parallel to the trusses in the building. But, under any circumstances, they should not be spaced at more than 10 ft. apart. Trusses are generally preferred when the span is more than 18 feet, and when there are no inside supporting walls for the purlins.

**King-post truss roof**: A King-post truss roof is suitable for spans varying from 16 to 30 ft. A King-Post truss roof consists of two principal rafters or principals, a tie-beam, a King-post and two struts. The principal rafters support the framework of the roof. The tie-beam receives the ends of the principal rafters and prevents the walls from being thrust outwards. Care should be taken to see that the ends of the tie-beam are not built into walls. The loads at the ends of a tie-beam are of a concentrated nature, and hence the tie-beam is placed on bed-plates. Bed-plates are also known as bed blocks, truss-
plates or templates. The King-post prevents the tie-beam from sagging at its centre. The struts support centres of the principal rafters and prevent sagging. The stress to which each member of the king-post truss roof is subjected is as follows:

<table>
<thead>
<tr>
<th>Member</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal rafters</td>
<td>Compressive stress</td>
</tr>
<tr>
<td>Struts</td>
<td>Tensile stress</td>
</tr>
<tr>
<td>King-post</td>
<td>Transverse or cross stress</td>
</tr>
<tr>
<td>Tie-beam</td>
<td>-do-</td>
</tr>
<tr>
<td>Common rafters</td>
<td>-do-</td>
</tr>
<tr>
<td>Purlins</td>
<td>-do-</td>
</tr>
</tbody>
</table>

Fig. 1081 shows the elevation of a King-post truss roof with the names of the different members appended. As will be noticed, the truss derives its name from the central wooden upright, called King-post. Note the common rafters, cleats, purlins and pole-plates shown in the figure. Purlins are stout pieces which are usually placed over the joints of principal rafters, and they support the common rafters. The purlins should be in as long lengths as possible, and all joints should come exactly over the middle of the principal rafters. Cleats are
### TABLE No. 17

Sizes of various members of teakwood trusses 10 ft. apart. Mandalore tiled roof. Weight of roof is 15 lbs. per sq ft. Wind pressure 20 lbs. per sq. ft. Slope of roof 30 degrees.

<table>
<thead>
<tr>
<th>Span ft</th>
<th>Tie-beam</th>
<th>Principal</th>
<th>King-post or Queen-post</th>
<th>Struts</th>
<th>Straining beam</th>
<th>Straining sill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length</td>
<td>Depth</td>
<td>Contents</td>
<td>Length</td>
<td>Depth</td>
<td>Contents</td>
</tr>
<tr>
<td></td>
<td>ft.</td>
<td>in.</td>
<td>ft.</td>
<td>in.</td>
<td>in.</td>
<td>ft.</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>-----------</td>
<td>-------------------------</td>
<td>--------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>15</td>
<td>3</td>
<td>0.94</td>
<td>152</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>1.52</td>
<td>32</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>2.08</td>
<td>64</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>20</td>
<td>3</td>
<td>0.97</td>
<td>192</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>22</td>
<td>4</td>
<td>2.21</td>
<td>86</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>24</td>
<td>4</td>
<td>2.50</td>
<td>104</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>26</td>
<td>4</td>
<td>2.86</td>
<td>104</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>28</td>
<td>4</td>
<td>3.22</td>
<td>104</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>30</td>
<td>4</td>
<td>3.58</td>
<td>104</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

**QUEEN-POST TROUS**

<table>
<thead>
<tr>
<th></th>
<th>Length</th>
<th>Depth</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>35-31</td>
<td>3.5-4</td>
<td>5-3.5</td>
<td>3.5-5</td>
</tr>
<tr>
<td>40-15</td>
<td>3-5</td>
<td>7-3.5</td>
<td>3.5-5</td>
</tr>
</tbody>
</table>
Pieces which are fixed on principal rafters to prevent the purlins from tilting; they are usually spiked on, but in good class work may be housed. Pole-plates are horizontal timber pieces, which run across the tops of tie-beams at their ends, or on principal rafters near their feet. Along the tops of King-posts, and supported in grooves cut thereon, runs the ridge piece or ridge board.

The King-post trusses are made sufficiently strong and have the dimensions of their parts fixed with reference to the load they have to carry, etc. In Table No. 17 are shown the sizes commonly used for the various members of King-post trusses for different spans. The trusses are usually placed at equal intervals of 8 to 10 feet resting on stone, wood or R. C. C. bed blocks.

The common rafters rest on the purlins at equal distances of 12 to 18 in, their upper ends supported by ridge piece, their middles by the purlins, and their lower ends by pole-plates. Reepers or battens are nailed across the common rafters and on the frame thus prepared, the roof covering is laid.

Connections between the various members of a King post truss roof:—While framing the various members of the truss, sufficient attention should be paid to jointing. The various joints of the truss must be strong and rigid, but simple in construction. A brief description of the connections between the various members of the truss is given below.

(i) Joint between principal rafter and tie-beam:—
The bottom of the principal rafter is jointed to one end of the tie-beam either by a bridle joint (see Figs. 763 and 764) or by an oblique mortise and tenon joint (see Figs. 765 and 765). These joints may further be strengthened by wrought iron hoop strip encircling the joint or by a bolt passing through the tie-beam and principal rafter as shown. The tie-beam is lengthened, if neces-
mary, by a scarf joint. The tie-beam is usually given a camber of 1 in 30 in order to prevent the unsightly appearance due to any settlement.

(ii) Joint between principal rafter and King-post: The King-post is formed with splayed shoulders to receive the upper ends of the principal rafters. Fig. 1082 shows the elevation of the joint between the upper ends of the principal rafter and the King-post, and the joint is secured by means of a three-way wrought iron or mild steel strap on each side. The three-way straps are attached to the three pieces by means of bolts.

(iii) Joint between King-post and tie-beam: The lower end of the King-post is tenoned into the upper edge of the tie-beam for a sufficient distance, and is usually secured with a wrought iron or mild steel stirrup strap. The stirrup strap is fitted at the joint and is held in position by metal clips called gib, and metal wedges called cotters (see Figs. 1084 and 1085). The joint may also be secured by a bolt or by a strap and bolts.

Fig. Nos. 1083 to 1085.
Joint between king-post and tie-beam
(iv) Joints at the head and feet of struts:—The foot of each strut is connected to the King-post by an oblique mortise and tenon joint as shown in Fig. 1085. An oblique mortise and tenon joint is used for fixing the head of each strut with the principal rafter, in order to prevent the strut from sliding down.

Fig. No. 1086
Joint between principal rafter and strut

The ridge piece or ridge board is held in position by slotting the head of the King-post. See Fig. 1082.

Queen-post truss roof:—A queen-post truss roof is suitable for spans between 33 and 45 feet. The elevation of a queen-post truss roof is shown in Fig. 1086, with...
the names of the different members indicated. This
truss differs from a King-post truss in having two wooden
uprights called queen-posts instead of King-post.

Fig. No. 1087
Queen-post truss roof

The queen-posts prevent sagging in the tie-beam. The
upper ends of the queen-posts are kept in position by a
horizontal wooden member called straining beam. Another
member which is not found in the King-post truss is the
straining sill, which is fixed on the tie-beam, between
the feet of queen posts, to counteract the thrust of the
struts. Thus a queen-post truss consists of two principal
rafters, two queen-posts, a straining beam, a straining sill
and two struts.

The joints of the queen-post truss are made similar
to those described for the King-post truss, with the
exception of the joint of the queen-post. Figs. 1088 and
1089 show the details of the joints at head and foot of
the queen-post, with details of the gib and cotter strap.
The tie-beam is lengthened, if necessary, by a splayed
scab joint. The queen-post truss may further be strengthen-
ted by triangulating the rectangular portion of the
truss with two diagonal braces, each extending from the
foot of the queen-post to the opposite corner formed by
the straining beam and queen-post.
The stress to which each member of the queen-post truss roof is subjected is as follows:

- Principal rafters: Compressive stress
- Struts: ---
- Straining beam: ---
- Straining sill: ---
- Queen-posts: Tensile stress
- Tie-beam: ---
- Common rafters: Transverse or cross stress
- Purlins: ---

Combination of King-post truss roof and queen-post truss roof: It has already been stated that a queen-post truss is suitable for spans up to 45 feet. For greater spans, a combination of a King-post truss and a queen-
Post truss is used. In such a combined truss intermediate wooden uprights, called princesses, or princess posts, and also diagonal braces are introduced between queen-posts and the ends of the tie-beams. When the span is more than 50 ft. the straining beam of the truss is liable to sag; it is, therefore, held up by a King-post and two struts. This type of combination truss is generally used for spans up to 60 feet. See Figs. 1090 and 1091.

Reference: S = Strut; T. B. = Tie-beam; S. S. = Straining sill; S. B. = Straining beam; K. P. = King-post; P. P. = Princess post; Q. P. = Queen-post; P. R. = Principal rafter.

A pitched roof may also be finished by raising the wall to form a parapet as shown in Fig. 1092. A gutter, called a parallel or box gutter, is formed behind the parapet wall. The feet of the common rafters are
birdsmouthed to a horizontal beam, called a pole-plate, which is notched out and spiked to the principal rafter. The gutter consists of 1 in. boarding laid to falls and supported by 3 in. by 2 in. gutter bearers at 15 in. centres which at one end are tongued and nailed to a gutter plate which is spiked to the tie-beam.

Fig. No. 1092

Showing another way of finishing a sloping or pitched roof by raising the wall to form a parapet. Behind the latter is formed a lead-lined parallel or box gutter. A lead flashing and a drif are provided in the parapet.

Mansard truss—An example of this type of truss is shown in Fig. 1093. This is often used to obtain the maximum amount of cube space under a truss for living purposes, while the general height of the roof is kept comparatively low. The truss has two different slopes, the lower is very steep, and the upper ordinary. The truss is a combination of a King-post truss and a queen-post truss. The upper is a King-post truss, and it is placed on a truss which is very much like a queen post truss, except that the wooden uprights, called queen-posts, are
placed almost near the end of the tie-beam of the King-post truss above. The Mansard roof was first used and designed by a French architect, Francois Mansard (lived 1598-1666), to make the attics available for rooms in consequence of a municipal law limiting the height of front walls. This form is extensively used in France and with some modification, in Germany also.

Fig. No. 1093
Mansard roof truss.

Wooden trusses are not generally used for spans exceeding 50 feet. Steel trusses are nowadays used in preference to wooden ones, and are also more economical for spans exceeding 40 feet. Steel roof trusses and their connections are discussed in the chapter on "structural steel".

Composite roof trusses.—Roof trusses constructed of timber and steel (or wrought iron) members are known as composite trusses. The tensional members of
Composite trusses are often built up of steel, because the latter has much greater tensile strength than timber; it also reduces the weight of the trusses. The principal rafters in composite trusses are always of timber, owing to the facility with which the purlins may be fixed, and to the high resistance of rectangular sections of timber to compression. Various forms of composite trusses are shown in Figs. 1094 to 1097.

Roof coverings for pitched roofs:—The following roof coverings are generally used in India:

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Roof coverings for pitched roofs:—The following roof coverings are generally used in India:

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Fig. 1094.
King-rod or King-bolt roof truss
Figs. 1095 to 1097.
Composite roof trusses.

1. Thatch
2. Tiles
3. Asbestos-cement sheets.
4. Galvanized corrugated iron sheets.
5. Slates.

1. Thatch:—This is extensively used in sheds and village buildings. It is the cheapest and lightest material and keeps the heat out, but it is easily combustible, harbours rats, absorbs moisture, rots and gives out a foul odour, and has to be renewed frequently. The slope of a thatched roof is usually kept at 45 degrees. Thatching is usually laid on bamboo roopers and bamboo rafters, with a bed of matting for the thatch. The thatch is
tightly secured to battens with the help of ropes and
twine dipped in tar. Sometimes fire-resisting properties
are imparted to thatch by soaking it in specially prepared
fire-resisting solutions, but this will be very costly.
Many local authorities will not permit the use of thatch
to buildings.

2. Tiles. Tiles are of various kinds such as pan
tiles, flat tiles, pot-tiles or half-round country tiles, and
patent tiles such as Mangalore, Quilon, Ferok and Railway
pattern tiles. They are largely used as roof coverings,
and if properly selected and laid, are eminently fire-and
water-resisting, nonconductors of heat, also strong,
durable and economical. For these, common rafters are
laid 9 to 18 in. centres and battens or reepers are nailed
across the rafters, spacing of the former depends on the
kind of tiles used. Flat tiles, ceiling tiles or boarding
may be used below the top covering of tiles for keeping
out cold and heat. Ridges and hips are formed by
using special tiles intended for the purpose, and are laid
dry and pointed with cement mortar. The valleys are
formed with the aid of lead flashing laid over boarding
as shown in Fig. 1076 and 1077. The lowermost row of
tiles, viz., at eaves, is usually screwed to the battens, or
secured by wires through holes drilled in them. The
last row of tiles near the eaves may also be laid in lime
or cement mortar. The pitch of a tiled roof is usually
one-third or one fourth the span (about 33-33 or 26-5
degrees) the former pitch being commonly used in India.

Sometimes country tiles are laid in two layers, one
over the other. This is called double-tiled roof.

For a Mangalore tiled roof laid on ceiling boards,
rafters are sometimes omitted. The boards are nailed
directly on the top of purlins, and the tiles are laid on battens nailed on the boards. A coat of coal-tar is applied on the upper surface of the boards upon which a cloth, preferably Khadi or cloth, dipped in tar is spread and stretched, and the battens or reepers are nailed on it.

3. Asbestos-cement sheets. As already stated previously, asbestos-cement is composed of asbestos and portland cement. Roof coverings made of this material are cheap, tough, durable, fire-resisting and light in weight. Almost all varieties of roof coverings are now made with asbestos-cement. Asbestos-cement roof coverings are supplied in flat, corrugated and ribbed sheets, in various sizes. Ribbed sections are available with ribs at 12 in. or 15 in. centres. Three types of asbestos-cement sheets are generally used in practice, viz., (a) Everite bigsix corrugated asbestos-cement sheets, (b) Everite standard asbestos-cement sheets and (c) Turnall Trafford asbestos-cement tiles. See Figs. 1098 to 1100.

(a) Everite “bigsix” corrugated asbestos-cement sheets (Fig. 1098).—These are manufactured by Messrs Turner’s Asbestos Company, and are 3 ft. 5½ in. wide, 3 to 10 ft. long in 6 in. rises, and 1/4 in. thick. There are
7½ corrugations per sheet at a pitch of 5½ in. and their overall depth is 2½ in.

(b) Everite standard corrugated asbestos-cement sheets (Fig. 1099) — These sheets are also manufactured by Messrs Turner's Asbestos Company. These sheets may be classified into two classes, viz. small section corrugated sheets and large section corrugated sheets. The small section corrugated sheets are 2 ft. 6 in. wide 1/4 in. thick and 3 ft. 6 in. to 10 ft. long. The overall depth of corrugation is either 1 in. or 1 1/2 in. There are 10½ corrugations per sheet of 1 in. depth and 2½ in. pitch. The head lap is 6 in. and the side lap is about 1½ corrugations or 4½ in.

(c) Turnall Trafford asbestos-cement tiles (Fig. 1100) — These tiles are also manufactured by Messrs. Turner's Asbestos Company, and are 3 ft. 8 in. wide, 4 to 10 ft. long with 6 in. increments, and 1/4 in. thick. Every sheet has four 2 in. deep corrugations alternating with flat portions. The tiles are obtainable in standard colours of natural grey, red and russet-brown. These
Sheets provide an excellent covering, especially for large spanned roofs of the industrial type.

Fig. 1100.

"Turnall Trafford"

The asbestos-cement sheets are fixed direct to either timber or steel purlins. The purlins are usually spaced at 2 ft. 6 in. to 4 ft. 6 in. The minimum overlap for lengthening is 6 in. and for widening the overlap is 2 to 4 in. or one and a half corrugations. The method of fixing the sheets to timber purlins is illustrated in Fig. 1101.

Fig. No. 1101.

Sketch showing the method of fixing the asbestos cement sheets to timber purlins.

The lengths of the sheets are so adjusted that the joint comes on the top of a purlin. The sheets are always fixed through the crowns of the corrugations, 1 1/32 in. diameter holes being drilled by a brace and bit to
receive the 5/16 in. diameter galvanized screws which are usually 4½ in. long. These are driven in, and an asbestos washer and a lead-cupped washer are employed, as shown in Fig. 1101, to render the joints water-tight. The alternative connection to a steel purlin is shown in Fig. 1102. A 5/16 in. diameter galvanized hook bolt is generally used for this purpose, and the length of this bolt depends on the size of the purlin. The hook is engaged in the edge of the purlin and is secured by a nut; lead-cupped and asbestos washers are also provided as before to ensure water-tight joints. A hook bolt and a driving screw are shown in Figs. 1103 and 1104. A
Eaves filler piece is used to fill in the underside of the corrugations. An eaves filler piece is shown in Fig. 1105.

Fig. No. 1105.
Eaves filler piece.

The depth and pitch of the corrugations are similar to those of the general sheeting, and when the hook is bolted (or screwed, if the purlin is of wood) a tight joint results and weather is effectively excluded. The unsupported overhang of the sheets should not be more than 1 ft. The ridge is formed with the aid of a pair of ridge cappings as shown in Fig. 1106. The left-hand roll wing

Fig. No. 1106.
Ridge details showing the method of fixing asbestos cement sheets to purlins.
has an external collar and is slightly longer than the small roll wing which has an internal collar. See Fig. 1107. The corrugations of the wings fit closely those of

![Fig. No. 1107. Large asbestos cement roll wing of ridge capping.](image)

the sheets. The wings and the upper ends of the sheets are secured by either hook bolts or driving screws. The top purlins must be correctly positioned, and the fixings should be 6\(\frac{1}{2}\) in. from the centre.

Asbestos-cement sheets are best suited for large roofs of buildings such as cinemas, factories, offices, workshops, garages, gas works, generating stations, farms, etc. They present a neat and clean appearance. Low initial and maintenance costs and speed of construction are additional merits.

4. Galvanized corrugated iron sheets — These sheets are extensively used for covering roofs or workshops, sheds, etc. The sheets are comparatively light in weight, easy to handle, and can be fixed easily. They are 2 ft. to 2 ft. 6 in. wide, 4 ft. 6 in. to 12 ft. long and of 16 to 24 gauge. The sheets are fixed to timber purlins at intervals about 2 ft. 9 in. apart with special galvanized screws and washers driven through holes drilled (not punched) in the crowns of the corrugations. The sheets may also be fixed to steel angle purlins by means of hook bolts. All bolts, etc., should be set in white lead. In roofing with corrugated iron each sheet should be laid on the
Roof with a lap of 6 in. in its length over the sheet below it, and the side lap should, as a rule, extend one and a half corrugations. Wind-ties, consisting of bar iron 1 ½ in. by 1/4 in., should be fixed along the eaves of the roof and the ventilators. When the bolts pass through these wind-ties, slot holes should be cut to allow for expansion and contraction. Special sections are available for covering hips, ridges and valleys.

Such covering rusts comparatively quickly, especially at the connections, unless it is protected by painting at suitable time intervals. Galvanized sheets should not be tarred or lime-whitened. These sheets have been superseded to a great extent, particularly for superior work, by the aforementioned asbestos-cement products. The latter are more durable and do not require to be painted.

Protected metal corrugated sheets consist of light gauge steel core which is protected against corrosion by being entirely encased by asphalt saturated asbestos felt. The natural colour is black, but other colours such as aluminium, etc., can be imparted by an additional outer coating. These sheets are light in weight, strong, durable and heat insulating. Cellarctic and Robertson Protected Metal are examples of protected metal corrugated sheets.

5. Slates—Slate is a stratified rock, normally blue grey in colour, capable of being split into comparatively thin sheets or laminates. It is obtained from either open quarries or from mines. Slates are produced in a large number of sizes, and they are usually from 24 in. by 14 in. to 8 in. by 8 in. Common sizes are 24 in. by 12 in., 20 in. by 10 in., 18 in. by 9 in. and 16 in. by 8 in. The thickness of the slates varies from 1/5 in. to 1/3 in. but usually 1/4 in. A good slate should be hard, tough and
durable, of rough texture, ring bell-like when struck, not split when holed or dressed, non-absorbent and of a satisfactory colour. When left immersed in water to half its height for 12 hours, the water-line on the slate should not be more than 1/8 in. above the level of the water in the vessel. A good slate should not absorb more than 2 per cent of its own weight when soaked in water for 24 hours, and if a specimen of slate is immersed in a solution of sulphuric acid for ten days it should not show any signs of flaking or softening.

Terms used in slates and slating:—The following terms are generally used for slates and slating:

1. **Back**: The upper and rough surface of a slate.
2. **Bed**: The under and smooth surface of a slate.
3. **Head**: The upper edge of a slate.
4. **Tail**: The lower edge of a slate.
5. **Course**: A row or layer of slates is called a course.
6. **Lap**: The lap is the distance that the tail of one course of slates overlaps the head of the next course. The lap varies from 2 3 in. to 4 in.
7. **Margin**: This is the portion of the slate exposed to view on the outside of a roof.
8. **Gauge**: This is the distance between the tails of the two adjacent slates when laid. The gauge depends upon (a) the length of the slate, (b) the amount of lap, and (c) the method of nailing, i.e., centre nailing or head nailing.
9. **Bond**: Where a joint of two adjacent slates in one course is immediately in the centre of the slate of the course below they are said to bond.
10. **Tilting fillets or Cant strips or Springing pieces**:
These are triangular or tapered pieces of wood, usually 3 to 6 in. wide and up to 3 in. thick, used at the eaves to tilt the lower courses of slates in order to assist in excluding rain (and snow) by ensuring close joints at the tails. The fillets are often dispensed with when eaves boards are used.

11. **Eaves**:
The eaves of the roof is the lowest part and here the slating is commenced. The slates in the lowest course laid are shorter than the others by the distance of the gauge. This lowest or first course of slates is called the **doubling eaves course**; the slates of this course are laid with their beds upwards.

12. **Pitch**:
This term has already been defined before. The pitch of the roof when covered with slates ought never to be less than 22 degrees to the horizontal, or with a rise in the centre of 1/5 the span. But it can only be as low as this when large slates are employed. The inclinations more commonly used are 26 1/2 degrees or a rise of 1/4 the span, and 33 degrees or a rise of 1/3 the span.

**Laying of slates**:
Roofing slates may either be laid on boards which cover the whole surface of the roof, or they may be carried by wooden battens fixed to common rafters. When the slates are laid on boards, battens may or may not be used. The battens vary in size from 3 in. by 1 in. to 2 in. by 1/2 in., and are so placed that the upper edge of each course of slates rests on the batten. The slates are secured by being nailed to the boards or battens. Two nails, which may be of galvanized iron, zinc or copper, are used for each slate. The two methods of nailing slates are briefly described below.
(a) Nailing near the centre or centre-nailing (Fig. 1108). This is the best method, and the one most frequently adopted. The advantage of this method is that the slates, being nailed near the centre of their length, are firmly held in position. Less number of slates are required and the method is therefore more economical. The gauge is determined as follows:—The lap is deducted from the length, and the remainder is divided by 2, and may be stated thus:—

\[
\text{Gauge} = \frac{\text{Length of slate} - \text{lap}}{2}
\]

Thus for a roof covered with 24 in. by 12 in. slates and laid with a 3 in. lap, the gauge = \( \frac{24 - 3}{2} = 10\frac{1}{4} \) in.
(206)

(b) Nailing near the head or Head-nailing (Fig. 1109). In this method of fixing slates, the holes are pierced 1 in. from the head. Advantage of this method is that the nail-holes are covered with two thicknesses of slates. There is, therefore, not the same danger, as with centre-nailing, of water getting through the nail-holes. A disadvantage of this system of nailing is that the tails of the slates are more readily lifted by a high wind owing to their big leverage; this allows rain to blow between them and the excessive movement of the slates may gradually damage and increase the size of the holes until the slates are ultimately displaced and blown off; hence large slates should not be head-nailed in exposed positions. More slates are required to cover a roof on account of the reduced gauge and hence this system of nailing is more expensive than centre-nailing.

The gauge is determined as follows: One inch plus the lap is deducted from the total length of the slate, the first being due to the material above the nail-hole not being included in the lap, and the remainder is divided by 2, which will give the gauge, and may be stated thus:
(207)

Gauge = \( \frac{\text{Length of slate} - (1 \text{ inch} + \text{lap})}{2} \)

Thus the gauge for 24 in. by 12 in. slates with a 3 in. lap

\[ = \frac{24 - (1 + 3)}{2} = 10 \text{ in.} \]

In either method the holes are about 1\( \frac{1}{2} \) in. from the edges.

**Ventilators in pitched roofs:** Sometimes ventilators are provided in the roof for the escape of heated and vitiated air, smoke, etc., by using specially made ventilating tiles, etc. Ridge ventilators are usually formed in the roof timbers, and may be of the form shown in Figs. 1110 to 1112.

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**Fig. 1110 to 1111.**

*Showing the section and elevation of a ridge ventilator*
Flat roofs.—With the advent of very reliable waterproofing materials, flat or terrace roofs have been coming into greater prominence even in localities where rainfall is heavy. The chief advantages of flat roofs are listed below:

1. They are simpler in construction than the other forms.
2. They may be used for roof-gardens, drying yards, play-grounds and even miniature golf courses.
3. In hot climates, they keep out heat from rooms during daytime, and in cold climates they keep out cold.
4. Buildings with flat roofs can be more easily made fire-proof than those with sloping ones. Generally flat roofs are proof against incendiary bombs.

Against the above advantages may be stated the following inconveniences and disadvantages:
1. They cannot be used for large spans.
2. They are comparatively much heavier.
3. On account of the great variation in temperature in this country, cracks are liable to occur on the surface of the flat roofs which cause leaks.
4. A leak in a flat roof is very difficult to trace and set right, whereas in a pitched roof can be easily traced and repaired.
5. A terrace roof, exposes the whole building to the elements, whereas the projecting eaves of a pitched roof tend to protect it.
6. Water runs slowly off their surface, and great care is necessary to render the top surface water-tight.

Construction of terrace roofing:—The different methods adopted are briefly described below:

Mud terrace roofs:—A very cheap fairly water-tight flat roof can be made with mud, in places where the rainfall is light. For this purpose, good white earth, containing a large percentage of sodium salt is used. The roof consists of rolled steel beams properly spaced according to the span, over which are placed T-irons usually 2 in. by 2 in. by 1/4 in. at 12 in. centres, flange upwards. Between the flanges of these T-irons, well burnt tiles measuring 12 in. by 12 in. by 2 in. or 12 in. by 6 in. by 2 in. are set in lime mortar. In Punjab, a 6 in. thick layer of stiff mud is laid on top of this base work and well beaten until it becomes hard. The top is plastered with mud plaster in which is mixed a sufficient quantity of cowdung. The surface is finally finished with a wash of 4 parts of cowdung and 1 part of cement. This wash is renewed from time to time. A slight slope, say, 1 in 30 is usually given on the surface. In Sind, the
initial 6 in. layer of stiff mud mentioned above, is replaced with three layers 2 in. mud and 1 in. bhan alternately.

In C. P. and Bombay presidency the mud terrace roof is constructed thus: On timber bridging joists, spaced at 12 in. centre to centre, pieces of teak boards, 1/4 in. to 2 in. thick, are nailed. On the top of the boards is spread a layer of about 1 in. thick of wood shaving, and then a layer of well burnt bricks on edges is laid and set in lime mortar. The topping is finally made with a 2 to 4 in. layer of good white earth containing a high proportion of sodium salt. The layer of loose earth should be renewed from time to time. A small surface slope, say, 1 in 30 is generally given.

Brick-concrete terrace roofs:—In places where the rainfall is heavy, layers of mud as water-proofing media are not found satisfactory. Under these circumstances, one of the following methods may be advantageously adopted:

(a) As shown in Fig. 1113, beams or girders of suitable sizes are placed, spanning across the room, over wall or girder plates of wood or stone at intervals of 4 to 8 feet; above these are placed joists at 12 in. centres at right angles to beams or girders. Over the joists
either two courses of flat tiles (or one course of bricks) are laid set in lime or cement mortar. This is finally covered by a 3 to 4 in. thick plaster of lime or cement, and rubbed to a polished surface.

(b) Another excellent method of making a watertight flat roof is as follows:

A course of well burnt terrace bricks, 6 in. by 3 in. by 1 in., is laid on edge in mortar diagonally across the joists of the roof frame, and allowed to set. On this, a course of 4 in. thick brick-bat concrete, consisting of three parts of brick-bats, one part of gravel and sand, and 50 per cent by volume of lime mortar, is laid and well beaten down for three days with frequent wetting with water. After the concrete has set, three courses of flat tiles are laid in mortar, care being taken to see that they break joint. The flat tiles should be well soaked in water before
being laid. The two under courses, as rule, consist of tiles 6 in. by 3 in. by \( \frac{1}{3} \) in., and the upper course of tiles 6 in. by 6 in. by \( \frac{1}{6} \) in., but sometimes the same sized tiles are used for all three courses. Finally three coats of plaster are applied and carefully rubbed to polished surface. A slope of 1 in. 30 is given on the surface. The thickness of terracing is about 9 in., made up as follows. (see Fig. 1114).

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick on edge</td>
<td>3 in.</td>
</tr>
<tr>
<td>4 in brick-bat concrete beaten down to</td>
<td>3 in.</td>
</tr>
<tr>
<td>3 courses of flat tiles</td>
<td>2 in.</td>
</tr>
<tr>
<td>3 coats of plaster</td>
<td>1 in.</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9 in.</strong></td>
</tr>
</tbody>
</table>

This type of terrace roof is extensively used in Madras Presidency and is known as the Madras Terrace Roof. The three courses of flat tiles mentioned above can be replaced by a covering layer of pieces of glazed china mosaic set in mortar. China mosaic pieces are hard and non-absorbent, and by adopting different colours for the mosaic pieces, any desired design could be laid.

The success of the Madras terrace roof in respect of prevention of heat, cold and moisture, depends on several factors, viz., (1) As the thickness of the flat roof is about 9 in., the effect of heat and cold cannot easily reach the inner depth. (2) The large percentage of mortar in the concrete makes the mass non-porous and water-proof. (3) Since there are innumerable joints on the surface, the movements due to expansion by heat or contraction by cold are evenly distributed and diminished, and (4) The polished surface at top reflects the sun rays away.
(c) Instead of bricks or tiles, slabs—such as Cuddapah slabs—are used in some places; a layer of concrete is spread over the slab and the surface plastered.

(d) Sometimes, instead of joists, arches with very slight rise (called jack-arches) are turned between the girders. Jack-arch roof is described in detail in the Chapter on "Upper Floors."

(e) If instead of joists, an R. C. C. slab is used, and layers of mud and loose earth are laid on it, a perfectly leak-proof and cool roof will be formed.

(f) A perfectly water-tight flat roof surface can be obtained by using mastic asphalt in a layer of $\frac{1}{2}$ to 1 in. thick on a flat sub-grade of R. C. C., jack-arched or any other type of floor. Mastic asphalt is supplied for building purpose by manufacturers in the form of blocks or cakes or in drums. At the time of laying, it is heated in iron pots and is mixed with grit or gravel in the ratio of 2 to 1. The mixture is applied hot and worked immediately to the required thickness. The finished asphalt surface is dustless, unaffected by acids, and sufficiently elastic to withstand damage due to expansion and contraction. The colour of asphalt, which is black or grey, is objectionable to some people when the terrace is used as an outdoor living-room; but coloured asphalts are now available to overcome this objection. The chief disadvantage of an asphalted surface is that it absorbs heat and radiates it very slowly at night. Otherwise, it forms one of the best floors, where a hard-wearing, sanitary, impervious, and particularly noiseless surface is a special consideration.

In another method, a layer of roofing felt and wire netting is laid before hot mastic asphalt is applied to provide water-proofing. This is required for timber
floors as mastic asphalt cannot be applied directly to
them. Fine gravel, sand grit may be spread on mastic
asphalt to increase its durability.

Sometimes two or more layers of bituminous sheeting
interposed with layers of bituminous mastic are laid as a
water-proofing medium. Nowadays several proprietary
bituminous sheets are available in the market in differ-
ent sizes.

In all the above types of flat roofs, all corners should
be rounded and the surface water-proofing layer used
should be carried to a height of at least 6 in. on the sur-
face of parapet walls and joined there to the plaster.

The upper surface of the flat-roof should be given a
slope to throw off water. It is advantageous to give a
good slope to the surfaces, say 1 in 25, the minimum
should be not less than 1 in 30.

The sloping surface is generally formed by increas-
ing the thickness of the covering material towards the
centre; but such practice leads to the extra weighting of
beams or joists at the very point (viz., middle) where
they are least able to bear weight, and hence this cannot
be considered a good method. A better method is to
cut the joist or beam even, and screw on wedge-shaped
or tapered pieces of wood so as to give a fall from the
middle towards the ends. The wedge-shaped or tapered
pieces are called firing pieces or firings.

Spouts of iron or zinc should be fixed in the apen-
tures of the parapet walls, to discharge the rain water
clear of the walls, either direct or by down-pipes which
convey the water to the ground surface. The diameter
of the pipe should be about 3 in., and care must be taken
to see that the joints are properly placed.
The joists (called bridging joists) are placed across the shortest span (from wall to wall) at intervals from 12 to 18 inches, from centre to centre, and rest on a continuous wall plate of wood or stone from 3 to 6 in. thick and 6 to 9 in. wide. The bearing of the joists on the wall should not be less than 6 in. It is usual to build up the wall between the ends of the joists with masonry, but this is not a good practice, as rot is almost certain to occur and the swelling of the confined timber is apt to crack the wall. A better plan is to let the ends of the joists be free and to strut them close to the wall to prevent them from shifting. A joist should be laid with its greatest sectional dimension vertical. The sizes of joists depend upon several factors, viz., (1) the span, (2) the distance between each joist, (3) the load on each square foot of floor and (4) the kind of timber used. The sizes given in Table No. 18 may be advantageously used for general purposes. The approximate depth of joists may be determined in inches by dividing the total span in feet by 2 and adding 2 to the quotient, or, briefly, depth of joists = \( \frac{\text{span in ft.}}{2} + 2 \) inches. Thus the depth of a 2 in. thick joist with a span of 12 ft. would be \( \frac{12}{2} + 2 = 8 \) in. The width of the joists is usually 2 to 3 in.

For fairly large spans beams or girders are used, and these stretch from side to side of the room at intervals of from 4 to 8 feet, from centre to centre, and rest on wall or girder plates, of wood or stone, about 6 in. broad and 2 ft. long. The bearing of a beam on a wall should not be less than 12 in., and the end should not be built into the wall but arranged as shown in Fig. 1115. The joists should be joined over the beams by nailing, and the spaces between the joists over the beams closed with
slips of wood. A rough rule for determining the sizes of beams of teakwood is for every unsupported foot of length in a beam \(\frac{1}{2}\) in. breadth and \(\frac{3}{4}\) in. depth. Wooden beams are not, as a rule, used for spans exceeding 25 ft.

With flat roofs it is easy to admit direct or diffused light into rooms below through skylights, lanterns or by introducing pressed glass or glass-crete blocks normally used for pavement lights. Sometimes openings are left in the terrace, and provided with a covering, raised 18 in. above the surface. The sides are suitably protected by netting or otherwise.

**Table No. 18**

<table>
<thead>
<tr>
<th>Maximum clear span</th>
<th>Size of joists (spaced at 15 in. centres)</th>
<th>Maximum clear span</th>
<th>Size of joists (spaced at 15 in. centres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3 in. by 2 in.</td>
<td>15</td>
<td>9 in. by 3 in. or</td>
</tr>
<tr>
<td>5</td>
<td>4 in. by 2 in.</td>
<td>16</td>
<td>11 in. by 2 in.</td>
</tr>
<tr>
<td>6</td>
<td>4½ in. by 2 in.</td>
<td>17</td>
<td>11 in. by 2 in.</td>
</tr>
<tr>
<td>7</td>
<td>5 in. by 2 in.</td>
<td>18</td>
<td>11 in. by 2¼ in.</td>
</tr>
<tr>
<td>8</td>
<td>6 in. by 2 in.</td>
<td>19</td>
<td>11 in. by 3 in.</td>
</tr>
<tr>
<td>9</td>
<td>7 in. by 2 in.</td>
<td>20</td>
<td>12 in. by 3 in.</td>
</tr>
<tr>
<td>10</td>
<td>7 in. by 2 in.</td>
<td></td>
<td>12 in. by 3 in.</td>
</tr>
<tr>
<td>11</td>
<td>8 in. by 2 in.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>9 in. by 2 in.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>9 in. by 2 in.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>9 in. by 2½ in.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Repairs.—Cracks in flat or terrace roofs are frequently caused by the sagging or sinking of the timbers, also by the unequal contraction of materials used in the roof-covering; and, in some cases, by bad work and materials. They may, to a very great extent, be prevented by the use of well seasoned timber, good materials and good workmanship. When cracks, and consequently, leaks occur, the surface of the roof-covering must be repaired with care. If the cracks are small, they should be opened out, and one of the following mixtures poured into each, and allowed to extend a few inches on either side. These compositions harden on exposure to the air, and close the cracks. They are:—

(i) Asphalt, pitch and sand
(ii) Tar and resin.
(iii) Linseed oil 2 seers, resin 2 seers and pumice stone 1 seer.
(iv) Cotton 2 ozs., slaked lime 20 lbs., and linseed oil 10 lbs.

The first and second must be applied hot, and in the third, the pumice stone and resin must be ground fine, sifted and intimately mixed with oil, while in the fourth the cotton must be cut up very small and the composition ground to the consistency of paste. When the roof is cracked in several places, it is better to break it up and relay it.

Bengal or sloping terrace roof:—This roof, which generally covers verandahs, is thus constructed. Rafters are inserted into the main wall about 8 in. deep, and, with a slight slope, are fixed at their lower ends to wall-plates or bressummers. The rafters may also be supported on wall-plates, resting on suitable corbels. The rafters are spaced 12 to 15 in. centres, and the reepers, 2 in. by
\( \frac{3}{4} \) in., are fixed to the upper surface of the rafters with 6 in. centres. On the reepers a course of flat tiles, 6 in. by 3\( \frac{3}{4} \) in. by \( \frac{3}{4} \) in., well soaked in white-wash is laid with mortar joints. The roof is then completed in one of the following two methods: (1) Two more courses of flat tiles are laid in mortar, and finished off with two or three coats of plaster, the outer surface of the last coat being rubbed smooth. (2) A layer of fine jelly concrete, 1\( \frac{1}{2} \) to 2 in. thick, is laid over the first course of tiles, then a second course of tiles, and lastly two to three coats of plaster well rubbed down.

**Flashings**—Flashings are strips of sheet lead used to render water-tight the various joints that occur between the vertical faces, of walls or framing and pitched roofs, flats, gutters, chimneys, etc. They are classified into four classes and are given below.

(1) **Horizontal cover flashings**, which are usually 6 in. wide strips having their upper edges turned 1 in. either into the raked-out joint of the brickwork or into the groove (terming raglet) formed in the stonework and the lower edges lapped over covering the upturn or up-

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1. Lead is a metal, which is produced from an ore, called galena, which is a compound of lead and sulphur. Sheet lead is used for covering roofs, gutters, ridges, etc.

Lead is usually described and specified by weight in lbs. per sq. ft. The following are the weights of lead recommended for various purposes:

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Weight in lbs. per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitched roofs, flats and gutters</td>
<td>6, 7 or 8</td>
</tr>
<tr>
<td>Hips and ridges</td>
<td>6 or 7 lb.</td>
</tr>
<tr>
<td>Flashings</td>
<td>5 lb.</td>
</tr>
</tbody>
</table>

One cubic foot of lead weighs 710 lbs. It follows that the thickness of 1 lb. lead = \( \frac{1}{710} \) in., and therefore the thickness of the above weights is the following bracketed figures: 5 lb. (0.085 in.), 6 lb. (0.102 in.), 7 lb. (0.119 in.), and 8 lb. (0.136 in.).
stand (vertical portion) of the lower pieces of lead. See Fig. 1092.

(2) **Stepped cover flashings**, which are fixed at the sides of brick chimneys, gables, etc. They are from 6 to 8 in. wide and have their upper edges cut into a series of steps; the horizontal edge of each step is turned 1 in. into the racked joint.

(3) **Raking cover flashings**, which are used instead of stepped COVER flashings when the walls are of stone. The upper edge of the flashing is let 1 in. into a groove or raglet formed parallel to the rake of the roof and this top edge is therefore not stepped.

(4) **Apron flashings**, which are provided at the front of dormers, chimney-stacks, skylights, etc. They are from 8 to 12 in. wide.

Flashings are in lengths cut across the width of the roll and the length varies from 7 to 9 ft. They are secured along their upper edges by means of tapered pieces of lead called **lead wedges**. The lead wedges are driven in between the turn-in of the flashing and the upper edge of the joint. In the case of horizontal and raking cover flashings, the wedges are driven in at about 9 in. intervals; one or two wedges are provided at each step of a stepped flashing. The raked-out joint between the wedges is pointed with either cement or mastic. Hardwood wedges are sometimes used instead of lead wedges in cheap work. These are apt to become loose when they shrink.

**Tacks, tinges or clips** are strips of lead, which are used to stiffen flashings and prevent their free edges being lifted by a strong wind. They are from 2 to 3 in. wide and are placed at a distance apart not exceeding 3 ft. 6 in.
Each tack is fixed in the joint, and it is long enough to turn over and grip the free edge of the flashing about 1 in. Copper tacks, being stiffer than lead, are used for superior work.

Lead has a high coefficient of linear expansion (it being 0.000016 per degree F. or 0.000029 per degree C) and it therefore readily expands and contracts when subjected to considerable variations of temperature. It is therefore that the use of very large sheets of lead must be avoided and ample provision must be made to allow lead to expand and contract. In this connection defects such as wrinkling, bulging and cracking will be avoided if the area of each piece of sheet lead is restricted to 24 sq. ft. and if only two of the adjacent sides of a rectangular sheet are fixed.

Steel roof trusses:—The steel roof trusses and their connections are discussed in the next chapter.
CHAPTER XII

QUESTIONS FOR REVISION

1. State the circumstances under which each is adopted:
   (a) a pitched or sloping roof, (b) a flat roof.
   Draw a dimensional sketch of a timber truss for a span of 24 ft., showing the tile roof, and give the details of the joints.
   (University of Sind, 1950).

2. (a) State how you will proceed to drain and water-proof a flat R.C.C. roof.
    (b) Give a cross-section of a verandah with a detached roof.
    (Karnatak University, 1952).

3. What are the various types of wooden trusses adopted in pitched roof construction?
   Draw a queen-post truss for a 30'-0" span, of a Mangalore-tiled roof showing sizes of teak wood members, iron flats and bolts.
   (Gujarat University, 1952).

4. (a) What are the various types of trusses adopted in pitched roof construction? State the maximum span upto which a particular type can be used.
   (b) Draw a sketch of a queen-post truss for a 30 ft. span, marking the dimensions of various members.
   (Gujarat University, 1953).

5. (a) Enumerate various types of pitched single timber roofs and sketch them.
    (b) Sketch an arrangement showing double roof for a room with trussed purlins.
    (Karnatak University, 1954).
6. A room 18 ft. wide by 30 ft. long clear inside is
   to be provided with Mangalore tile roof. The
   roof is to be supported by double (two-way)
   arrangement of timber. Sketch fully the con-
   struction and briefly describe it.
   (Karnatak University, 1955).

7. Write short notes on the following:—
   (a) Collar-beam truss (Gujarat University, 1953).
   (b) Jack-rafter ( —do— —do— ).
   (c) Drip moulding ( —do— —do— ).
   (d) Queen-post truss (University of Baroda, 1953).

8. Describe the following with sketches:—
   (a) A monitor over a pitched roof
       (University of Baroda, 1953).
   (b) Eaves gutter (Karnatak University, 1955).
   (c) Bed block (University of Poona, 1956).
   (d) Flashing ( —do— —do— ).

9. In a king-post truss, detail to 1\frac{1}{2} in. scale, the
   joint between the king-post, tie and struts. The
   members are 11 in. by 3 in., and 5 in. Draw a
   vertical section, showing the form of metal
   fastening adopted.

10. In an area subject to frequent violent storms,
    say where and how the roofwork is likely to
    suffer damage in the case of (i) A.C. sheet roof,
    (ii) Mangalore tile roof. State with sketches,
    the precautions you would take to avoid such
    damage.
    (University of Poona, 1956).
CHAPTER XIII

STRUCTURAL STEELWORK

Amongst the various materials used in building construction, cast iron, wrought iron and mild steel are very common, the most important of these being mild steel.

**Cast iron**—It contains about 2 to 6 per cent of carbon. It is so called because it can be melted and cast into the required shapes or forms by means of suitable moulds. Cast iron is used for making gates, girders, railings, lamp posts, columns, staircases, water and other pipes, etc. It is hard but brittle and is therefore not so well adapted as wrought iron or steel to bear shocks and vibrations, such as occur in railway bridges. Owing to its brittleness, separate pieces of cast iron cannot be connected either by riveting or by welding, but must be bolted together, flanges being cast on the pieces for this purpose. It is very strong in compression but weak in tension; its ultimate strength in short pieces is about 40 tons per sq. in. in compression, and 7 tons per sq. in. in tension. Hence it is very much suited to columns and struts. Cast iron columns are relatively cheaper than those of steel; and they resist fire better, and corrode or rust less than steel columns. But there are possibilities for internal defects like air bubbles, honeycomb, cinders, etc. to be present in them which seriously affect their strength. Further, cast iron columns are liable to crack if suddenly (or unequally) cooled by water after they are heated as in the case of a fire occurring in a building.

Cast iron columns are usually circular in section and are either solid or hollow. A circular cast iron column 12 ft. high, capable of supporting a dead weight of 30 tons
is shown in elevation by Fig. 1116, and in sectional plan by Fig. 1117. The junction of rolled steel joists on the head of the column is also shown. As a rule, the diameter of a cast iron column should be at least 5 in., and if hollow the thickness of the metal should be at least 3/8 in. Their length should not be more than 20 times their diameter. The base of the columns should be provided with suffici-
ent number of boles, and they should be made to rest on concrete beds. The thickness and the base area should be sufficient to distribute the load on the soil below. Cast iron columns are often encased in terracotta hollow blocks, concrete or brickwork for fire protection.

Wrought or malleable iron:—It contains the smallest proportion of carbon—not exceeding 0.25 per cent; very nearly pure metal contains not more than 0.15 per cent of carbon. Wrought iron is malleable (can be beaten out), ductile (capable of being drawn into wire) and comparatively soft; at red heat the metal can be hammered into any form. Its ultimate strength in bars is about 24 tons per sq. in., tension, and 20 tons in compression, and it is, therefore, well adapted to bear transverse stress. It is also more suitable than cast iron for very long columns, since these tend to fail by cross breaking and not by direct crushing. At a white heat (2370 degrees Fahrenheit) two separate pieces of wrought iron can be welded together, or integrally connected together by hammering, the joint being as strong as the original piece. It lends itself easily to alteration of form by forging, and in building construction it is used in the form of rivets, bolts and nuts, rods, bars, small water-pipes, flat and corrugated sheets, etc. It fuses with difficulty and is not therefore applicable to castings. If W. I. is allowed to remain exposed to the air at a white heat, it becomes burnt and brittle.

Corrugated iron sheets are made by passing W. I. sheets between grooved rollers which force and bend them into a series of parallel waves or corrugations. These corrugations enormously increase the strength and stiffness of the sheets and are largely used for roof covering. These sheets are usually covered with a coating of zinc, and then the sheets are called galvanised corrugated iron.
sheets. The thickness of the sheets usually varies from 16 to 26 wire gauge.

Steel:—It is a very important building material used extensively in structural engineering. It is a compound of pure iron with from 0·1 to 1·5 per cent of dissolved carbon. It is manufactured from iron ore which is subjected to a very high temperature in the blast furnace to produce pig iron, this is converted into steel in the smelting furnace, reheated and finally rolled to the required sections. It is elastic, ductile, malleable, weldable and can be tempered to different degrees of hardness. Thus it contains all the best qualities of cast iron and wrought and is harder, tougher and sounder than cast iron or wrought iron. The strength of steel depends mainly on the proportion of carbon it contains. Thus, 0·20 per cent gives a tensile strength of about 30 tons per sq. in.; 0·30 per cent 35 tons; 0·40 per cent 40 tons. Steel can be made having a tensile strength of 60 to 80 tons per sq. in.; and wire has been produced with a strength of 150 tons per sq. in. The harder grades of steel temper, but do not weld.

Steel containing up to 0·25 per cent of carbon is called mild steel, and is extensively used in building construction. Some of the various standard sections into which mild steel is rolled are shown in Figs. 1118 to 1125.

Flat bars (Fig. 1118):—The sizes of flat bars vary from 1/4 in. by 1 in. to 80 in. by 1 in., the wider sections being known as plates. Flats are sometimes used for tension members in steel roof trusses, and plates are used for connections in steel roofs, base plates and caps of steel pillars, plate girders, etc.

1. Dr. Percy has defined steel as "iron containing a small percentage of carbon, the alloy having the property of taking a temper."
Square bars (Fig. 1119):—The sizes of square bars vary from $\frac{1}{16}$ to 12 in. length of side, and are used in staircases and also sometimes in reinforced work.

Fig. Nos. 1118 to 1121.
Different forms of mild steel sections.

Round or circular bars or Rods (Fig. 1120):—The diameters of the circular bars vary from $\frac{3}{15}$ to 12 in. and are used in the construction of R.C. C. floors, columns, lintels, foundations, etc.

Beams (Fig. 1121):—These are popularly referred to as “rolled steel joists” (abbreviated to “R. S. J.”). The flanges are thicker than the web and the web is of uniform thickness and the flanges are tapered from the root to the toe. The beams are specified according to the overall dimensions, thickness, and weight per linear foot. The minimum size of the beams is 3 in. by 1$\frac{3}{4}$ in. by 4 lb., and the maximum size is 24 in. by 7$\frac{3}{4}$ in. by 100 lb. They are
largely used in the construction of floors, columns, lintels, foundations, etc.

For equal depths and weights per foot the comparative strength of the various steel sections used as beams is as follows:

Beam (I) section = 100 per cent; channel section = 90 per cent; unequal angle section = 50 per cent; equal angle section = 40 per cent; equal tee section = 40 per cent; unequal tee section = 20 per cent.

Therefore, it will be seen that 1 section (R. S. J.) is the strongest and most suitable section for beams and should be used as far as possible.

Channels (Fig. 1122):—The sizes of the channels vary from 3 in. by 1½ in. by 4-60 lb. to 17 in. by 4 in. by 44:34 lb., and are used as girders, pillars, roof purlins etc.

Tees or Tee bars (Fig. 1123):—A tee bar consists of a flange and web, and its size varies from 1½ in. by 1½ in. by 3/16 in. by 1/16 lb. to 6 in. by 6 in. by 1/8 in. by 24:23 lb. They are sometimes used in the construction of steel roof trusses.

Angles (Figs. 1124 and 1125):—The angle shown in Fig. 1124, having two unequal arms, is called unequal angle, and the angle given in Fig. 1125, having two equal arms, is known as equal angle. The proportions of these angles conform to the latest British Standard Specification, and these angles are called British Standard Unequal Angle (B. S. U. A.) and British Standard Equal Angle (B. S. E. A.) respectively. The sizes of the unequal angles vary from 2 in. by 1½ in. by 1/8 in. by 1-43 lb. to 8 in. by 4 in. by 1/4 in. by 33:11 lb., and equal angles from 1½ in. by 1½ in. by 1/8 in. by 1-01 lb. to 8 in. by 8 in. by 1 in. by 51:1 lb. These angles are extensively used in
structural engineering including all members of a steel roof truss.

![Diagram of structural engineering elements]

Rivets: These are made of mild steel and are used at the connections of steel beams, columns, roof members, etc. There are two forms of rivets, viz., snap-headed or cup-headed rivets and countersunk rivets.

The snap-headed or cup-headed rivet is generally employed. A rivet of this type is illustrated in Fig. 1126 with all necessary particulars. The diameter of the shank varies from 3/8 to 1 1/2 in., 1 1/4 in. rivets being largely used. The shank before fixing or riveting extends to the length.
indicated by dotted lines and this length depends on the diameter of the rivet and the amount of grip (the overall thickness of the plates, angles, etc. which are joined together). The second head is formed during riveting, the heated end of the shank being forced in the process to a cup shape.

![Diagram of rivets](image)

An example of a countersunk rivet is shown in Fig. 1127. This type of rivet is used when the bottom head is required to finish flush with the underside of the lower member being riveted.

**Bolts, nuts and washers**—These are described elsewhere in this book.

**Beams**—Steel beams may be either simple rolled steel sections in one piece and of uniform section throughout, (see Fig. 1121), or compound sections built up of one or more rolled beams with the addition of flars riveted to the top and bottom flanges, thus increasing the flange area for obtaining greater strength. The various types of

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1. "Beam" and "Girder" are general terms, though the latter is applied to larger sections. The term "joist" is used for smaller sections employed in floors at short distances (i.e. 12 to 18 in.) apart. "Strut" is an inclined member under compression.
built-up or compound beam sections are shown in Figs. 1128 to 1132. Beams are connected to stanchions with the aid of angle iron or steel cleats to the flanges and webs as shown in Fig. 1133.

Plate girders:—These are used for carrying heavy loads. This type generally consists of plates, angles and tee sections riveted together. The webs and flanges are strengthened with stiffeners of tees or angles cut to fit and
riveted between the flanges and against the longitudinal angles, a level surface, is being formed with the latter by a vertical packing piece having a width equal to the stiffener and of the thickness of the longitudinal angle sections. Figs. 1134 and 1135 show the section and elevation of a plate girder. Fig. 1136 shows the section of a plate girder with cranked stiffeners, and this type is used where wide flanges are necessary.

**Box girders**—These are made with two webs and shown in Fig. 1137 to 1141, and are used where girders...
are required with extra wide flanges. Box girders are not so liable to twist laterally or to bend laterally.

Fig. Nos. 1139 & 1141.
Sections of box girder.

Warren, Lattice and "N" girders: These are made on the principle of the truss, and are used for very large spans; 150 feet span is quite common and spans up to 200 feet have been erected. The three types of girders are shown in Figs. 1142 to 1144. In these figures, when the girders are uniformly loaded on the upper flange, the thick lines indicate the members in compression and the thin those in tension. The compressional and tensional members are called "struts and ties" respectively, and are made of either angles, tees or channels.

Fig. Nos. 1142 to 1144.
Steel stanchions and Columns:—When a pillar is of circular cross-section and of approximately cylindrical form it is termed a column; if cast into rectilinear form or built up from rolled steel sections of rectilinear outline it is termed a stanchion. A post is usually of timber, either round or square.

Steel stanchions may be of a single rolled steel section or a built-up section of one or more such rolled steel sections. Various forms of steel sections suitable for stanchions are shown in Figs. 1149 to 1154. Sufficient
attention should be paid in the selection of the section. Simple good connection and ease of fabrication in the

Fig. Nos. 1155 to 1157.
Show the sectional plan, elevation and end view of the base of a steel stanchion.

Fig. Nos. 1191 to 1193
Sectional plan, elevation and end view of a built up steel stanchion.
shop are factors of no smaller importance in the selection. Steel stanchions tend to fail by bending in the direction of their least dimension and hence sections, which have nearly equal moments of inertia about their principal axes, should be selected, and compounds should be designed where possible with the same object in view. Channel stanchions give better results with regard both to strength and cost. Two I-beams are not only costly, but they do not permit good connections on the flange side.

Steel stanchions are provided with specially built up bases and caps as shown in Figs. 1155 to 1157 and 1191 to 1193. Gusset plates are fixed on the sides of the stanchions to which are again fixed base angles on the outer sides. Additional base angles may also be fixed to the web of the stanchion as shown. Finally the stanchion is placed on a base plate which is fixed to the "lewis bolts" called grouted with cement in a concrete base. Sometimes it is necessary to join two lengths of stanchions end by a single length being not readily available. For this purpose cover plates, called "splice plates", are employed over the flanges and webs of the stanchions. The splice plates should be long and thick enough to get a satisfactory joint.

Steel columns or circular steel stanchions are either solid or hollow. The diameter of the solid columns varies from 2½ to 12 in., and the diameter of the hollow columns from 5 to 12 in.

Steel roof trusses:—The safe working stress on mild steel is about twenty times that for ordinary structural timber in direct tension. Thus mild steel is much stronger than timber, and it is more fire-resisting, not attacked by insects or fungus, and can be obtained in sections to suit the particular requirements of the job and can be ordered
in lengths with practically no waste. Its sections are easy to transport, and the various sections can be readily assembled to form comparatively simple connections. Corrosion is negligible provided the structure is well protected by means of a suitable paint. It is mainly for these reasons that mild steel is now employed extensively for roof trusses. Mild steel trusses have now practically superseded timber trusses even for spans as short as 20 to 35 ft., and are more economical for spans exceeding 40 feet.

The most suitable sections for mild steel roofs are angles, and most of the members of modern steel roof trusses are of angles. Angles effectively resist both compression and tension stresses. They can be easily attached and they are produced economically. Until comparatively recently, it was a common practice to use flat bars for a main tie, as they were suitable for resisting tension stresses. However, owing to wind pressure and the abnormal strain imposed during the transporting and erection of trusses, members may be subjected to changes of stresses, and flats will not resist compression stresses. Flat main ties therefore tend to become buckled. If a timber joisted ceiling is to be provided to the underside of the tie or tie-beam, ceiling joists can be readily and easily fixed to an angle than to a flat bar, and this is an additional reason why angles should be used instead of flats. Rods (round bars) are never used as ties in modern practice and T-bars are very occasionally used as it is more convenient to make good connections to angles.

Angles are generally used for purlins. Channel purlins may also be used. Timber purlins are sometimes used and are convenient if insulation or lining is to be connected to the underside of the roof slope. Purlin spacings
will vary with the type of the roof covering material adopted.

Small trusses are fabricated (riveted or bolted together) at the works and transported to the working site. Owing to the difficulty of conveying larger trusses, they are usually fabricated at the works and assembled together on the job. Trusses are erected by a crane gantry and connected to the building by means of rag bolts. The distance between the steel roof trusses usually varies from 8 to 15 ft. The pitch or slope of steel roof trusses, like those of timber construction, depends upon the type of roof covering and the architectural effect desired. Sound stone or R. C. C. templates of sufficient thickness and area are provided to give a reliable and level bearing for the ends of the truss and to receive the steel fixing bolts (called ragged lewis bolts or rag bolts). The templates course with the brickwork. For small trusses the ends are usually fixed. But it is a better practice to make provision for expansion and contraction due to temperature changes. For a small truss oblong slots are provided in the base plates through which the truss is fixed to its supports. In the case of a large truss, one of its ends is placed on a chair mounted on steel rollers, and the other end is fixed. For series of trusses wind ties, diagonal braces between the two end trusses are provided on either side to increase the rigidity of the roof, and thus to prevent the general distortion of the roof due to wind action.

**Truss layout:** A steel roof truss should be properly triangulated, i.e., all members of the truss should be arranged to form triangles so that the truss will not alter in outline to a considerable degree. The connections of bars to each other are called nodes or panel points, and are made by means of thin flat plates called gusset plates or gussets to which the ends of members are riveted or
Panel points on rafters are spaced at about 6 ft. centres for average cases. Care should be taken to see various types of ordinary or open steel trusses. The compression members of trusses are shown in thick lines and the tension members in thin lines.

1. Welding is an alternative to bolting and riveting, and is a comparatively recent development. Gusset plates are dispensed with and the members are welded together.
that each member is either in direct compression or in direct tension, and the purlin connections are made at a "node" point. If the purlin loads are carried between the

Various types of ordinary or open steel trusses. The compression members of trusses are shown in thick lines and the tension members in thin lines.

"node" points, the principal rafters will tend to bend and will have to be made considerably larger on that account:
this action is called "local bending". A long compression member will not carry as much load as a short one which has the same cross section. All compression members should, therefore, be made as short as possible. This is sometimes effected by giving a camber in the bottom tie. The tension members should be braced together.

The usual types of steel roof trusses for different spans are shown in Figs. 1158 to 1170. These roof trusses are called open trusses. For small spans, the bottom member is level and in one piece for the whole span, but in longer spans, a camber is very often introduced to reduce the effective length of the struts (which are in compression).

The roof truss shown in Fig. 1168 is known as a Fink, French or Belgium truss.

Three special forms of trusses, viz., Bowstring truss, Arched truss and North-light or Saw-tooth or Weaving-shed truss are illustrated in Figs. 1171 to 1174.
String trusses are used for large spans. A roof constructed of bowstring trusses is more expensive than ordinary pitched trusses on account of the labour required to curve the principal rafter. Further the covering itself should be carried with great care to provide a dry building. The arched trusses are usually designed together with the stanchions which support them. The north-light or saw-tooth trusses are generally used for factories and workshops. They are not commonly used over a larger span than 40 ft. The roof slopes are at about 90 degrees to each other, the flatter slope being completely galvanized corrugated iron or corrugated asbestos-cement sheeted and the steep slope covered with glazing. The glazed slope always faces North and is so disposed to avoid direct sun-light shining into the building. A common shoe plate is used for adjoining spans. The end trusses in each line are fastened down by a steel stanchion. North-light trusses are usually fixed at heights above 14 ft. from the floor.

**Design of steel roof trusses**—A steel roof truss should be properly designed to carry its own weight, the weight of purlins and the roof covering materials. An allowance must also be provided for loadings caused by wind, snow and ice. Each member of the truss must be carefully proportioned to carry the maximum load it is likely to sustain. The thickness of the members should not be less than 1/4 in.

While designing a steel roof truss, some practical considerations should be borne in mind. Unequal angles connected to gusset plates by their larger legs are more economical in tension. The diameter of the rivet-holes is always made alike to ensure economy. This arrangement will also save considerable time during connection. Usually the holes are made 1/16 in. larger than the nominal diameter of the rivet or bolt to be used. The rivets...
are driven hot and are closed by machine, the Shank of the rivet being made to fill the hole completely.

The size of the rivets and bolts depends upon that of the members to be connected. Thus 4 in. diameter rivets and bolts are generally used for angles and flats up to 2 in. wide, and 3 in. diameter rivets and bolts for larger members. According to the British Standard Specification, (1) the minimum pitch of rivets or bolts shall not be less than three times the diameter of the rivets or bolts (2) the maximum pitch is 6 in. for compression members and 8 in. for tension members, and (3) the minimum distance from the centre of any rivet or bolt to the end of a member or edge of a gusset plate shall be 11 in. and 1 1/2 in., for 2 in. and 3 in. diameter rivets (or bolts) respectively.

The thickness of gusset plates depends upon the bearing value of the rivets employed. Usually 1/4 in. thick gusset plates are used for small roof trusses, and 3/8 in. thick gusset plates for large roof trusses. Gusset plates vary in size and shape according to the pitch of the rivets, size and inclination of the connecting members and the appearance required. If a member consists of double angles, gusset plates are usually placed between them.

Joints in steel roof trusses:—Two types of joints are used in steel roof trusses. They are (a) Riveted joints and (b) Welded joints.

(a) Riveted joints:—The various members of a steel roof truss are usually connected together by means of rivets and gusset plates. To facilitate construction and transport, large trusses are sometimes fabricated in parts at the works and assembled together at the job with the aid of bolts.

1. The pitch of rivets or bolts is the distance between their centres.
(b) **Welded joints**—During the past few years the art of welding has developed to a great extent, and the various members of a steel roof truss may be welded together as an alternative to riveting and bolting. The various advantages of welding are given below:

1. Welding eliminates the noise of riveting, which is a remarkable advantage in big cities.
2. As there are no rivet holes drilled or punched in the member, the entire cross-section of a tension member becomes available for taking the stresses.
3. The process of welding saves much time, and is comparatively an easy and a very convenient one. Riveting is generally considered as a laborious process, specially in intricate positions such as acute corners, etc.
4. Due to the elimination of angle cleats, welding becomes cheaper for beams, joists and stanchion connections and thus the process of welding becomes economical on a large scale.

**Method of making a welded joint**—A welded joint is made thus: An electric current or gas (an oxy-acetylene flame) is employed to melt a steel rod or wire (called an electrode) and the adjacent edges of the members to be welded in such a manner that the molten metal from the electrode is deposited along the points of contact and fused into them: the joint thus formed is called a welded joint. It is found from experiments that if the welding is properly done, it is possible to develop the full strength of the members joined.

**Details of steel truss and roof**—In Fig. 1175 are given the details of a steel truss roof with eaves gutter, and the method of fixing the steel roof truss to the suppor-
The use of stone pads, rag bolts, gusset plates and bearing plates (also called base plates or sole plates) is also shown. No common rafter is required when corrugated asbestos cement sheets or corrugated iron sheets are used as roof covering. These sheets are fixed direct to steel purlins as shown in Fig. 1176. Wooden purlins may also be used instead of steel purlins; the method of fixing to wooden purlins is shown in Fig. 1101; the wooden purlins are secured to the mild steel principal rafters by means of mild steel angle cleats as shown. A sketch of a rag bolt is shown in Fig. 1177; its thickness is equal to the diameter of the upper threaded shank and the lower
Eaves detail of a mild steel truss. Note that the asbestos-cement sheets are fixed direct to steel purlines.

A rag bolt with a nut.

Portion is tapered in its width; its edges are jagged as shown to afford a key for the fixing material, which is usually molten lead run in to secure the bolt when placed in the hole in the stone template. The lead should be well caulked to prevent corrosion. The rag bolts are
provided with nuts, and are obtainable in overall lengths of 4, 6, 9, 12 and 15 in. and of $\frac{1}{4}, \frac{1}{2}, 1,$ and 1 1/4 in. diameter. Two rag bolts are generally required at each end and these are fixed in readiness to receive the truss. A short angle cleat is fixed at each side of the gusset plate and these rest upon the base plate. The base plates are placed in position and the truss is hoisted and lowered.

Fig. No. 1178
Details of a steel truss roof with parapet wall and lead gutter.
Showing the ridge details of a steel truss roof.
till the holes in the angle cleats are engaged by the shanks of the rag bolts, the nuts are then tightened.

In Fig. 1178 is shown part of a steel truss roof with a parapet wall and a lead gutter. The method for fixing the truss to the supporting wall is also clearly shown with necessary details.

The details of connections at the apex are shown in Figs. 1106, 1179 and 1180. In Fig. 1106 the roofing consists of corrugated asbestos-cement sheets, and a pair of asbestos-cement ridge cappings are provided at the ridge (galvanized corrugated iron sheets may also be used instead of asbestos-cement sheets). Steel angle purlins or wooden purlins may be used as shown. The method of fixing the roof covering to the purlins with the aid of hook bolts or driving screws is also shown in the figure. The roofing shown in Fig. 1179 consists of common...
rafters, teakwood boarding, and steel angle purlins. The ends of the steel principal rafters are mitred and those of the diagonal ties and the vertical tie are square cut. The steel angle purlins are fixed to the steel principal rafters by means of bolts. Rivets are never used for fixing these purlins, as riveting is not practicable after the trusses have been fixed in position. Wooden plates of short lengths called fillers, are bolted at 2 to 3 ft. intervals to the purlins as shown to provide fixings for the common rafters. Coach bolts (also called carriage bolts or timber bolts) are now generally used for fixing these wood plates to steel purlins. The ridge shown in Fig. 1180 is an alternative arrangement to the ridge shown in Fig. 1179. The wood ridge is secured by two bolts to two bent plates or flats which have been either bolted or riveted to the steel principal rafters, the former being usually preferred. During setting out care must be taken to see that the

![Diagram showing ridge details of a steel truss roof.](image-url)
bolts or rivets connecting these bent plates to the rafters do not foul the rivets fixing the latter to the gusset plate.

Elevations of two typical steel roof trusses up to 40 ft. span with necessary details are shown in Figs. 1181 to 1190. It is necessary to note that sizes of the various members, number and sizes of the rivets or bolts are dependent upon the forces in the members, i.e., the weight of roof covering material, the distance between the trusses and purlins, provision or otherwise of a ceiling and the degree of exposure of the building to wind pressure.

Some practical hints for making and fixing steel trusses:
1. The minimum sizes of truss members are:
   - Angles ... 2 in. by 1 1/4 in. by 1/4 in.
   - Flats ... 2 in. by 1/4 in.
   - Rods ... 1/4 in. diameter,
Details of a steel roof truss for 30 to 40 feet span. For detail "F" see Fig. 1180. An alternative ridge detail is given in Fig. 1179. See also Figs. 1101, 1102, 1106, and 1175 to 1180.

Angles should be preferred to flats or rounds for ties and other tension members to ensure stiffness and rigidity of framework and to minimise bending and distortion during handling and transport.

(2) Principal rafters should not be longer than 10 ft. between struts.

(3) All the purlins should be fixed at the joints.

(4) Nos. of panels is generally taken = \( \frac{\text{Span}}{5} \)

(5) All the struts should be made as short as possible because long struts will not carry as much load as short ones.
(6) Where a tie is to be cambered, it is 1/30th to 1/40th of the span. Where the main tie has to be kept horizontal, a camber of 1/480 of the span is given to avoid appearance of sagging.

(7) The rise of steel truss is usually kept one-fourth to one-fifth of the span, but it depends largely on the nature of roof-covering materials and climatic conditions. Regions subject to heavy rains need steeper slopes. Pitch of roof on the West Coast is usually one-third.

(8) The spacing of steel trusses is generally kept 10 ft. up to 50 ft. span and beyond that one-fifth of the span. Spacing is more for light roofs, may be 15 ft. for galvanized corrugated iron sheets.

(9) The thickness of walls for steel trusses should be as follows:

<table>
<thead>
<tr>
<th>Span</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 to 24 ft</td>
<td>18 inches</td>
</tr>
<tr>
<td>25 to 40 ft</td>
<td>24 inches</td>
</tr>
</tbody>
</table>

(10) Mild steel bearing plates of size 1 ft. by 1 ft. by 3/8 in. thick are fixed over the stone pads (9 in. by 6 in. 14 in. long) under the steel truss ends with shoe angles of size 2½ in. by 2½ in. by ½ in. Two angles are on each end, fixed with the gusset plate.

(11) Ends which are to be fixed in masonry should be properly anchored down with lewis bolts of sufficient lengths. The diameter and length of the bolts should not be less than ½ in. and 6 in. respectively.

(12) Provision should be made for expansion and contraction of the steel trusses due to temperature changes. Up to 20 ft. span both ends may be fixed, but beyond this span, either one of the truss ends is made free to move.
and the other is fixed or both the ends are made free according to the span and the temperature variations. For free ends, slotted holes are made in bearing plates of the truss and the ends are made free to slide. For large spans, say 60 ft. or above, ends may be built on rollers. The free ends are made away from the direction of the prevailing wind.

Reactions at the ends of the trusses are vertical for free ends and inclined on fixed ends.

(13) A lead sheet 1/8 in. thick is provided under the sole plate on the free end. Slotted holes 2 in. long and 1/16 in. larger than the diameter of the holding down bolts are made in the sole plate, and lewis bolts passed through them, in the free end. In the fixed end, holes for lewis bolts are round and not slotted and the lead sheet is omitted and replaced by cement grout.

(14) Mild steel roof trusses must be painted at intervals to prevent corrosion.

Some practical considerations for making and fixing columns or stanchions:

(1) The strength of a column, stanchion or strut depends on its slenderness ratio and the method by which the ends are fixed. Columns or stanchions generally fail by buckling unless the length is small.

\[
\text{Slenderness ratio} = \frac{\text{effective length or unsupported length}}{\text{least radius of gyration}}
\]

\[
= \frac{l}{r}.
\]

Radius of gyration = \[
\sqrt{\frac{\text{moment of inertia}}{\text{Area of section in sq. in.}}}
\]
Moment of inertia, \( I = Ar^2 \) where

\[ A = \text{Area of section in sq. in.} \]

\[ r = \text{Radius of gyration in inches.} \]

The measure of stiffness of a member is the ratio of its Moment of Inertia to its length. The most economical section is that which for the same area of cross section has the greatest radius of gyration.

Long stanchions or columns tend to fail by bending in the direction of their least dimension (or the least radius of gyration), therefore, for economy of the material, variation between the maximum and minimum radii of gyration about the two principal axes of the section should be as small as possible. For this reason single sections are used for light columns, and for heavy columns two or more sections are joined. No deduction is allowed for rivet holes in the calculation of radius of gyration and modulus of section of compound stanchions or columns.

The slenderness ratio of columns or stanchions shall not exceed the following values:

(a) For both ends fixed \( ... 160 \)
(b) For one end fixed and one end rounded \( ... 120 \)
(c) For both ends rounded \( ... 100 \)

In practice no column or stanchion is completely fixed or hinged at the ends and the half fixed end conditions can be generally taken in design. Stanchions or columns fixed by rag bolts at the bottom are considered partially fixed.
The slenderness ratio of struts shall not exceed the following values:

(a) For any member carrying loads resulting from dead weights and superimposed loads.

(b) For any member carrying loads resulting from wind forces only, provided the deformation of such member does not adversely affect the stress in any part of the structure.

(c) For ties in roof trusses

The slenderness ratio for bridge structures shall not exceed 100 for main members, and 125 for bracings.

(2) The weight of the stanchion or column should not be reduced without regard to the cost of labour. For instance, weight can be saved by substituting lattice for plate girders, or compounds for single rolled sections; but in these cases, the cost of labour is bound to be higher than that of the material saved.

(3) The foot of every column or stanchion after riveting up complete with all gussets, cleats, etc., should be machined over the whole area so that the base plate is in effective contact with the entire area of the column or stanchion foot, and all joints should be close butted.

(4) The width of the base plate usually varies from 2 to 4 times the width of the column or stanchion and the height of the gusset plates from \( \frac{1}{2} \) to 3 times the width of the column or stanchion. The base plate should not project more than 10 times its thickness to avoid shear
and bending moment in the plate itself, and for its overhanging portion acting as a cantilever. The number of rivets connecting the base plate to the stanchion or column should be sufficient to carry about two-thirds of the total load.

(5) The size of the stanchion or column cap should be as small as possible to prevent eccentricity of loading.

(6) Skew framing and eccentric loading should be avoided as far as possible, and girders or beams should be directly connected into the stanchions or columns.

(7) Stanchions or columns supporting upper floor loads and roof should be continuous from the foundations as far as possible; if it is necessary to splice, it should be done just above the girder connections (say, 1 ft. 6 in.) at any storey level. The ends of the section to be joined should be well planed to obtain a good contact, and sufficient number of rivets must be provided on each side of the joint.

(8) The thickness of the concrete footing under stanchions or columns should not be less than twice its projection to avoid cantilever action; 12 in. should be taken as minimum.
CHAPTER XIII

QUESTIONS FOR REVISION

1. Draw a steel roof truss for a clear span of 30 ft. Pitch of roof 30 degrees. The roof is covered with Mangalore tiles.

2. Draw, to any suitable scale, the detail of the joint at the foot of a steel roof truss 30 feet span and 30 deg. pitch. The roof is covered with corrugated sheeting, finished with 6 inch, half-round C.I. gutter. The truss rests on a stone pad on an 18 in. thick brick pier.

3. Indicate by sketch a suitable steel roof truss for 30 ft. span giving sections of members. Assume the pitch to be 30 degrees and the roof to be covered with corrugated asbestos sheeting.

4. Sketch an outline diagram of a steel roof truss for 30 ft. span, and indicate which members are in compression and which in tension.

5. Draw to a scale of 1/8 inch to 1 foot. a steel roof truss, suitable for a span of 40 ft. Draw to a large scale detail of joints at ridge, and at foot of principal rafter showing gutter, wall, etc.

6. A depot built in 13\(\frac{1}{4}\) in. brickwork has an unceiled asbestos sheeted roof carried over a 45 ft. span on light steel trusses and metal purlins. The rain-water is collected in a C.I. gutter. Draw to a scale of 1/4 in. to 1 ft. half elevation of steel roof truss and to a larger scale details of all joints in truss and arrangement of foot of truss and gutter.

B. C.—17
7. (a) Discuss briefly the advantages and disadvantages of (i) timber, (ii) steel, (iii) concrete trusses for supporting roofs of buildings.

(b) Draw a neat sketch of a steel roof truss for a span of 30 ft. Show the details of connections of any one important joint of the truss.

(University of Poona, 1951)

8. Give an idea of the structural connection that you will use in fixing a horizontal R.S.J. beam 18" x 6" to the flange of a broad flanged beam 9" x 9" used as a stanchion. Sketch a typical concrete footing for such a stanchion.

(Karnatak University, 1952)

9. Give a sketch of the fixed-end joint of two steel beams 12" x 5" resting on either side of the rolled steel column 10" x 5". Detail the pedestal of the column on the concrete block.

(Gujarat University, 1952)

10. Draw a cross-sectional sketch of the newly constructed workshop building showing the roof, the truss columns and the walls and their footings and foundation. Detail the joint of the columns and the truss by a separate sketch drawing.

(University of Baroda, 1953)

11. Draw neat sketches to show details of a compound steel column composed of a 10" x 6" R.S.J., with a 10" x 3/8" plate attached to each of its flanges and running throughout the length of the column. The column rests on a steel grillage foundation. Your sketches should show details of the column base and also of the grillage.

(University of Poona, 1956)
CHAPTER XIV

GROUND AND UPPER FLOORS

GROUND FLOORS

Ground Floors:—The following are the various types of floors generally used in India for ground floors:—

1. Muram or Mud floors.
2. Brick floors.
3. Tiled floors.
4. Flagstone floors.
5. Chunam or Terraced floors.
6. Tar and sand floors.
7. Asphalt floors.

Terrazzo floors and china mosaic tile floors are described under the caption "Cement Concrete Floors."

1. Muram (disintegrated rock) or mud floors:—
These floors are generally used for unimportant buildings, and in rural districts of India, these are very common. They are made with great care and are maintained in a good condition. They can be cheaply and easily made and repaired. These floors last sufficiently long for the purpose, and are very suitable for Indian conditions. They maintain an equable temperature both in the summer and winter seasons. But these floors are absorbent to some extent, and they should occasionally be given a wash of cow-dung, which is objectionable from the sanitary point of view.
A muram floor is prepared thus:—At first, a sub-grade of rubble or well burnt brick-bats, about 9 in. thick, is formed and the same is well rammed by using sufficient quantity of water; this sub-grade or sub-base is sometimes called hard core or penning. Upon the sub-grade a 6 in. thick layer of muram (or murum) is spread. Over this, a layer of powdery variety of murum, about 1 in. thick, is spread, and water is sprinkled until the floor surface is fully saturated with water and a thin film of water (say, 1/4 in.) is formed on the top. The surface is well trampled until the cream of murum rises to the top, and then left to itself for about 12 hours. The surface is then rammed well for 3 days by means of rammers. After this, the surface is smeared with a thick paste of cow-dung, and the floor rammed for two days in the morning. Finally, a thin coat of a mixture of 4 parts of cow-dung and 1 part of Portland cement is given evenly to the surface and wiped clean immediately by hand. In order to maintain the surface of the floor in a good condition, it should be given a thin wash of cow-dung and cement (2 : 1 or 3 : 1) once in a week or two.

In places where muram is not available, mud may be used. The difference between a muram floor and a mud floor lies in the quantity of water. While a muram floor requires much water, a mud floor requires only a small quantity of water. The formation of a mud floor is as follows:—A layer of well selected moist earth, about 9 in. thick, is evenly spread and well rammed to about 6 in. thick. Then the surface is given a thin wash of Cow-dung and cement (suitable proportions are given above) and wiped clean immediately by hand. The floor thus prepared is fairly smooth and hard. Once in a week the surface of the floor should be given a thin coat of cow-dung.
and cement and wiped clean immediately to maintain the surface in a good condition. The surface should never be treated with a thicker coat, as it would soon cake and peel off.

Small quantities of chopped straw are often mixed with muram or mud to prevent the formation of cracks.

2. Brick Floors

These are made of ordinary bricks laid flat or on edge, set in ordinary mortar and pointed with cement, or set in hydraulic mortar. Brick-on-edge is preferable to bricks laid flat, the former being less liable to crack under pressure than the latter, and from its superior depth a greater thickness to resist moisture is obtained. The bricks should be of the best quality (i.e., the bricks should be well burnt and well shaped and free from defects such as cracks, flaws, etc.), and the tops and sides rubbed down to obtain a smooth surface and a small regular joint (say, about 1/16 in. thick). Brick floors are very suitable for stores, godowns, etc., where heavy materials and articles are put. The only disadvantage of these floors is that they are absorbent. The method of formation of brick-on-floors is described below:

An excavation is made about 15 in. below the intended surface of the floor; the earth is then levelled, watered and well rammed until dry and hard. On the bed so prepared a layer of pure and dry river sand, about 3 in. thick, is spread evenly, as a preventive against white ants and damp. Upon this, two courses of bricks are laid flat and set in mortar. Instead of forming the bed of bricks laid flat in mortar, it may be formed of well rammed concrete about 6 in. thick. Finally, the brick-on-edge course is laid carefully. Care should be taken to see that the sides of bricks have a coat of mortar over their entire surface for proper adhesion. The joints should be carefully filled in with cement or lime water, or pointed
neatly. The brick-on-edge course may be laid either in parallel rows breaking joint, or in herring-bone bond.

3. Tiled Floors: For these, paving or flooring tiles are generally used and these tiles are 6 to 18 in. square and 1\(\frac{1}{4}\) to 2\(\frac{1}{2}\) in. thick. The tiles should have neat edges for good fit and jointing. Hexagonal and rectangular tiles are also manufactured. Various patterns of ornamental tiles are nowadays available and they may also be used for this class of work. Tile floors are formed in the following manner:

The ground for receiving the floor is levelled, well watered and rammed, and on this a sub-grade of lime concrete, about 6 in. thick, is made. On the sub-grade thus prepared a thin layer of cement mortar containing 1 part of Portland Cement and 1 part of fine sand is spread evenly, and the tiles are laid flat and set in a thin paste cement. Great care is exercised to see that the sides of the tiles have a thin coat of cement mortar over their entire surface for proper adhesion. The joints are very thin, i.e., as thin as paper, and the extra cement that oozes out through the joints to the surface is immediately wiped clean. About 3 days after, the joints are well rubbed, with a carborundum stone, so that slight projections rising above the surface are levelled. The entire surface of the floor is then polished with the aid of a softer variety of carborundum stone and a pumice stone. Finally the surface is washed with a solution of soft soap in warm water.

4. Stone, stone paved or flagstone floors: Stone floors are very durable and are not easily injured. Where slabs of stone are available, they may be used. The stone slabs are laid in the same manner as tiles, on a bed of lime concrete not less than 6 in. thick, carefully rammed and
263

Leveled. When all the stone slabs are laid, the mortar in the joints is raked out, and the joints are flush pointed with cement mortar (1:3). The stone slabs should be of uniform size (usually 12 to 15 in. square) and should have the edges squared. No stone slab should be less than 1\(\frac{1}{4}\) in. thick. The thickness of the joints should not be more than \(\frac{3}{8}\) in. thick. Slabs of Cuddapah slate are much used for flooring in Tamil Nad and Andhra. Stone floors are very suitable for motor-shed, workshops, godowns, stores, etc.

5. Chunam or Terraced floors:— These floors are often used in Tamil Nad, Andra and Kerala. For this type of flooring the excavation should be from 9 to 12 in. deep, and the earth should be leveled, watered and rammed well until dry and hard. The first course may consist of concrete from 6 to 8 in. thick, of a single course of brick-on-edge in mortar, or two courses of bricks laid flat and set in mortar. The second course consists of a layer of brick-jelly concrete, about 3 in. thick. Upon the concrete bed, is placed a layer of good mortar, about 1 in. thick, which is well beaten and then rubbed smooth with the aid of a trowel. Finally the surface is given a thin paste of lime evenly and the surface is well rubbed with a wooden float and soapstone until it attains a high polish.

To avoid cracks in the surface no portion of the work should be allowed to dry before the whole of the work is completed. A layer of damp leaves, matting or sand will keep the work moist, and one of these should invariably cover the floor until fit for exposure. The excellence of these floors depends upon the quality of the materials used, and the care taken in using them. These floors are not suitable for public buildings as the surface soon gets broken and repairs to it very unsightly and never effectual.
6. **Tar and Sand or Tar floors** — These floors consist of a firm bed of brick or concrete, about 6 in. thick, on which a layer of tar and sand mixture, about $\frac{1}{4}$ in. thick, is laid. The surface of the brick or concrete bed is made level with rough plaster, and then coated with a mixture of tar and sand which is applied by means of a trowel. The mixture which must not be applied till the rough plaster is thoroughly dry is prepared as follows:

- The tar is boiled in chatties or cauldrons, and, when boiling, hot sand is stirred into it until the mixture becomes too stiff to stir any longer; it is then ready for use. The sand is heated to drive out any moisture in it. These floors are not much used in India.

7. **Asphalt floors** — Asphalt, owing to its bad smell and black colour, has been regarded as suitable only for outdoor paving and road surfacing. However, with various improvements in its manufacture and use, and notably with the introduction of colour, it is becoming more and more popular for indoor flooring also. Asphalt floors are non-slippery, dustless, noiseless and extremely watertight. Various particulars of asphalt floors are given below:

- The ground for receiving the floor is levelled, watered and well rammed until dry and hard; upon the bed thus prepared, about 7 inches of brick-jelly or broken stone concrete is laid and beaten down to 6 inches and allowed to get perfectly dry before any attempt is made to lay the asphalt compost. The mastic asphalt is prepared thus:

- The solid asphalt sold in drums is broken into pieces and boiled in an iron cauldron. It is stirred well while it melts, and when thoroughly fused, coarse sand which is passed through a 16 to 20 mesh to the sq. in. and which has been well washed and dried in the sun, is mixed
with it in the proportion of 2 to 1, i.e., 2 parts pure asphalt (by weight) to 1 part clean sharp sand. Sometimes half a pound of coal tar is added for every 100 lbs. of the mixture whilst boiling. The whole mixture is kept well stirred during the operation; when ready for use it will emit jets of light brown smoke, and drop freely from the stirrer (or stirring rod). The cauldron is then taken off the fire, and the mixture is used as quickly as possible.

To lay the asphalt compost, four straight pieces of wood or bar iron \( \frac{3}{4} \) in. wide and \( \frac{1}{4} \) in. or \( \frac{1}{2} \) in. thick are prepared so as to form a rectangle 4 ft. by \( \frac{3}{4} \) ft. If wood is used, the inner edges of these boundary pieces are levelled down to \( \frac{1}{4} \) in. or \( \frac{1}{2} \) in. according to the thickness of asphalt required. Three or four hand rubbers or plaster floats are also required. When these are ready, the boiling asphalt compost or mastic is taken from the cauldron (which should be as near to the work as possible) by means of an iron ladle, and as much as will just cover the surface of the rectangle to the required thickness is laid on and spread; then a handful of the clean coarse sand is thrown over the surface and beaten well until it begins to get hard; the surface is then covered with some very fine dry sand, and rubbed well with the aid of wooden rubbers or plaster floats until it becomes perfectly true and even. The frame is then removed and the process continued by laying down another rectangular piece in continuation of the above. All the corners and edges at ends are usually rounded off by carrying the asphalt compost layer 2 to 3 in. vertically against the wall flush with the plaster.

Before laying the asphalt compost, care must be taken to see that the concrete bed is perfectly dry, as the slightest moisture or dampness prevents the asphalt from adhering properly, and the steam cracks the asphalt or raises bubbles. If the joints between any rectangular patches are
found uneven, a hot iron should be applied for a few seconds to soften the asphalt and then it should be rubbed down carefully until perfectly even.

By increasing or decreasing the quantity of sand, the asphalt compost can be made to suit the heat of the locality where used. If too little sand is used, the heat in the hot weather softening it will cause any ordinarily heavy article to sink into it; and, on the other hand, if too much sand is used, the material will become too brittle, and there will not be enough of the mastic to bind the sand together in the requisite manner.

For ordinary purposes, a single layer of asphalt compost ½ in or ¾ in, thick is sufficient; but in places where infiltration of moisture under pressure is expected, it is necessary to lay two layers breaking joint.

8. Cement concrete floors:—These floors are now very common and are largely used for schools, hospitals, bath rooms, water-houses, etc. They are very hard, smooth, non-absorbent and last long. They are comparatively cheaper and possess all the advantages of the costlier types. But, if they are not made properly, they can never be satisfactorily repaired by patch work.

Preparation of ground:—The ground for receiving the floor is levelled, well watered and rammed.

Formation of hard core and laying lime concrete:—Upon the above well rammed and levelled ground, a layer of broken bricks or stone, about 6 in. thick, is evenly spread and well consolidated; this sub-base or sub-grade is called hard core or penning. A layer of lime concrete (1:2:4), about 6 in. thick, is then laid evenly on the hard core or penning. Necessary slope is given to the surface of lime concrete to facilitate the washing down of
The finished floor; usually a slope of 1 in. 120 to 240 is sufficient for ordinary inside floors, and that an outward slope of 1 in 36 to 1 in 40 to bath-room and verandah floors. The lime concrete layer is watered and well rammed for two days.

Laying cement concrete: On the following third day, the surface of the lime concrete is well moistened with great care. Care should be taken to see that no water-pools are allowed to stand on the surface. A small quantity of dry Portland cement is then carefully sprinkled over the surface, and this is swept with a boom and immediately a layer of well-mixed cement concrete (1:2:4), about 1½ to 2 in. thick, is laid evenly and rammed well with the aid of wooden rammers. The concrete may be either machine or hand mixed, the former being preferred. Only sufficient quantity of water should be used for mixing; a slump test must not exceed 1½ in. An

The draft Indian Standard Code for Plain and Reinforced Concrete for General Building Construction suggests the use of the following water contents in gallons per Cwt. of cement for ordinary concrete (weight of 1 gallon of water = 10 lbs., and 1 Cwt = 112 lbs):

<table>
<thead>
<tr>
<th>Mix</th>
<th>Normal Mix</th>
<th>1:1:2</th>
<th>1:1:4:3</th>
<th>1:2:4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 to 6 gallons</td>
<td>5 to 6-5 gallons</td>
<td>6 to 7 gallons</td>
<td></td>
</tr>
</tbody>
</table>

It also says that the water content for any mix should generally be equal to 5 per cent by weight of the aggregates plus 30 per cent by weight of cement, the necessary variation being made for the required consistency of the concrete (for vibrated concrete the quantity of water should be reduced by about 10 per cent).

U. P., P. W. D. Specifications for concrete in road construction recommend the use of 5 to 6 gallons of water per Cwt. of Portland cement for 1:2:4 mix according to temperature and weather. In Building Specifications a thumb rule is given according to which the quantity of water required will vary from 7 to 10 per cent of the weight of cement and aggregates according to weather conditions.
excess of water should be avoided, as this considerably reduces the strength and wearing properties of concrete and produces what is known as a dusty floor.

**Laying wearing coat** — After an hour of laying the cement concrete, a finishing surface or wearing coat, about \( \frac{3}{4} \) in. thick, is laid on the surface of the former. A hard wearing surface, known as *granolithic finish*, is obtained from a mixture of 1 part Portland cement, 1 part clean fine sand and 2 parts clean stone chippings capable of passing through a 1/4 in. square mesh sieve; the mixture should give a 1 in. slump. The wearing coat is tamped and floated with a wooden float, and then it is trowelled smooth by means of a steel trowel. Excessive trowelling brings to the surface a liquid scum, called *laitance*; such practice should be avoided, as this destroys the initial set and produces a friable, non-wearing surface having a glossy finish which has a tendency to dust and craze. Sometimes dry cement is sprinkled on the freshly laid concrete surfaces to get a good finish with less labour; but this should be avoided, as the dry cement forms scales (or skin coats) which chip off in course of time.

All the surfaces of the cement concrete floors are not finished as described above. Thus, for common work, the wearing coat is often omitted, and the top of the cement concrete layer is rendered smooth by means of a wooden float and a steel trowel.

**Grinding and Polishing** — A hard-wearing surface of attractive appearance may be produced by mechanically operated grinding discs which are applied to the floor after it has become sufficiently hard. This grinding removes laitance or loose material and produces a smooth finish.

**Terrazzo finish** — Terrazzo is another finish used in first-class work. In one method the cement concrete
base is covered with a 1 in. thick wearing coat composed of 1 part Portland cement and 2 parts clean sharp sand; marble chips free from dust and of 1/4 in. gauge are sprinkled over the surface of the wearing coat whilst it is still soft and pressed or rolled. **In another method** a layer of cement mortar (1 part cement and 2 parts sand), ½ in. thick, is evenly spread over the cement concrete base whilst the latter is still wet; when the cement mortar has sufficiently hardened, a 1 in. coat of well-mixed terrazzo mixture consisting of 1 part ordinary Portland cement or coloured cement and 2½ parts crushed marble of ½ in. gauge or less, is laid and well rammed with the aid of wooden rammers, and finally trowelled slightly.

When the terrazzo finish has sufficiently hardened, the surface is carefully polished by means of a grinding machine fitted with carborundum grinding stones. During the process of grinding, the surface is kept wet. Holes, if any, are carefully filled with a thin grout of coloured or ordinary cement paste. After this, the surface is ground once more to a give a fine finish. Finally the whole surface is washed with a weak solution of soft soap in warm water.

Cement concrete floors finished with terrazzo are also called terrazzo floors.

**China mosaic tile floors**—On the top of the cement concrete base, whilst it is still wet, a ½ in. layer of cement mortar composed of 1 part cement and 2 parts sand is evenly laid; upon the bed of cement mortar small pieces of broken tiles (either china glazed or of cement) are arranged in such designs and colours as may be desired. After this, dry, ordinary Portland cement or coloured cement is sprinkled on the top and the surface is carefully rolled
with a light roller without even slightly disturbing the pattern. Finally the whole surface is wiped clean with sawdust. Care should be taken to see that the tiles are broken in the proper way; the tiles should be broken to the shape of a wedge, with the polished or glazed side on the broad face.

**Coloured floors:**—These can be made with 1 cubic foot of cement and 17 lbs. of Red Oxide or Ivory Black laid 1/4 in. thick. The colouring pigment should not be more than 1:3 and not less than 1:12 (colouring pigment with white or ordinary cement); it is better to mix the colouring pigment with white cement than with ordinary Portland cement. Floor paints are now available in various colours. They give a hard, wear-resisting surface and withstand the action of water better. Steel or iron floats should not be used on coloured floors as they will cause crazing. The coloured floors are ground down to a smooth surface by stone discs mechanically operated. 1 part beeswax and 3 parts turpentine are well rubbed over the floors for high class polish. Cement paints are available which are water paints and can be applied to all cement or concrete surfaces and brickwork. Cement paints are supplied as powder to be stirred into water just before use. They are applied with distemper brushes.

Cement concrete floor can also be rendered with cement mortar (1:1) uniformly floated on. The rendering should be carried out after the concrete has been thoroughly rammed and has dried somewhat to allow the rendering to be worked up. The rendering is usually 1/4 in. thick. Cement rendering 3 in. thick (1:3) can also be done over a lime concrete surface or over brick floors.

**Curing:**—After the flooring is completed, the whole surface is covered with damp sacks or with 2 in. of wet
sand and kept wet for at least 10 days by sprinkling water at suitable intervals. This water curing not only helps to develop strength but resistance to weathering also. It also adds to the wear resisting qualities of concrete and therefore curing of concrete pavement is very important.

Method of cement concreting large areas:—Large areas of cement concrete are liable to crack, due to contraction during setting. Hence large floors are formed in a series of bays or sections, a convenient size being 5 ft. square concreted alternately.

For the joints between the sections or bays of cement concrete floors (made to prevent cracks) 1/16 in. hoop steel lining is generally used. The metal should be oiled to prevent adhesion of concrete. Teakwood or ebonite strips are also used; these wooden strips are also known as edge-boards or battens. The joints are kept so fine that it will suffice for them to be filled with fine sand. In hospitals (especially operation halls), the flat bars should be removed before the adjoining sections are commenced and strips of oiled paper substituted.

9. Timber floors:—These floors are not much used in India for ground floors. However, they are sometimes used for carpentry halls, ball rooms and dance halls, and are eminently suited for buildings on hill-stations or in localities where the climate is damp.

The area of the building below the ground floor constructed of timber is covered with an impervious material in order to exclude dampness. The material used may be either cement concrete or asphalt. Generally a 6 in. layer of good cement concrete is evenly spread, and spade-finished, i.e., the surface is beaten down, and smoothed over with the back of the spade. This layer of cement concrete
A suitable mix of concrete consists of 1 part Portland cement, 3 parts sand (fine aggregate) and 6 parts broken bricks or stone (coarse aggregate) of \( \frac{1}{2} \) in. gauge. Besides excluding dampness, surface concrete prevents the growth of vegetable and the admission of ground air. Before laying the surface concrete, care should be taken to see that all vegetable soil is excavated and removed.

Intermediate walls, called dwarf or sleeper walls, are then constructed on the surface concrete at suitable intervals to support the joists, called floor or bridging joists. The sleeper walls are usually \( \frac{3}{4} \) in. thick and are built at a maximum distance apart of 6 ft. The sleeper walls are intended to reduce the span for the joists, and their tops are made just below the floor level. On the top of the sleeper walls, longitudinal wooden members, called sleeper plates or sleeper wall plates (usually \( \frac{3}{4} \) in. by 3 in.), are solidly bedded level by means of lime mortar and the timber joists are nailed to these sleeper plates. All sleeper walls are honeycombed simply by omitting bricks during their construction to facilitate the circulation of air. The voids may be arranged haphazard, or by the two alternative forms shown in Figs. 1194 and 1195. All sleeper walls are provided with damp proof courses immediately below the sleeper plates.

The ends of the joists are made to rest upon the wall plates, and are fixed by driving nails through their sides.

1 Some authorities do not insist upon the provision of surface concrete. But its omission has been a frequent cause of dry rot, which is a virulent disease of timber. To prevent dry rot, only well-seasoned timber should be used and adequate ventilation should be provided. When timber is attacked by dry rot, the best remedy is to cut away the worn parts and then paint the remainder with a solution of copper sulphate.
into them. Housed, notched and caged joints may also be used for fixing the ends of the joists with wall plates.

Wall plates are lengths of timber, generally about 4 in. by 3 in. or 4½ in. by 3 in., which (a) serve as a suitable bearing for the joists, (b) afford a fixing for the ends of the joists, and (c) uniformly distribute the loads from the joists to the wall below. They are usually placed on offsets, which are formed by having the walls thicker below the ground floor (see Fig. 1196); the wall plates are solidly bedded level on lime mortar for the full length and width of the floor. Sometimes the wall plates and ends of the joists are built into the wall for purposes of economy; but this is an undesirable practice. Wall plates and sleeper plates are generally lengthened by means of a half lapped joint.
Ground floor wall plates are usually placed immediately over the horizontal damp proof course as shown in Fig. 1196.

The bridging joists are usually placed at 12 to 16 in. centres, and are fixed across the shortest span. The sizes of the joists depend upon the loads they have to carry. A rough rule for determining the size of joists is given before. The sizes given in Table No. 18 will satisfy the requirements of most building bylaws. After the joists have been carefully fixed and levelled with their upper edges in the same plane, 1 in. thick (usually tongued and
grooved) boards are fixed over the joists by means of nails. Before fixing the floor boards, care should be taken to see that the site concrete is free from debris, etc.

Sometimes the floors are laid in two thicknesses. The bottom or first covering, called sub-floor or counter-floor, consists of \( \frac{1}{2} \) in. roughly sawn square edged boards laid diagonally across the joists and the top covering consists of \( \frac{1}{2} \) to 1 in. boards fixed at right angles to the joists. The timber floors thus formed are called double boarded-floors or double floors. These floors are sometimes used for factories and workshops where the floors are subjected to excessive wear.

On completion, timber floors are traversed or flogged, i.e., the floor boards are carefully levelled and rubbed smooth with glass-paper and finally oiled or waxed and polished.

1. The boards are usually fixed by means of an appliance known as a metal cramp. When a cramp is not available the boards may be laid folding thus: Two boards are laid and nailed at a distance apart a little less than three or four boards. These are then put into the space and forced home by laying a plank upon them and jumping upon it. See Fig. 1197.
Timber ground floors are subject to rot unless proper precautions are taken to keep the timbers dry and well ventilated. To attain this, only well seasoned timber is used and surface concrete and damp proof courses are provided carefully as described above; further, the hollow space between the ground floor and the surface concrete is properly ventilated by providing openings below floor level in the external walls, generally about 9 in. by 9 in. with special air-bricks built in on the outside face of the wall. Cast iron ventilating grates may also be used instead of air-bricks.

In Fig. 1196 are shown the various details of a timber ground floor.

UPPER FLOORS

Upper Floors:—The following types of upper floors are ordinarily used in India:—

1. Timber floors.
2. Floors of steel joists, flagstones and concrete.
3. Brick or concrete jack arch floors.
4. Filler joist floors.
5. Hollow clay block floors.
7. Pre-cast R. C. C. beam or slab floors.

1. Timber floors:—Timber floors used for upper floors are usually classified into three classes, viz., (a) Single floors, (b) Double floors and (c) Framed floors. Single floors consist of only one set of joists called floors joists, common joists or bridging joists. In double floors, additional and larger joists, called binders, are introduced at suitable intervals to support the bridging joists. Framed floors
consist of three sets of joists, i.e., bridging joists which transmit the load to binders, which are in turn framed into and supported at suitable intervals by much larger joists, called girders. In all types of timber floors, the floor boards rest directly on the bridging joists.

Timber floors should be strong and rigid enough to bear the loads. The strength of a member indicates its capacity to carry a load without over-stressing the material, whereas its rigidity relates to its capacity for resisting deflection or sag under a load. Floors which are not strong enough will yield under loads by failure in the material, and floors which are not rigid enough will vibrate as people walk on them; hence such floors are unsuitable for use.

The spacing of bridging joists varies from 12 to 16 in. centres and 1 in. thick floor boards are usually laid upon them. The floor boards are usually tongued and grooved; various forms of end (or heading) and longitudinal joints used for floor boarding are described elsewhere. The bridging joists should be strong and stiff enough to bear the load in a satisfactory manner. Their sizes should be calculated on the basis of the total load to be supported and the span. The approximate depth of bridging joists is determined with the aid of the following formula:

\[
\text{Depth of bridging joists} = \left(\frac{\text{Span in ft.}}{2} + 2\right) \text{ inches.}
\]

The width of the bridging joists varies from 2 to 3 in. The sizes of bridging joists for various spans are given in Table No. 18.

(a) Single floors:— These floors are made by fixing floor boards to bridging joists which are spaced at 12 to 16 in. centre to centre as already stated
(see Figs. 1198 & 1199). The bridging joists are placed across
the shortest span, and the span for single floors is limited to 12 feet. The ends of the bridging joists are placed on the wall plates and are fixed by driving nails through their sides into them. Housed, notched and cogged joints are sometimes used for fixing the ends of joists with wall plates. Always it is a better practice to place the wall plates on specially built offsets as shown in Fig. 1106. The wall plates are usually bedded in mortar on the offsets. If the wall plates and ends of the joists are built into the wall, it is necessary to form an air space round the sides and tops of the joists (see Fig. 1200); and the wall plates and ends of the joists should be either charred, tarred or creosoted to prevent rot from contact with wet brickwork. Built-in timber should, however, be avoided wherever possible.

Fig. 1106.
A single floor.
Single floors are economical and easy to construct. As all the bridging joists of the single floors are made to rest directly on the load bearing walls, the floor load is uniformly distributed on the walls. But the ceilings, fixed to the underside of the bridging joists, are liable to crack. Single floors allow the passage of sound from floor to floor, and are unsuitable for large spans.

**Strutting** — When the span of the bridging joists is more than 8 feet, the joists are cross braced or struttoed in continuous rows at intervals not exceeding 6 ft. apart in order to prevent the joists buckling and also to prevent vibration, and to stiffen the floor. Joists are usually deeper in section as compared to their width, and such deep joists have a tendency to twist or tilt sideways; this defect may be prevented by providing strutting or cross bracing. There are two forms of strutting, viz., *herring-bone strutting* and *solid strutting*.

**Herring bone strutting.** (Figs. 1201 to 1204) — This is unquestionably the best form, and is formed by pieces of timber, about 2 in. by 1½ in., crossing each other between the bridging joists as shown. The ends of the timber pieces or struts are splayed and secured to the sides of the joists by means of one 2½ in. nail at each end. The ends of the struts are generally kept about ¾ to ½ in. from the top and bottom of the joists respectively. Usually short saw cuts are made at the ends of the struts to receive the nails to avoid the nails splitting the struts; but this practice reduces the holding power of the nail to a considerable scale and hence it should be avoided as far as possible. Sometimes folding wedges are driven in between the wall and the adjacent joist, and in line with the strutting, to give more stiffness to the flooring.
Figs. 1201 to 1204.

Showing the details of herring bone strutting.
Solid strutting (Figs. 1205 and 1206):—In this type, short pieces of timber are inserted between the joists in a continuous row, and these are secured to the sides of the joists by means of nails. This form is quite ineffective and is frequently adopted for cheap work. The pieces of timber are about 1 in. less than the depth of the bridging joists, and from 1 to 1½ in. thick. In superior work, a long steel or wrought iron bolt, about ½ to 1 in. in diameter, is passed through the centre of the depth of the whole joists in contact with the struts, and the nut is screwed up very tightly after the struts have been properly fixed. This type of strutting is not as sound in action as the previous one (herring bone strutting) since the struts tend to become loose by shrinkage in the course of time; for this
reason this form is now seldom adopted. Fig. 1206 shows a single floor with ceiling fixed to the underside.

(b) Double floors:—These are used where the span is between 12 feet and 24 feet. In double floors the bridging joists, instead of spanning from wall to wall, are supported by large horizontal members, called binders, at suitable intervals, and the bridging joists carry the floor boards. These binders are usually spaced at 6 to 8 ft. centres, and rest on concrete or stone templates of sufficient length and depth embedded in the walls. The binders are placed across the shortest span in order that their dimensions may be kept down to a minimum, and the bridging joists are placed at right angles to the binders and fixed in the direction of the longest span. The bridging joists are usually cogged to the binders as shown in Fig. 1207; the depth of the sinking should not exceed two-thirds the depth of the bridging joists and their bearing need not exceed 1 in. In another method, the ends of the bridging joists are cut and timber pieces, called fillets, are provided along the two sides of the binders to support the joists, (see Fig. 1208) this is a better method...
as no part of the binders is weakened by notching. Details of a double floor are shown in Figs. 1213 and 1214.

![Diagram of double floor structure]

**Fig. 1213.**
Section through bridging joists of double floor

**Fig. 1214.**
Section binder of double floor

In fixing the positions of the binders, care should be taken to see that no binder comes immediately above a
window or door opening or other opening where the wall is weak; but if this is not possible, the binders should be made to rest on specially built pilasters between the openings. Provision should be made for a free circulation of air round the ends of the bridging joints and binders, and the wall plates and the ends of the joists and binders should be either charred, tarred or creosoted to prevent rot from contact with wet brickwork.

The binders may be made of steel, R. C. C., wood or wood with a steel flitch. Timber and timber-flitched binders are now rarely used. Steel and R. C. C. binders are in every way satisfactory and economical, and are extensively used for large spans and for supporting heavy loads.

1 Flitched binders or beams: A flitched binder or beam is made thus: A large wooden horizontal member is cut longitudinally in half and reversed so that the hardwood portion lies on the outside and then the two halves or flitches are bolted together carefully (see Figs. 1209 and 1210). Flitched beams are stronger than timber beams.

---

Figs. 1209 and 1210.
Steel flitched binder in section and elevation.

Steel flitched binders or beams: A steel flitched binder or beam is formed by inserting a steel plate depthwise between two timber halves or flitches, and the three pieces are bolted together as...

(see next page)
Double floors are stiffer than single floors, and prevent the passage of sound better. Plaster ceilings, fixed to the under-side of the binders, are not liable to crack. If the walls consist of many an opening, double floors provide a sound construction, since the binders could be made to rest on the specially built pilasters between the openings and thus leaving weak portions of the walls free from load; but this increases the cost of the building. The binders throw the entire load of the floor on the walls at a few points only, and thus the floor load is not evenly distributed on the walls. Double floors require additional labour and material, and this increases the cost of the building. The increased depth of the flooring also reduces the available head-room. Alternatively, the height of the walls may be increased suitably for a fixed head-room, but this item involves extra labour and cost.

(See previous page)

Intervals of about 2 ft. The steel plate is made slightly less than the depth of the timber and the breadth sufficient to make up the required deficiency in the resistance of the timber. A steel flitched beam is shown in Figs. 1211 and 1212.

Steel flitched binder in section and elevation.
(c) Framed or Triple floors:—(Figs. 1215 to 1217); When the span is more than 24 ft. and the superimposed (live) load is relatively heavy, framed or triple floors are employed. In framed floors, the binders are supported at suitable intervals by large and heavy joists, called girders; thus framed floors consist of three sets of joists, viz., bridging joists, binders or binding joists and girders. The bridging joists carry the floor boards as usual. The ends of the girders are placed on stone or concrete templates embedded in walls. The binders are generally framed into the girders to increase the rigidity of the floor and also to avoid the loss of head-room and to minimise the height of the building; the
framing is usually effected by means of a tusk tenon joint which is described in detail elsewhere.

Fig. 1216.
Section through binder of framed floor.

Fig. No. 1217.
Section through rolled steel girder of framed floor.
The binders should be framed at a sufficient distance apart in a staggered fashion as shown in Fig. 1215. The ends of the binders are sometimes supported by iron stirrups which are secured to the girders by means of bolts. To obtain maximum stiffness, the breadth of the girders should be five-sevenths of the depth. The ends of all timbers set in masonry should have a space of 1/4 in. left on both sides to permit free circulation of air; they should also be either charred, tarred or creosoted to prevent rot. The floors should be made high up in the centre by about 1 in. per 20 ft. to allow for subsequent settlement which is likely to take place. The girders are usually spaced at 10 ft. centre to centre. The sizes of the girders are calculated as simple beams.

Girders and binders are now made of mild steel, and this metal has largely superseded timber as a material for binders and girders.

Trimming.—Where openings in floors are required either for fire places or staircases, the bridging joists cannot be supported at both ends by the walls, and hence it is necessary to introduce additional horizontal wooden members to receive the ends of the joists which have to be cut. This operation is called trimming. A trimmed opening for a fire place is shown in Fig. 1198. The opening has a thick joist, called a trimming joist, which is 1 ft. 6 in. from the fire place and spans the full width of the room. The trimming joist supports two cross joists called trimmer joists, which in their turn support two pairs of short joists called trimmed or tail joists. The trimming and trimmer joists are made thicker than the bridging joists on account of the greater weight which they have to carry. As a rule, the thickness of the trimming and trimmer joists shall be 1 in. greater than that
of the bridging joists. Either tusk tenon joint or dove-tailed, housed or notched joint is generally adopted for the connection between the trimmer and trimming joists. These joints are described in detail in the chapter on "Carpentry".

An alternative arrangement of framing timbers about a fire place opening is illustrated in Fig. 1218. In this arrangement of framing, two trimming joists support a trimmer joist, and the latter in its turn supports four trimmed joists.
(291)

In Fig. 1219 is shown the framework generally provided around a stair well.

![Diagram of framework around a stair well]

Fig. No. 1219.
Framework around a stair well

**Floor ceilings** — Ceilings are provided to the underside of the floors to improve their appearance from below and also to prevent the passage of sound from floor to floor. The ceilings are usually ½ to ¾ in. thick and are made either of planks or of (wood or metal) laths and plaster, or of special plaster boards. A ¾ in. teakwood ceiling is frequently fixed to the underside of the floor. The various methods generally used for fixing the ceilings are briefly described below.
1. In the first method:— The ceiling boards are directly fixed to the underside of the bridging joists by means of nails (see Fig. 1220). This method is the simplest and cheapest; but the flooring with this type of ceiling is not sufficiently soundproof, and the ceiling is liable to crack or open at joists due to vibration. Ceiling formed in this way is called "closed ceiling".

Sometimes wood laths are nailed to the underside of the bridging joists at 3/8 in. apart. The wood laths are generally about 1/4 in. thick, 7/8 in. wide and 3 ft. long. Metal lathing (cut sheets of galvanised steel) may also be fixed to the joists instead of wood laths. Three coats of plaster are then carefully applied to give a finished thickness of about $\frac{1}{8}$ in.
2. **In the second method**, pieces of timber, called *fillet pieces or fillets* (which are usually about \( \frac{1}{2} \) in. square) are nailed to the sides of the bridging joists, and the lathing is nailed to the fillets from below as shown in Fig. 1221. Two or three coats of plaster are then applied to the lathing to get a finished thickness of \( \frac{1}{2} \) in. The ceiling thus constructed is called "open ceiling."

Instead of laths and plaster, planks or specially made plaster boards or slabs may be used. For this purpose, grooves are cut in the sides of the bridging joists and the ceiling planks or boards are inserted in them, as illustrated in Fig. 1222. The lower arises of the bridging joists may be chamfered or otherwise moulded.

3. **In the third method**, every third or fourth bridging joist is made deeper than the others, and to these...
are fixed small horizontal pieces, called **ceiling joists**. The ceiling is then fixed to the underside of the ceiling joists as shown in Fig. 1223. The flooring with this type of ceiling is more sound-proof, but this method is costly and the flooring becomes thicker.

4. **In the fourth method**, small horizontal pieces of timber called **ceiling joists**, are fixed to separate beams called **ceiling beams** (see Fig. 1224), and the ceiling is completely independent of the members which support the floor. The ceiling joists run at right angles to the bridging joists and ceiling beams. Ceiling planks are then fixed to the underside of the ceiling joists. Lath and plaster may also be used instead of ceiling planks. This type of construction is much sound-proof, but very costly. The ceiling constructed in this way is known as **independent ceiling**.

5. **In the fifth method**, the ceiling joists are fixed to the underside of the binders by cutting notches in the binders, and the ceiling is then fixed to their underside as shown in Figs. 1213, 1215, 1216 and 1217. Alternatively, the ceiling joists may be fixed with the aid of parallel **filar pieces**, usually about 2 in. by 1½ in., driven along the sides of the binder as shown in Fig. 1214. This is the best method as no part of the binder or joist is weakened by notching. The ceiling may be of ceiling boards, or of special plaster boards, or of lath and plaster as required.

**Pugging**—The chief drawbacks of the timber floors are that they are inflammable and are not sufficiently sound-proof. Many a method is adopted to make the timber floors sound-proof. **Pugging** is one of the several methods used for preventing the passage of sound waves through timber floors, and it consists in filling a coarse plaster (which is a mixture of mortar and chopped straw).
called pugging plaster, on special supports provided for the purpose at a lower level by the side of the bridging joists, as shown in Fig. 1225. On each side of the bridging joists, fillet pieces, usually about 2 in. by 1 ½ in., are fixed by nails for supporting the sound or insulating boards to carry the pugging. Since the object of providing pugging is to absorb and deaden the sound waves, materials like sawdust, coke breeze concrete, asbestos, silicate cotton, cork, fibrous plaster and slag wool are also used instead of pugging plaster. The only disadvantage of pugging method is that it prevents the access of air to the interior of flooring and hence the flooring is liable to rot.

Various types of plaster boards and wall boards are now available in the market which are claimed to have high absorbing powers. Wall boards are sheets of wood fibre (shavings) which are cemented together under great pressure; the wall boards are usually ⁴⁄₅ to 1 in. thick, 3 to

1 Slag wool is a very light fibrous fire-proof material, which is produced by the blowing of steam through molten blast-furnace slag. Slag wool has a high sound-absorbing power.
<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Kind of timber</th>
<th>Weight of timber per yd. in.</th>
<th>Tensile stress in bending ft./sq.in.</th>
<th>Shear stress in lb./sq.in.</th>
<th>Compressive stress in lb./sq.in.</th>
<th>Acting grain</th>
<th>Perpendicular to grain</th>
<th>Modulus of Elasticity in grains</th>
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</thead>
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<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7)</td>
<td>(8)</td>
<td>(9)</td>
</tr>
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<td>1.</td>
<td>Piri, Partal</td>
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<td>85</td>
<td>120</td>
<td>850</td>
<td>230</td>
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<td>270</td>
<td>315</td>
<td>1600</td>
<td>920</td>
<td>1240 000</td>
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<td>1850</td>
<td>130</td>
<td>180</td>
<td>1200</td>
<td>520</td>
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<td>4.</td>
<td>Toon</td>
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<td>Deodar</td>
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<td>145</td>
<td>1100</td>
<td>280</td>
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<tr>
<td>6.</td>
<td>Walnut, Akhrot</td>
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<td>170</td>
<td>950</td>
<td>320</td>
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<td>1100</td>
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<td>129</td>
<td>800</td>
<td>240</td>
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<td>900</td>
<td>280</td>
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<td>54</td>
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<td>190</td>
<td>225</td>
<td>1050</td>
<td>1130</td>
<td>1900 000</td>
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<tr>
<td>13.</td>
<td>Bijaval</td>
<td>50</td>
<td>2100</td>
<td>133</td>
<td>186</td>
<td>1200</td>
<td>580</td>
<td>1460 000</td>
</tr>
<tr>
<td>14 (a)</td>
<td>Sal ( M. P. )</td>
<td>50</td>
<td>2400</td>
<td>133</td>
<td>196</td>
<td>1500</td>
<td>650</td>
<td>1800 000</td>
</tr>
<tr>
<td>14 (b)</td>
<td>Sal ( Bengal, U. P. )</td>
<td>55</td>
<td>2850</td>
<td>180</td>
<td>260</td>
<td>1900</td>
<td>1160</td>
<td>2040 000</td>
</tr>
<tr>
<td>15 (a)</td>
<td>Teak ( M. P. )</td>
<td>39</td>
<td>2000</td>
<td>140</td>
<td>200</td>
<td>1250</td>
<td>570</td>
<td>1340 000</td>
</tr>
<tr>
<td>15 (b)</td>
<td>Teak (Burma, Malabar)</td>
<td>42</td>
<td>2200</td>
<td>140</td>
<td>200</td>
<td>1500</td>
<td>630</td>
<td>1600 000</td>
</tr>
<tr>
<td>16.</td>
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<td>50</td>
<td>1750</td>
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<td>130</td>
<td>1030</td>
<td>740</td>
<td>1100 000</td>
</tr>
<tr>
<td>17.</td>
<td>Sain</td>
<td>55</td>
<td>2200</td>
<td>140</td>
<td>210</td>
<td>1350</td>
<td>780</td>
<td>1280 000</td>
</tr>
</tbody>
</table>

1"Indian Forest Records" — The Forest Research Institute.
Different Kinds of Indian Timbers.

Explanation of the Table and Remarks.

Col. 3:— Is maximum fibre stress for design of beams and other tension members; Col. 4:— For design of beams; Col. 5:— For design of fastenings, bolts and dowel joints; Col. 6:— For design of short columns.

Remarks:—

(1) The strengths of the timbers given in the table provide for only ordinary good class having only minor defects. Where the timber is of exceptionally good quality or bad quality, the strengths should be increased or decreased accordingly.

(2) These are the recommended safe working stresses for inside locations where the timbers will remain continuously dry or protected from atmospheric influences and dampness. For works built in outside locations or where timbers are occasionally subjected to wetting and quick drying, the safe tensile stresses (Column 4) should be multiplied by 5/6 and safe compressive stresses (column 7) by 8/9. Where the timbers are in a continuously wet position, the safe working stresses should be multiplied by 2/3 and 8/11 respectively.

(3) Where the beams are subject to continuous heavy loading the value of Modulus of Elasticity (E) should be reduced by 75 to 50 per cent of the tabulated values or the beams should be calculated for lesser deflection than 1/360.

Dehra Dun.
4 ft. wide and 6 to 14 ft. long. Celotex, Insulite, Masonite, Tentex and Lloyd Board are examples of wall boards. Slabs of slag wool, slabs of coke breeze concrete and slabs of cork are also now available.

Design of timber floors — For this the bending moment\(^3\) (B. M. is calculated, assuming the member as simply supported.)

\[
B. \ M. = \frac{W l^4}{8}, \text{ where } W = \text{load (superimposed load} + \text{dead load)} \text{ in lbs. per sq. ft.}, \text{ and } l = \text{effective span in feet.}
\]

Also B. M. = \(f z\), where \(f = \text{safe working stress of timber in lbs. per sq. in.}\), and \(z = \text{modulus of section} = \frac{bd^3}{6}\) where \(b = \text{breadth in inches and } d = \text{depth or height in inches.}\)

In \(\frac{bd^3}{6}\), \(d\) should be within the limits of 1/18 to 1/24 of the span and the ratio between \(b\) and \(d\) should be such that \(d\) should be between 1.5 and 4 times \(b\). The safe working stresses for different kinds of timber are given in Table No. 19.

1 The bending moment (B. M.) at any section is the algebraic sum of the moments of all the external forces on either side of the section.
2 The minimum superimposed loads on floors, staircases, balconies, etc., are given in Table No. 3.
3 The dead load includes the weight per sq. ft. of the floor boards and the equivalent weight per sq. ft. of a bridging joist. The dead weight of the timber can be obtained from Table No. 1; the general figure taken for ordinary woods is 30 lbs. per cub. ft. and 45 lbs. per cub. ft. for hardwoods.
4 The stress to which a material may safely be subjected in actual practice is known as the "working stress". The working stress of a material is usually determined by dividing its ultimate strength by a factor, called factor of safety. Briefly, Working Stress = \(\frac{\text{Ultimate stress}}{\text{Factor of safety}}\)
Timber beams may deflect under load though they may be sufficiently strong to withstand the calculated bending moment. Hence they must always be calculated for deflection. Normally a deflection of \( \frac{L}{360} \) of the span is taken. The following formula is generally used for deflection:

\[
\delta = K \frac{Wl^4}{48EI}
\]

where \( \delta \) = Maximum deflection allowed,

\( K \) = A coefficient depending upon how the beam is supported and how it is loaded.

The values of \( K \) are given in Table No. 20,

**TABLE No. 20**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Condition of beam</th>
<th>Coefficient K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cantilever with load at free end</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>Cantilever with load uniformly distributed</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Beams supported at both ends (load at centre)</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Beams supported at both ends (load uniformly distributed)</td>
<td>5/8</td>
</tr>
</tbody>
</table>

\( W \) = Load in lbs.

\( l \) = Span in inches.

\( E \) = Modulus of elasticity in lbs. per sq. in.

\( I \) = Moment of inertia in inches\(^4\)

\( I = \frac{bd^4}{12} \) for rectangular beams.
ILLUSTRATE EXAMPLES ON DESIGN OF TIMBER FLOORS:

Illustrative Example 1:—Calculate the size of timber joists for a single floor to span a width of 12 feet with the following data:

Safe working stress in timber in tension = 2000 lbs. per sq. in.

—do— in compression = 1250 lbs. per sq. in.

Modulus of elasticity of timber = 136,000 lbs. per sq. in.

Permissible shear stress in timber = 140 lbs. per sq. in.

Deflection = 1/360 of the span.

Spacing of joists = 12 in. centre to centre.

Solution:—

(A) For domestic, hotel and hospital buildings:—

(a) Loads:

Superimposed load (live load) = 50 lbs. per sq. ft.
Dead load (joists and flooring) = 30 lbs. per sq. ft.

Total load = 80 lbs. per sq. ft.

Since the bridging joists are spaced at 12 in. centre to centre the load on each bridging joist is 80 lbs. per sq. ft.

(b) Bending moment and size of bridging joist:

If "L" is the effective span of the joist in feet, then the bending moment at its centre is:

\[ B.M. = \frac{Wl^2}{8} \]

1. See Table No. 3
For all ordinary purposes the width of the bridging joist is usually taken as 2 in. The required depth of the joist is then calculated as follows:—

B. M. = \( \frac{80 \times f^2}{8} \)

= 10 ft. lbs., or 10 \( \frac{ft.}{in.} \) \( \times 12 \)

= 120 \( \frac{lb.}{in.} \) ft. lbs.

\( B. M. = \frac{fz}{z} \) ; where \( f \) = working stress in lbs. per sq. in. = 2000 lbs. per sq. in.,

\( z \) = modulus of section in cub. in. = \( \frac{bd^3}{6} = \frac{2d^3}{6} \)

(\( b \) and \( d \), the breadth and depth in in.,

\( B. M. = \frac{fz}{z} = f \frac{bd^3}{6} \)

\( 120 \frac{lb.}{in.} = \frac{2000 \times 2d^2}{6} \)

\( 120 \frac{lb.}{in.} = \frac{2000}{3} \cdot d^3 \)

\( \therefore d^3 = \frac{120 \frac{lb.}{in.}}{2000} \times 3 = 0.18 \frac{lb.}{in.} \)

\( d = \sqrt[3]{0.18 \frac{lb.}{in.}} = 0.424 \) ft. in.

If \( l = 12 \) ft., then \( d = 0.424 \times 12 \) in.

= 5.088 in., say 5\( \frac{1}{4} \) in.

Therefore size of bridging joist = 5\( \frac{1}{4} \) in. by 2 in.

(c) Shear stress in bridging joists:—The design may be tested for shear. The load carried by each bridging joist = \( \frac{80 \times 12 \times 12}{12} \)

= 960 lbs. (the joists are spaced
at 12 in. centres). As half of this load is carried by each support, the shear stress in the joists near the support is—

Shear stress, \( S = \frac{3}{2} \times \frac{960}{2} \times \frac{1}{54 \times 2} = \frac{720}{11} \)

= 65.455 or 65 lbs. per sq. in.

This is less than the permissible value of shear stress for teakwood. The design may be further tested for deflection.

\[ \text{Note} :- \text{If the bridging joists are spaced at 15 in. centre to centre, then the total load on each joist} = \frac{15}{12} \times 80 = 100 \text{ lbs. per sq. ft.} \]

Depth of joist = \( \sqrt{\frac{15}{12} \times 0.424} \) \( \text{ft.} \)

= 1.0 \times 0.424 \times 12 \text{ in.}

= 5.629 in., say 6 in.

\( \therefore \) size of bridging joist = 6 in. by 2 in.

(B) For office, school and library buildings:

(a) \textbf{Loads}:

Superimposed load = 80 lbs. per sq. ft.\(^1\)
Dead load (joists and flooring) = 30 lbs. per sq. ft.
Total load = 110 lbs. per sq. ft.

The bridging joists are spaced at 12 in. centre to centre. Hence the total load on each joist is 110 lbs. per sq. ft.

(b) \textbf{Bending moment and size of bridging joist}:

\[ \text{B. M.} = \frac{Wl^2}{8} = \frac{110 \times l^2}{8} = 13.75 \frac{l^2}{8} \text{ ft. lbs.} \]

= 13.75 \( \frac{l^2}{8} \times 12 = 165 \frac{l^2}{8} \text{ in. lbs.} \)

\(^1\) See Table No. 3.
If a width of 2 in. is adopted for the bridging joists then the depth of the joists is—

\[ B. M. = f_\alpha = f \times \frac{6A^2}{6} \]

\[ 165 = 2000 \times \frac{165}{6} \]

\[ 165 = 2000 \times \frac{165}{12} \; \therefore \; d = 0.497 \; \text{in ft.} \]

If \( l = 12 \) ft., then \( d = 0.497 \times 12 \)

= 5.96 in., say 6 in.

\( \therefore \) size of bridging joist = 6 in. by 2 in.

Note:—If the bridging joists are spaced at 15 in. centres, then the total load on each joist = 15/12 \times 110 = 137.5 lbs. per sq. ft.

Depth of bridging joist = \( \sqrt{\frac{15}{12}} \times 0.497 \; \text{in ft.} \)

= 1.12 \times 0.497 \times 12

= 6.6768 in., say 7 in.

\( \therefore \) Size of bridging joist = 7 in. by 2 in.

Illustrative Example 2:

An office room measures 18 ft. by 16 ft.

Design a double floor for this room with the aid of the following particulars:—

Safe working stress in timber in tension = 1,200 lbs. per sq. in.

Safe working stress in timber in compression = 800 —do—
Modulus of elasticity of timber $= 10,00,000$ 
do-
Permissible shear stress in timber $= 120$ 
do-
Deflection $= 1/360$ of the span 
Spacing of joists $= 12$ in. centre to centre.

Check your design for deflection and shear.

Solution:—The office room in question measures 18 ft. by 16 ft. The span between the binders is usually kept at 6 to 8 feet. The problem may be solved in two cases as hereunder:

**Case 1:** If one binder is used centrally on the long walls, the office will be divided into two equal panels of 18/2 ft. by 16 ft. or 9 ft. by 16 ft. Thus the span of the bridging joists is 9 ft., and the joists are spaced at 12 in. centres.

(a) To determine the size of joists:

**Loads:**

Superimposed load $= 80$ lbs. per sq. ft.
Dead load (joists and floors) $= 30$ lbs. per sq. ft.
Total load $= 110$ lbs. per sq. ft.

**Bending moment:**

As the bridging joists are spaced at 12 in. centre to centre, the load on each joist is 110 lbs. per sq. ft.

$$\therefore B.M. = \frac{WL^2}{8} = \frac{110 \times 9}{8} = 13-75 \, \text{ft. lbs.}$$

$$= 13-75 \times 12 = 165 \, \text{in. lbs.}$$

**Size of joist:**—If a width of 2 in. is adopted for the bridging joist, then the depth of the joist is

$$B.M. = \frac{fx}{f} = f \times \frac{bd^3}{6}$$
(305)

\[ 165 l^2 = 1.200 \times \frac{2d^3}{6} \]

\[ d^3 = 165 l^2 \times \frac{3}{1200} \]

\[ = 0.4125 l^2 \]

\[ d = \sqrt[3]{0.4125 l^2} = 0.642 l \text{; in. ft.} \]

\[ \therefore d = 0.642 l = 0.642 \times 9 \]

\[ = 5.78 \text{ in.}, \text{ say 6 in.} \]

\[ \therefore \text{ size of bridging joist} = 6 \text{ in. by 2 in.} \]

Bld. 12

Note:—If the bridging joists are placed at 15 in. centres, then load on each joist = \( \frac{15}{12} \times 110 = 137.5 \text{ lbs. per sq. ft.} \)

Depth of the joist \( d = \sqrt{\frac{15}{12} \times 0.642 l \text{; in. ft.}} \)

\[ = 1.12 \times 0.642 \times 9 \]

\[ = 6.47 \text{ in.}, \text{ say 7 in.} \]

\[ \therefore \text{ size of joist} = 7 \text{ in. by 2 in.} \]

The design may be tested for shear stress and deflection in the usual way.

(b) To design the binder:

LOADS:

Load on each joist = 110 lbs. per sq. ft. (already determined).

\[ \therefore \text{ Total load on each joist} = \text{ span in ft.} \times \text{ load in lbs. per sq. ft.} \]

\[ = 9 \times 110 = 990 \text{ lbs.} \]

B.C.—20
Since the bridging joists are spaced at 12 in. centres in the space of 16 ft., there will be 16 joists in each panel.

\[ \text{total load on 16 joists in two panels} = 16 \times 990 + 16 \times 990 = 31,680 \text{ lbs.} \]

Half of this load is taken up by the supporting wall, and the other half is supported by the binder. Thus the load to be supported by the binder \( \frac{31,680}{2} = 15,840 \text{ lbs.} \)

Assuming a size of 12 in. by 8 in. of timber binder,

\[ \text{safe load of binder} = \frac{12}{12} \times \frac{8}{12} \times 16 \times 50 \text{ (weight of 1 cub. ft. timber is taken as 50 lbs.)} \]

\[ = 533.33 \text{ lbs., say 534 lbs.} \]

Total load = 15,840 lbs. + 534 lbs.

= 16,374 lbs.

**Bending moment and size of binder:**

As the bridging joists are spaced at 12 in. centres, the total load of 16,374 lbs. may be taken as uniformly distributed on the binder.

\[ \text{Maximum Bending Moment} = \frac{WL}{8} = \frac{16,374 \times 16 \times 12}{8} \text{ in. lbs.} \]

\[ = 392,976 \text{ in. lbs.} \]

\[ \text{B. M.} = fx; f = 1200 \text{ lbs. per sq. in. and } z = \frac{bd}{6} \]

\[ 392,976 = \frac{1200 \times \frac{bd^3}{6}}{6} \]
It is necessary to note that the width of the binder should not be less than 5 in. While specifying the size of a binder, the ratio between its width and depth should be kept between $\frac{1}{2}$ and 3 as far as possible.

If

1. $b = 8\text{ in.}$, and $d = 12\text{ in.}$, $bd^2 = 8 \times 12 \times 12 = 1152 \text{ in.}^3$
2. $b = 8\text{ in.}$, and $d = 13\text{ in.}$, $bd^2 = 8 \times 13 \times 13 = 1352 \text{ in.}^3$
3. $b = 8\text{ in.}$, and $d = 14\text{ in.}$, $bd^2 = 8 \times 14 \times 14 = 1568 \text{ in.}^3$
4. $b = 8\text{ in.}$, and $d = 15\text{ in.}$, $bd^2 = 8 \times 15 \times 15 = 1800 \text{ in.}^3$
5. $b = 8\text{ in.}$, and $d = 16\text{ in.}$, $bd^2 = 8 \times 16 \times 16 = 2048 \text{ in.}^3$
6. $b = 8\text{ in.}$, and $d = 17\text{ in.}$, $bd^2 = 8 \times 17 \times 17 = 2312 \text{ in.}^3$
7. $b = 9\text{ in.}$, and $d = 15\text{ in.}$, $bd^2 = 9 \times 15 \times 15 = 2025 \text{ in.}^3$
8. $b = 9\text{ in.}$, and $d = 16\text{ in.}$, $bd^2 = 9 \times 16 \times 16 = 2304 \text{ in.}^3$

From the above sizes it is seen that 16 in. by 8 in. section is sufficient to resist the bending moment. But the section should be checked both for deflection and shear stress.

**Test for deflection:**

Maximum deflection allowed $= \frac{l}{360} = K \cdot \frac{Wl^3}{48EI}$,

where $l = 16\text{ ft.}$, $K = 5.8\text{ ft.}$, $W = 16374\text{ lbs.}$, $E = 100000000$

and $l = \frac{bd^2}{12}$,

$$bd^2 = \frac{360 \times 5 \times 16374 \times 16 \times 16 \times 12 \times 12}{16 \times 8 \times 48 \times 1000000}$$

$$= \frac{33953125600}{1000000} = 339531.256, \text{ say 33954.}$$
If

(1) \( b = 8 \text{ in.}, \) and \( d = 16 \text{ in.}, \) \( bd^3 = 32768 \) which is less than 33954.

(2) \( b = 8 \text{ in.}, \) and \( d = 17 \text{ in.}, \) \( bd^3 = 39304 \) which is greater than 33954.

(3) \( b = 9 \text{ in.}, \) and \( d = 16 \text{ in.}, \) \( bd^3 = 36864 \) which is greater than 33954.

Hence 8 in. by 17 in. is a suitable size and not 8 in. by 16 in. for the binder. The 9 in. by 16 in. binder. \((9 \times 16 = 144 \text{ sq. in.})\) would cost a little more than the 8 in. by 17 in. binder and be less stiff.

Test for shear stress:

Total shear at ends = \( \frac{16,374}{2} = 8,187 \) lbs.

\[ \text{Shear stress} = \frac{3}{2} \times \frac{8,187}{8 \times 17} = 90.3 \text{ or } 91 \text{ lbs. per sq. in.} \]

which is less than the permissible value (as per problem, the permissible shear stress in timber = 120 lbs. per sq. in.).

(c) To design the bed blocks to support the binders on walls:

Total load on the binder (including self load) = 16,374 lbs.

\[ \text{load at one end of the binder} = \frac{16,374}{2} = 8,187 \text{ lbs.} \]

\[ = \frac{8,187}{2,240} \text{ or } 3.655 \text{ Tons.} \]
As a rule, the bed block should be for the full width of the wall. Assuming the width of the wall is 1 ft. 6 in., the size of the bed block will be 1 ft. 6 in. by 1 ft. 6 in. The bed block may be either of cement concrete or of cutstone.

Stress on the wall = \( \frac{\text{load}}{\text{area}} = \frac{3.655}{1.5 \times 1} \)

= 2.44 tons per sq. in. which is quite safe.

Assuming that the binder rests for a length of 9 in. on each bed block.

Bearing stress = \( \frac{\text{load}}{\text{area}} \) = 9 in. by 9 in. (see the size of binder).

\[
\frac{8167}{9 \times 9} = \frac{101}{1} \text{ lbs. per sq. in.}
\]

Results:
Size of joists (required no. of joists = 16) = 6 in. by 2 in.
Size of binder (required no. of binder = 1) = 17 in. by 8 in.
Size of bed block (width of wall 1 ft. 6 in.) = 1 ft. 6 in. by 1 ft. 6 in.

Case 2: If two binders are used on the long walls, the office room will be divided into three equal panels of 18/3 ft. by 16 ft. or 6 ft. by 16 ft. The bridging joists are spaced at 12 in. centres, and their span is 6 ft.

(a) To determine the size of bridging joists:

Loads:
Superimposed load = 80 lbs. per sq. ft.
Dead load (joists and flooring) = 30 lbs. per sq. ft.

Total load = 110 lbs. per sq. ft.
Since the joists are spaced at 12 in. centres, the load on each joist = 110 lbs. per sq. ft.

\[ \text{B. M.} = \frac{Wl^2}{8} = \frac{110l^2}{8} \]

\[ = 13.75 \text{ ft. lbs.} \]

\[ = 13.75 \times 12 = 165 \text{ in. lbs.} \]

**Size of joist:**

If a width of 2 in. is used for the joist, the depth of joist is

\[ \text{B. M.} = f_x = \frac{bd^4}{6} \]

\[ 165 \times 1200 \times \frac{2d^4}{6} \]

\[ d^2 = 0.4125 \]

\[ d = 0.642 \text{ ft.} \]

\[ \therefore \text{Depth of joist} = 0.642 \times 6 = 3.85 \text{ or 4 in.} \]

\[ \therefore \text{Size of bridging joist} = 4 \text{ in. by 2 in.} \]

The design may be checked for shear and deflection as usual.

**(b) To design the binders:**

**Loads:**

Total load on each joist = span in ft. \times load in lbs. per sq. ft. = 6 \times 110 = 660 lbs.

As the joists are spaced at 12 in. centres in the space of 16 ft., there will be 16 joists in each panel of 6 ft. by 16 ft.

\[ \therefore \text{Total load on 16 joists in one panel} = 16 \times 660 \text{ lbs.} = 10,560 \text{ lbs.} \]
(311)

Assuming a size of 12 in. by 8 in. of timber binder,

\[ \text{safe load of binder} = \frac{12}{12} \times \frac{8}{12} \times 16 \times 50 \]

\[ = 533.33 \text{ or } 534 \text{ lbs.} \]

\[ \therefore \text{Total load on the panel floor} = 10,560 + 534 = 11,094 \text{ lbs.} \]

B. M. and size of binders:

As the joists will be placed at 12 in. centres, the load may be taken as uniformly distributed.

\[ \text{Max. B. M.} = \frac{Wl}{8} = \frac{11,094 \times 16 \times 12}{8} \text{ in. lbs.} \]

\[ = 266,256 \text{ in. lbs.} \]

B. M. = \( fz = f \times \frac{bd^3}{6} \)

\[ 266,256 = 1,200 \times \frac{bd^3}{6} \]

\[ \frac{bd^3}{6} = \frac{266,256}{1,200} \]

\[ = 133.128 \text{ or } 133.12 \text{ in.?} \]

If (1) \( b = 8 \text{ in.}, \) and \( d = 12 \text{ in.}, \) \( bd^3 = 1,152 \text{ in.}^3 \)

(2) \( b = 8 \text{ in.}, \) and \( d = 13 \text{ in.}, \) \( bd^3 = 1,352 \text{ in.}^3 \)

(3) \( b = 8 \text{ in.}, \) and \( d = 14 \text{ in.}, \) \( bd^3 = 1,568 \text{ in.}^3 \)

(4) \( b = 8 \text{ in.}, \) and \( d = 15 \text{ in.}, \) \( bd^3 = 1,800 \text{ in.}^3 \)

For resisting bending moment 8 in. by 14 in. seems to be the most economical size for the binder. But let us check this section for deflection.

Test for deflection:

\[ \text{Deflection} = \frac{l}{360} = K \frac{Wl^3}{48EI} ; I = \frac{bd^3}{12} ; K = \frac{5}{8} \]
If \( b = 8 \text{ in.} \) and \( d = 14 \text{ in.} \), \( bd^2 = 21,952 \) which is less than 23,005, and hence this size is not suitable.

If (1) \( b = 8 \text{ in.} \) and \( d = 15 \text{ in.} \), \( bd^2 = 27,000 \) which is greater than 23,005.

(2) \( b = 7 \text{ in.} \) and \( d = 15 \text{ in.} \), \( bd^2 = 23,625 \) — Do —

(3) \( b = 7 \text{ in.} \) and \( d = 16 \text{ in.} \), \( bd^2 = 28,672 \). — Do —

7 in. by 15 in. (sectional area 105 sq. in.) is the most economical size, but it is better to use the 7 in. by 16 in. size. The 8 in. by 15 in. binder (sectional area = 120 sq. in.) is a little costlier than the 7 in. by 16 in. binder (sectional area = 112 sq. in.) and is not as stiff as the latter. Hence 7 in. by 16 in. is the most suitable size for the binder and not 8 in. by 14 in.

**Test for shear Stress:**

The above section may now be tested for shear stress.

Total shear at ends \( = \frac{11094}{2} = 5547 \text{ lbs.} \)

\[
\therefore \text{Shear stress} = \frac{3}{2} \times \frac{5547}{7 \times 16} = 74.3 \text{ or } 75 \text{ lbs. per sq. in.}
\]

This is less than 120, and hence it is quite permissible.

The design of bed blocks for each binder is then made on the same lines as given above for a single binder.
Illustrative Example 3.—Design a first class Malabar teakwood beam to support a uniformly distributed load of 500 lbs. per foot run over a span of 20 feet. Take deflection \( l/360 \) span.

Solution.—(necessary data taken from table No. 19).

Load on beam per running foot = 500 lbs.

\[ \text{Total load on a 20 ft. beam} = 20 \times 500 = 10,000 \text{ lbs.} \]

Assuming a size of 8 in. by 12 in. of the binder,

\[ \text{Safe load} = \frac{8}{12} \times 12 \times 20 \times 42 = 560 \text{ lbs.} \]

\[ \text{Total load} = 10,000 + 560 = 10,560 \text{ lbs.} \]

In the problem it is given that the load is uniformly distributed.

\[ \text{Max. B. M.} = \frac{Wl}{3} = \frac{10,560 \times 20 \times 12}{8} = 316,800 \text{ in. lbs.} \]

\[ \text{B. M.} = f_z = f \times \frac{bd^2}{6} \]

\[ 316,800 = 2300 \times \frac{bd^2}{6} \]

\[ bd^2 = 316,800 \times \frac{6}{2300} = 626.43 \text{ or 627 in.}^3 \]

If (1) \( b = 8 \text{ in. and } d = 12 \text{ in.}, bd^2 = 1152 \text{ in.}^3 \)

(2) \( b = 8 \text{ in. and } d = 11 \text{ in.}, bd^2 = 968 \text{ in.}^3 \)

(3) \( b = 7 \text{ in. and } d = 11 \text{ in.}, bd^2 = 847 \text{ in.}^3 \)

For resisting B. M. 7 in. by 11 in. seems to be the most economical size. But it should be checked for both deflection and shear stress.
Test for deflection:—

Deflection = \( \frac{5}{360} = K \cdot \frac{Wt^4}{48EI} \); \( I = \frac{bd^4}{12} \); \( K = \frac{5}{360} \).

\[ b_d^2 = \frac{360 \times 5 \times 10,560 \times 20 \times 20 \times 20 \times 12 \times 12 \times 12}{20 \times 8 \times 48 \times 1,560,000} \]

\[ = \frac{85,536}{4} = 21,384. \]

If \( b = 7 \) in. and \( d = 11 \) in., \( bd^2 = 9,317 \) which is much less than 21,384.

If (1) \( b = 8 \) in. and \( d = 11 \) in., \( bd^2 = 10,648 \) which is less than 21,384.

(2) \( b = 8 \) in. and \( d = 14 \) in., \( bd^2 = 23,952 \) which is greater than 21,384.

Hence \( 8 \) in. by 14 in. is a suitable size and not 7 in. by 11 in.

Test for shear stress:—

Total shear at ends = \( \frac{10,560}{2} \)

\[ = 5,280 \text{ lbs.} \]

\[ \therefore \text{Shear stress} = \frac{3}{2} \times 5,280 \times \frac{1}{8 \times 14} \]

\[ = 70.7 \text{ or } 71 \text{ lbs. per sq. in. which is less than } 140 \text{ lbs. per sq. in. permissible for Malabar Teak.} \]

Fire-resisting floors:—Timber is inflammable and hence it cannot be specified for construction when fire-resisting properties of building have to be mainly attended to. Similarly when heavier loads and larger spans have to be dealt with in a design, steel and cement concrete are extensively used on account of their strength and the
consequent smaller sections. In such cases, the timber sections become very heavy and costly; for this reason, apart from its susceptibility to catch fire, the use of timber is limited to a certain extent in modern buildings.

In modern practice steel is used in many a form in combination with cement concrete. Floors constructed with steel and concrete are durable and resist fire better. These floors are also rigid and carry heavy loads satisfactorily. Floors are also constructed with steel sections, flagstones and cement concrete, these floors are also rigid and bear heavy loads in a satisfactory manner. Sometimes clay products such as bricks of different shapes, generally hollow and specially moulded for the purpose, are used with steel and concrete in many proprietary floors.

Various types of fire-resisting floors, generally used in India, are briefly described in the following pages:

2. Floors of steel joists, flagstones and concrete:

An example of this type is illustrated in Fig. 1226. In this

![Fig. 1226. Double flagstone flooring.](image-url)
type, if the span between the walls is small, say up to 12 ft., rolled steel joists of suitable section are placed on the walls at a spacing of 12 to 8 in., centre to centre. If the span is more than 12 ft., rolled steel beams of the required section are placed below the steel joists to support the joists. The beams run at right angles to the joist and the ends of them are placed on bed blocks embedded in masonry as shown. The beams are generally spaced at 6 to 10 ft. centres. The spaces between the joists are then filled in thus: Flagstones, about 1/4 in. thick and of widths to suit the distance apart between the joists, are inserted from one end and placed on the lower flanges of the steel joists. The portions above the flagstones are then filled with either concrete or muram up to about 1 in. above the top of the joists. Finally, a layer of flagstones is laid on the concrete or muram filling, and the flagstones are properly jointed with mortar and pointed in cement mortar. The top layer of flagstones may be replaced by any other type of floor finishing. Sometimes the lower layer of flagstones is omitted and cement concrete is used instead. If lime concrete is used as a filling material the steel joists (and beams) should be protected from the action of lime by interposing a screed of cement concrete, or at least with a protective coat of paint or bitumen.

3. Brick or concrete jack arch floors:—These floors are formed by constructing brick or concrete arches, called jack arches, on the lower flanges of mild steel joists. The joists are spaced at 2 to 4 ft. centres. The jack arches are usually given a rise of 1/12th of the arch span. The floor is finished in one of the usual ways, and the underside of the floor is plastered. For large spans, rolled steel beams are provided to support the joists. The only draw-

---

1. Steel joists (and beams), if embedded in lime concrete, are liable to rust from the action of lime.
back of this type of flooring is that the ceiling of the floor is not plain from below.

The methods of construction of brick jack arch floors and concrete jack arch floors are briefly given below:

(a) Method of construction of brick jack arch floors — A timber centering is made to the required size and shape (usually made segmental in shape), and is laid on edge with the circular part (or intrados) upwards, on the lower flanges of the rolled steel joists at a distance of 3 in. from the wall. Well burnt and saturated bricks are then laid on edge from both the joists and the work is closed at the centre. The end bricks are cut to the required shape to fit into the joint properly, and the joint next to the joint is filled with cement mortar to prevent contact of the joist with lime. The centering board is then removed and the rest of the arches are constructed as described above. The brick jack arches are well watered for about 14 days and then the upper surface is levelled with either cement or lime concrete, and finished with the required type of flooring. The underside of the arches is plastered and white or colour washed. A brick jack arch floor is shown in Fig. 1227.

![Fig. 1227. Brick jack arch floor.](image)
Hollow concrete or clay blocks may also be used instead of bricks for constructing jack arches.

(b) **Method of construction of cement concrete jack arch floors**—The construction of cement concrete jack arch floors is comparatively simple. Rolled steel joists are first placed on the walls at 2½ to 4 ft. centres and the arches of concrete are then constructed. The centering for the jack arches need not be supported on vertical props resting on the ground floor, but it can be directly supported on the lower flanges of the rolled steel joists. The centering for the concrete arches is usually made of 1½ in. thick mild steel plate bent to the exact shape of the intrados and having holes at the two ends, about 2 ft. 6 in. centre to centre longitudinally. Two iron rods, about ½ in. in diameter and of suitable length, are hooked at the ends so as to form eyes (see Fig. 1228), large enough to pass a ½ in. rod, and each iron rod is passed through the eye of the other in such a way that by sliding the eyes the total length of the two iron rods can be increased or decreased. These iron rods are passed through the holes made in the mild steel plate, and are supported on the lower flanges of the floor joists (see Fig. 1229). In order to give rigidity to the centering, a block of wood is driven tight between the iron rods and the curved plate. Concrete is then laid on the top of the centering to the specified thickness and well consolidated by means of rammer. Finally, the flooring is completed with the required type of finishing.
The entire flooring is kept wet for about 14 days, and after this period the centering is removed and the underside of the arches is plastered. A concrete jack arch floor is illustrated in Fig. 1230.
The following points should be noted in the construction of brick or concrete jack arch floors:

(a) Steel joists, if allowed to come in contact with lime mortar or concrete, are liable to rust due to the action of lime. Hence they should be protected from the action of lime by interposing a screed of either cement mortar or cement concrete. (see Fig. 1227).

(b) The extreme pair of steel joists on either side should be tied by means of bolts and nuts in order to prevent the end joists from being pushed out horizontally by the thrust of the arch (see Figs. 1227 and 1230).

(c) If the span between the walls is more than 12 ft., the rolled steel joists should be supported by means of rolled steel beams of the required section (see Fig. 1230). The R. S. beams should be placed from wall to wall at a spacing of 6 to 10 ft., and their ends should be placed on stone or concrete bed blocks embedded in masonry.

4. Filler joist floors (Figs. 1231 to 1233)—In this type of floor mild steel joists of the required section
are spaced at 1\frac{1}{2} to 3 ft. centres, and the spaces between the joists are filled with cement concrete. The floor is then finished in one of the usual ways. The filler joists may rest on walls or be cleated to main rolled steel beams as shown. For forming such a floor, the centering is first laid and then rolled steel joists are laid on the walls at the required spacings. The concrete should completely envelop the joists to an extent of 1 in. above and below the top and bottom flanges, and 2 in. below and at the sides of the rolled steel beams. In good class work, the joists are held in position at the required spacing by means of tie rods passing through the webs.

5. Hollow clay block floors—Hollow clay blocks are usually 9 to 12 in. wide, 3 to 12 in. deep and about 12 in. long. In one method, the hollow clay blocks or tiles...
are employed in combination with reinforced cement concrete as shown in Figs. 1234 and 1235. The floor finishing may consist of a paving of cement tiles or simply of a 1 in. cement plaster. The thickness of the floor varies from 6 to 9 in. for spans from 12 to 20 ft. In another method, the R. C. C. ribs between the hollow clay blocks are replaced by rolled steel joists as shown in Fig. 1236, and the hollow clay tiles span the distance between the joists as lintels. Rolled steel beams are also used to support the joists when the span between the walls is
more than 15 ft. A layer of concrete is then laid on the
top of these hollow blocks to provide a bearing surface for
flooring finishing. A cement wash is usually given to the
sides of the hollow clay tiles just before concreting, in
order to increase the bond and to prevent cracks. The
finishing on this may be of any type mentioned above.
The underside of the floor is plastered. Before plastering
on the underside, the blocks should be wetted with water,
and the underside of the blocks should be given a coat of
cement slurry.

The following are the advantages of hollow clay
block floors—

(1) They are less costly.
(2) They keep the room cool in summer.
(3) They are sufficiently sound-proof.
(4) They are light in weight.

Hollow concrete block floors may also be constructed
as described above by using pre-cast hollow concrete
blocks. Pre-cast R. C. C. joists and beams are used in the
construction of such floors instead of steel joists and beams.
This type of floor is very efficient and carries heavy loads
satisfactorily.

6. Reinforced cement concrete floors:—As already
stated, R. C. C. is a combination of two materials, cement
concrete and steel. Concrete is weak in tension and to
overcome this, steel, which is strong in tension, is intro­
duced to form a composite material; thus in R. C. C.
the steel reinforces or strengthens the concrete.

1 For design of R. C. C. floors, refer to any good text book on
"R. C. C."

2 A composite material is one in which there is no relative
movement of its components when subjected to a load.
When concrete sets, it contracts and therefore the steel embodied in it is held firmly, the grip between the two materials being so good that they act as a composite material. R. C. C. is equally strong both in compression and tension. The design and construction of R. C. C. structures are usually made on the following assumptions, which are universally recognised:

(i) The bond between the cement concrete and steel is perfect, i.e., no slipping occurs.

(ii) Stress is proportional to strain (Hook's Law), i.e., the modulus of elasticity (Young's modulus) is constant.

(iii) The modulus of elasticity is the same both for compression and tension.

(iv) Sections which are plane before bending remain plane after bending. The position of the neutral axis is also constant (Bernoulli's assumption).

(v) Steel takes all tensile stress, and the tensile strength of concrete (which is small) is neglected.

(vi) The working stresses in a beam subjected to loading are within the elastic limits of the materials.

(vii) In simple designs, stresses due to shrinkage and plastic flow are neglected.

R. C. C. floors may be divided into two main classes, (a) Beam and slab floors and (b) Beamless or flat slab floors. The following are the important points, which should be noted in the design and construction of R. C. C. floors:

1. The slabs and beams should be continuous, as far as possible,
(2) The floor panels should be square or as nearly square as possible.

(3) The span should be as short as possible. If the space to be slabbed is rectangular in shape, with width less than 12 ft., the width should be taken as the span and the main reinforcement should be provided in that direction, e.g., in the apartments, 7 ft. by 13 ft., 8 ft. by 14 ft., 10 ft. by 15 ft., 12 ft. by 20 ft., 7 ft. by 8 ft., 10 ft. by 12 ft., should be taken as the spans. If the width of such rectangular spaces is more than 12 ft., intermediate beams should be provided at not more than 12 ft. apart, and the distance between the beams should be taken as the span.

(4) For main reinforcement, steel rods of less than \( \frac{1}{4} \) in. diameter should not be used. The maximum diameter is not fixed, but rods of diameter greater than \( \frac{1}{4} \) in. are rarely used. The distance between the main reinforcement bars should not exceed 12 in. nor should it be more than three times the effective depth of the slab, whichever is lesser. The minimum distance between bars should not be less than the diameter of the bar or the maximum size of the aggregate plus \( \frac{1}{4} \) in. whichever is greater. Twenty per cent of steel should be used for distribution steel. The distribution steel is often called "temperature reinforcement," secondary reinforcement, distributing bars or "binders," and its object is fourfold: (a) to bind all the reinforcement together (b) to resist partly the temperature and shrinkage stresses, (c) to take any bending stresses in its direction and (d) to assist in distributing local loading over as wide an area as possible. For distribution steel 3/16 in. to 1/2 in. diameter bars are used, 3/8 in.

1. For calculations, the effective span is taken equal to clear span plus effective depth. Effective depth is from top of concrete to neutral axis of tensile steel.
or $\frac{1}{2}$ in. diameter bars being extensively used. These bars should not be placed further apart than four times the effective depth of the slab or 24 in. whichever is less. The main and cross bars should be tied together with No. 16 gauge (0.065 in. thick) soft black iron wires.

(5) The approximate depth or thickness of an R.C.C. floor may be determined by using one of the following thumb rules:

(a) The overall thickness of an R.C.C. slab should not be less than 3 in.

(b) For uniformly distributed loads on a slab simply supported at ends the depth should be $\frac{1}{3}$ in. for every foot of the span. This depth should be limited to 7 in. for a 14 ft. span. If the span is more than 14 ft., some means to reduce it and, eventually the depth, should be adopted, such as providing intermediate beams, etc.

(c) For a slab with fixed ends such as a lintel with considerable weight of wall on ends, or middle spans of a continuous beam, the depth of slab may be taken as equal to $\frac{span}{30}$

(d) For a cantilever slab with uniformly distributed load the thickness at support should not be less than $\frac{span}{8}$

(5) For fixing the cross-section of a beam, the effective depth should be taken not less than the breadth and not more than three times the breadth. As an approximation, the thickness of an R.C.C. rectangular beam

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1. These thumb rules are applicable only when the loads are uniformly or almost uniformly distributed; but unsuitable for concentrated, point loads.
should be calculated at 1 in. per foot of span, and the breadth of the beam (or the breadth of the rib of a T-beam) should be taken 3/5th of the total depth of the beam. See Figs. 1237 and 1238.

\[ b = \text{BREADTH IN INCHES} \]
\[ d = \text{EFFECTIVE DEPTH IN IN.} \]
\[ A_T = \text{AREA OF TENSILE REINFORCEMENT IN SQ. IN.} \]

\[ b = \text{BREADTH IN INCHES}; \ d = \text{DEPTH IN INCHES}; \]
\[ N.A. = \text{NEUTRAL AXIS}; \ dc = \text{DISTANCE OF THE CENTROID OF COMPRESSION STEEL FROM THE COMPRESSED EDGE IN INCHES}; \ Ac = \text{AREA OF COMPRESSIVE REINFORCEMENT IN SQUARE INCHES}; \]
\[ A_T = \text{AREA OF TENSILE REINFORCEMENT IN SQUARE INCHES}. \]

Figs. 1237 and 1238.

Singly reinforced rectangular beam. Beam with compression reinforcement.
(7) The unsupported length of a beam should not be more than 32 times the width of the beam for rectangular beams or the width of the flange for T-beams. The protective cover of concrete must not be less than 1 in. or the diameter of the main bars, whichever is greater.

(8) When the flange of a T-beam (or flanged beam) forms part of a slab, its width should be governed by one of the following conditions. The condition that gives the smallest dimension, should be used. See Figs. 1239 and 1240.

\[ B = \text{Breadth of T-beam or flange} \]
\[ D = \text{Effective depth of T-beam} \]
\[ t = \text{Thickness of flange} \]
\[ b = \text{Breadth of rib} \]
\[ d = \text{Depth of rib which is usually made about } 1/2b \text{ to } 2b. \]
\[ N.A. = \text{Neutral axis} \]

Figs. 1239 and 1240.

Stresses in a T-beam

(a) The width of the T-beam should not exceed one-third the effective span of the beam.
(b) The beam width should not exceed 12 times the flange thickness plus breadth of the rib of T-beam.

(c) The beam width should not exceed the distance between ribs of T-beams.

When the flange of a T-beam does not form part of a slab, its width should be limited to four times the width of the rib. Further, the thickness of the flange should not be less than half the width of the rib.

(9) In long span 1 in. maximum should be allowed for expansion per 100 ft. length of the slab with 1 in. minimum, according to temperature changes.

(10) The top surface of the centering should be given a camber of 1/12 in. for every foot of span subject to a maximum of 1 in. for slabs, and 1/18 in. for every foot of span subject to a maximum of 1/2 in. for beams, to allow for initial settlement.

(11) The following bearings should at least be allowed on walls:

<table>
<thead>
<tr>
<th>Solid slabs</th>
<th>Lintels</th>
<th>Concrete joists</th>
<th>Concrete beams</th>
<th>Beam and slab floors</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 in.</td>
<td>6 in.</td>
<td>6 in.</td>
<td>8 in.</td>
<td></td>
</tr>
</tbody>
</table>

Beam and slab floors: In these the beams and slabs are designed as rectangular sections, and the slabs are supported on beams. In monolithic construction, the beams and slabs are cast together as shown in Figs. 1241 and 1242. These floors may be subdivided into (i) one way slabs or slabs supported on two sides and with main reinforcement in one direction only, and (ii) two-way slabs or slabs supported on four sides and with reinforcement in two directions.
Figs. 1241 and 1242.

R. C. beam and slab. R. C. slab and steel beam.

(i) One-way slabs:—In these the main reinforce-
ment is provided parallel to the shorter span and the slabs
are supported on cross-beams. This is the usual arrange-
ment of a beam and slab floor in a building. The beams
are supported on girders extending from column to
column. For an economical design the cross beams may
be kept 4 to 12 ft. apart. Cross beams are sometimes
provided from column to column only and at right angles
to the girders and are sometimes omitted altogether. If
the spaces or panels to be slabbed are square or nearly
square, consideration should be given to two-way
slabs (see below) as they will be more economical there.

For purposes of calculation, the total load on the
slabs is considered as transmitted to the cross beams;
similarly the load on girders is considered to be imposed
by cross-beams only.

The tensile rods are normally hooked at the ends to
form anchorages in order to increase the tensile stress
near the ends. Three types of hooks are illustrated in Figs. 1243 to 1245, the most common type being the semi-circular hook. A hook is assumed to carry a load which produces a tensile stress in the bar up to a limit of 10,000 lbs. per sq. in. If hooks or bends (see below) are not provided, an additional length of reinforcement equal to 44 diameters is considered necessary for anchorage.

![Diagram showing three forms of hooks.](image)

In continuous slabs, part of the tensile reinforcement is bent over the supports for the negative bending moments and for shearing stresses. Such bent up bars should extend a sufficient distance (say 0.25 to 0.30 span) beyond the centre of the support to provide adequate bond. In large slabs, separate reinforcement over the support may be necessary. The tensile reinforcement bars are bent up about 30 degrees in shallow beams or slabs to 45 degrees in deep beams. The values of shear resistance of inclined bars are given in Table No. 21.

Four arrangements of slab reinforcement are shown in Figs. 1246 to 1249. Mesh reinforcement or wire fabric is a convenient form of reinforcement for slabs.
Reinforcement at right angles to the main reinforcement, is provided in slabs to care for temperature stresses, shrinkage stresses, bond, and distribution of the load in the slab.

(ii) **Two-way slabs**—As already stated, the two-way slabs are supported on all four edges and reinforced in two directions. Two-way slabs are more economical than simply reinforced beams, when the slabs are square or nearly square. These slabs are generally stronger and stiffer even with less depth, as the load is distributed on four sides instead of two.

The two-way reinforcing system of slab design is statically indeterminate and the exact solution is very complicated. However, a number of empirical formulae

**TABLE No. 21.**

<table>
<thead>
<tr>
<th>Diameter in in.</th>
<th>Working tensile stress in steel, $f_s = 16,000$ lbs. per sq. in.</th>
<th>Working tensile stress in steel, $f_s = 18,000$ lbs. per sq. in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H/V = 1$</td>
<td>$H/V = 1.73$</td>
<td>$H/V = 1$</td>
</tr>
<tr>
<td>$\phi = 45^\circ$</td>
<td>$\phi = 30^\circ$</td>
<td>$\phi = 45^\circ$</td>
</tr>
<tr>
<td>1.220</td>
<td>860</td>
<td>1,370</td>
</tr>
<tr>
<td>2.270</td>
<td>1,750</td>
<td>2,500</td>
</tr>
<tr>
<td>5.000</td>
<td>2,460</td>
<td>3,900</td>
</tr>
<tr>
<td>6,800</td>
<td>3,750</td>
<td>5,600</td>
</tr>
<tr>
<td>8,080</td>
<td>4,830</td>
<td>7,650</td>
</tr>
<tr>
<td>11,340</td>
<td>6,300</td>
<td>10,000</td>
</tr>
<tr>
<td>13,880</td>
<td>9,850</td>
<td>15,600</td>
</tr>
<tr>
<td>16,800</td>
<td>11,920</td>
<td>18,900</td>
</tr>
<tr>
<td>19,990</td>
<td>14,150</td>
<td>22,900</td>
</tr>
</tbody>
</table>

*Note:* $H$ — is the horizontal and $V$ the vertical projections of the bent part of the bar.
Based on experiments has been established for the design of two-way slabs and they are safe, simple in application and reasonably accurate. For purposes of design the following assumptions are made: (1) The slabs act as a perfectly elastic thin plate with Poisson's ratio having a zero value; (2) the load is uniformly distributed; and (3) the supports are rigid. The method of design is to consider the slab as divided into a number of unit widths in two directions at right angles to one another. Each unit width is then designed as a one-way slab loaded with a fraction of the total load.

**Flat or beamless slabs**—Flat slabs are reinforced concrete slabs which are directly supported on columns without the agency of beams or girders. The flat slabs are generally used where heavy loads are to be carried and head-room is limited. The columns supporting the flat slabs are usually circular in section, and the tops of columns are invariably flared or tapered in order to give good bearing to the slab (see Figs. 1250 and 1251). This flared or tapered portion is called the *capital*. Sometimes, a portion of the slab, symmetrical with the column, is thickened in order to give additional strength to the capital and consequently to the slab; this thickened portion is called a *drop panel*. Though a drop panel increases the cost a little, it effects a correspondingly greater saving in concrete, as it allows a thinner slab to be used.

Flat slabs are generally thicker than beam and slab floors but are more economical when the floor loads are heavy, the panels are square or nearly square and when the column spacing is between 16 ft. and 24 ft. They are advantageous where a large number of panels (in rows of not less than three) of equal and nearly equal dimensions are required as in a large floor, where large clear floor spaces are required and where the head-room is limited.
Flat slabs are designed as continuous frames. The framing plan should be made, remembering the following points:

(a) There should be at least three rows of panels in each direction, i.e., lengthwise and breadthwise.

(b) The ratio of length to breadth of panels should not be more than 4 : 3.

(c) End spans should not be more than the interior ones.

(d) The length and breadth of any two adjacent panels should not differ by more than ten per cent of the greater of the two. If any two adjacent spans differ in length, the bending moment must be calculated on the longer span.

There are several systems of steel reinforcement, but the most used are (i) the two-way system and (ii) the four-way system. The four-way system is the more common in use. In the two-way system, the reinforcement extends from column to column at right angles to one another; thus, this system leaves an area in the centre of the panel which is regarded as supported on four sides. In the four-way system, in addition to the bands of reinforcement at right angles to one another, two side bands of reinforcement are introduced diagonally between columns. The two diagonal bands and one half of each of the four straight bands cover the whole area of the panel.

The diameter (or side) of the columns head should be between $\frac{1}{8}$ and $\frac{1}{16}$, $l$ being the average of $l_1$ and $l_2$, the sides of the panel. The angle of the greatest slope of the column head should not exceed 45 degrees with the vertical axis as shown in Fig. 1250. The thickness $l$ of a flat

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1. In accordance with the Building Regulations of the American Concrete Institute, the slab thickness shall not be less than $\frac{l}{40}$ for panels with drops and $\frac{l}{80}$ for panels without drops, $l$ being the average of $l_1$ and $l_2$, the sides of the panel.
slab should be at least 5 in. and it should not be less than.
For arrangements of slab reinforcement. Details of a flat or beamless slab floor. Expanded metal rib-mesh floor jack arch type.

(a) \( \frac{1}{32} \) for panels without drops, (b) \( \frac{1}{36} \) for panels with drops, in panels fully continuous and also in end panels without drops, and (c) \( \frac{1}{40} \) for fully continuous panels with drops (\( l = \text{average of } l_1 \) and \( l_2 \), the sides of the panel). The side (or diameter) of a drop panel should not be less than \( 0.35L \), where \( L \) is the span in the direction in which bending moments are considered. The thickness of the drop panel should be between \( \frac{1}{2} \) and \( \frac{1}{3} \) of the slab thickness.

Flat slabs are very suitable for warehouses, theatres, factories, mills, public buildings, etc. The chief advantages of flat slabs are given below:

(i) The flat ceiling has a neat and good appearance, and may be kept clean easily. It gives better lighting facilities, and also affords the convenience of hanging pipes or shafting from the flat ceiling, which is a good advantage in factories.
The formwork required for the slabs is very simple and cheap.

For the same clear head-room there is a considerable saving in the storey height (i.e., flat slabs are very suitable where the head room is limited).

The system, particularly the four-way reinforcement system, distributes the load uniformly, and therefore, the slab is stronger than the ordinary one with the same amount of reinforcement.

Flat slabs are more economical when the floor loads are heavy, when large floor areas are required and when the column spacing is between 16 ft. and 24 ft.

The flat or beamless slabs were first introduced and developed in the United States of America and later followed in Britain. They are not yet extensively used either in India or in Pakistan.

Construction of R.C.C. floors:—The method of construction of cast in-situ reinforced concrete floors are briefly described hereunder:

(a) Erecting Centering:—A suitably designed centering or falsework, made of either steel or timber, is first erected to support the slabs and beams during and after construction until they harden sufficiently to support their own weight (dead load) and the superimposed load. The centering should be sufficiently strong and rigid and of the correct dimensions of the finished floor. It should also be as light as possible. Facility for erection and for easing and striking-off should be the main features in their design.

(b) Placing reinforcement and laying concrete:—After the erection of the centering, the interior surface of the centering is given a thin coat of oil to prevent con-
crete from adhering to it. A thin layer of cement concrete (about 1 to 2 in. thick) is then evenly spread on the interior surface of the centering, and on this concrete layer the slab and beam reinforcement are placed accurately in position. Care should be taken to see that the reinforcements are free from rust or greasy matter. Cement concrete is then poured around the reinforcement and for the required thickness of the slab, and well consolidated by means of rammers. Care should be taken to see that no hollows are left within the slab and the reinforcements are well encased in concrete.

(c) Water curing and striking-off formwork — The concrete is now allowed to attain its full strength by keeping it wet for about 14 days. After this period, the formwork is struck off and the upper and under surfaces of the slab are treated as desired.

R. C. C. floors are highly efficient and in most cases they are the least expensive forms of fire-resisting floors, but they are extremely sonorous.

7. Precast R. C. C. beam or slab floors:—These are constructed by employing precast reinforced beams or slabs of about 10 in. in width, and a depth varying to the requirements of the load and span. Precast slabs (or beams) for different spans are now available in the market. The precast slabs may be supported direct upon walls or be placed between rolled steel joists of the required section. The sides are grooved to form joggles. Cement mortar is used to grout the joints and the floor is completed by giving a desired finish. In superior work, continuity rods hooked at the ends are placed over the supporting beams in the joints between the slabs. For heavy work, these floors can be reinforced in a manner similar to the hollow block floors by placing rods in the joints, and
cross reinforced by rods placed in the surface concrete. The precast R. C. C. beam or slab floors are sufficiently strong and rigid and are, therefore, very suitable to all positions where concrete surfaces are required.

The principal advantages of precast R. C. C. slab floors are:—(1) No centering is required (i.e. the cost of all centering is eliminated).

(2) The method of construction is very easy.

(3) They are constructed rapidly.

(4) They are generally light in weight and hence a considerable saving in the steel frame is ensured.

(5) They can be used 48 hours after fixing.

8. Expanded metal rib-mesh floors:—The following are the various forms of expanded metal rib-mesh floors generally used in this country:—

(i) In the first type, rolled steel joists of the required section are placed on the walls to span the distance at 2 to 4 ft. centres and hy-rib or self-centering steel mesh sheets are laid in the form of an arch between the steel joists as shown in Fig. 1252. On the top of these steel mesh sheets cement concrete of the required strength and consistency is evenly laid to the required depth. The floor is finished in one of the usual ways and the undersurface of the floor is cement plastered. The arches are usually given a rise of one-twelfth of the arch span.

1 Hy-rib and self-centering are two ribbed types of expanded metal lath of steel. A hy-rib ribbed steel mesh sheet is shown in Fig. 571. In self-centering, the ribs are connected by diamond mesh expanded metal. These sheets are used for partitions and floors for which no centering is required. This type of reinforcement is very convenient and economical in the case of curved surfaces where the centering cost is heavy.
In the second type, the steel joists are placed on the walls at the required spacings and the hy-rib or self-centering steel mesh sheets are laid horizontally between the steel joists as shown in Fig. 1253. The steel sheets directly rest on the top of the lower flanges of the joists. The upper and bottom surfaces of the floor are then treated as usual.

![Fig. 1253. Expanded metal rib-mesh flat floor with rolled steel joists.](image)

In the third type, the rolled steel joists are replaced by R.C.C. T-ribs and a concrete slab of the required thickness is cast monolithically with these R.C.C. ribs (see Fig. 1254). The spacing of R.C.C. ribs varies from 18 in. to 24 in. and the depth of the ribs varies from 6 to 12 in. below the underside of the concrete slab. The width of the ribs varies from 4 in. to 6 in. The thickness of the concrete slab usually varies from 3 in. to 5 in. A flat ceiling of hy-rib or self-centering and cement plaster is provided at the bottom of the R.C.C. T-ribs with the aid of wooden fillet pieces, as shown in Fig. 1254, in order to give a better appearance to the floor.

In the fourth type, rolled steel joists are placed on the walls at 2 to 4 ft. centres, and on the top of these joists an R.C. slab of the required thickness is cast as shown in Fig. 1255. Hy-rib or self-centering steel mesh sheets are generally used in the concrete slab. The
bottom reinforcement, provided in the slab, is continuous which takes up the bottom tension in the slab, and the top reinforcement, which consists of strips, takes up the top tension in the slab. The slab thickness usually varies from 4½ in. to 9 in.

In the fifth type, the rolled steel joists mentioned in the above fourth type of floor are encased in cement concrete and the hy-rib or self-centering reinforcement is placed just a little below the top flanges of the steel joists as shown in Fig. 1256. The top and bottom surfaces of the floor are then treated as desired. A flat ceiling of hy-rib or self-centering sheets and cement
plaster may also be provided at the underside of the steel joists by a suitable means.

Fig. 1256.
Expanded metal rib-mesh floor with rolled steel joists. The joints are encased in cement concrete.
CHAPTER XIV

QUESTIONS FOR REVISION

1. A room on the ground floor of a building is treated with wooden flooring. Narrate the construction and state the sizes of the various parts.

   What precautions should be taken to prevent damp rising up from the ground and through the walls?

   (Gujarat University, 1954)

2. A room 39 ft. by 18 ft. is to be roofed over with 5 in. R. C. C. slab supported on four 18 in. by 18 in. T-beams and the end walls. The bottom of the slab is 10 ft. from the ground floor level. Sketch fully an arrangement of formwork indicating approximate sizes of required timber.

   (Karnatak University, 1954)

3. (a) Describe in detail the method of laying Terrazzo floor in situ.

   (b) What are the defects of timber floors?

   (Karnatak University, 1954)

4. Write out the analysis of the materials required for 100 sq. ft. of floor two inches cement concrete over 4 inches lime concrete.

   Explain various methods of "curing" the same.

   (University of Sind, 1950)

5. State briefly and explain by section to a scale of 1 inch equal to 1 ft. any type of solid wood floor on cement concrete.

   Explain the special precautions to be taken to

   (a) prevent its decay.
make it silent.
allow for subsequent settlement.

University of Sind, 1950.

6. (a) Describe three types of floors, using different materials. Illustrate your answer with neat sketches.
(b) State why waterproofing is required and describe two methods of waterproofing concrete slab roof.

University of Sind, 1950.

Gujarat University, 1954.

7. A room 18 ft. wide by 30 ft. long clear inside is to be provided with Mangalore tile roof. The roof is to be supported by double (two-way) arrangement of timber. Sketch fully the construction and briefly describe it.

Karnatak University, 1955.

8. A room, 18' × 10' and height of 12' has a timber floor supported on end walls and one timber beam at centre. The timber beam is decayed and requires to be replaced by another beam of the same size.

Explain with fully dimensioned sketches the method of executing all the work involved.

Bombay University 1953.

9. Give the complete section of a 13½" thick wall showing all the details from foundation to roof, giving the names of its various parts. There are two floors supported by the wall. On one floor, the section should be taken through a door and on the other through a window; you may take a flat roof or a pitched roof resting on the wall.

University of Baroda, 1952.

10. List the different types of floors. Explain by means of sketches the construction of a hollow tile floor.

University of Sind, 1950.

11. (a) State how you will proceed to drain and waterproof a flat R. C. C. roof.
(345)

12. (a) Describe with a dimensioned sketch the construction of a double floor of timber carrying a ceiling below it.

(b) What are the requirements of a factory floor? What type of floor will you recommend for this situation?

(Karnatak University, 1952)

13. State the different types of floors that are normally adopted in the building trade. Explain the advantages and disadvantages of each type and propose a floor for a lecture hall 25' - 0" x 60' - 0".

(Karnatak University, 1952)

14. Describe with sketches the method of construction of a suitable floor for a kitchen and bath-room on an upper floor. The floor framework consists of wooden beams and joists.

(Gujarat University, 1952)

15. The country-tiled roof of a town library hall is to be replaced by a flat R. C. C. slab. The hall is 20' x 50'. Submit a proposal with a neat cross-sectional dimensioned sketch for the old and new work for the scrutiny of the damaging committee and indicate the minimum requirements of cement and steel for the execution of that work.

(University of Poona, 1951)


Draw a dimensioned sketch for R. C. C. slab with details of reinforcement to cover a residential room 12' x 14'.

(Gujarat University, 1952)
17. (a) Sketch in detail the formwork you would use for a reinforced concrete beam and floor slab over a room 16 ft. wide and 20 ft. long. Give all sizes.

(b) Sketch longitudinal and cross sections of the beam and of the slab to show the placing of the reinforcement. (University of Poona, 1956).

18. Draw to \( \frac{1}{4} \) inch scale a plan and section through a concrete floor 7 inches thick, over a bay 24 feet long by 10 feet wide. Figure on the sizes of the rolled steel filler joists and their distance apart, centre to centre.

19. Draw to a scale of 3 inches to the foot the sections through one of the patent hollow-tile floors. State the name of the floor and give full dimensions.

Give the dead weight per foot super of the floor and the live loads per foot super which a designer should allow for when designing the floor for

(a) Working-class flats   (c) Schools
(b) Offices   (d) Ballrooms
(e) Warehouses.

20. Signs of rot are apparent in the timber of a ground floor. Describe very briefly what steps you would take to remedy this and prevent a recurrence of the trouble.

21. Draw, to 3-inch scale, two sections through an upper floor having 9-inch by 3 inch joists, 1 1/8 inch floor boarding, lath and plaster ceiling. Alternative forms of strutting to be shown, and also three forms of jointing the floor boards. Give the names of the joints.

22. Draw, to 1/8-inch scale, the plan view, showing the arrangement of main beams and filler joists in a steel and concrete floor 48 feet by 24 feet. The main joists are 15 inches by 6 inches R. S. J.'s, at 8-foot centres, and support 4 inches by 14 inches R. S. J.'s, at 2-foot centres.
Draw also to 1½ inch scale, two sections through the floor which is finished with 1-inch cement.

23. Draw, to a scale of 1 inch to 1 foot, the section through the ground floor of a building 20 feet wide having an 18 inch external brick wall with footings and concrete base, the inside wood floor is of joist boarded construction on sleeper walls and 18 inches above ground level.

24. Draw to a scale of 1 inch to 1 foot the half plan at one end and a cross-section of upper room measuring 18 feet 9 in. by 12 feet 9 inches inside of 13½ inch brick walls which are increased to 18 inches thick to the room below.

The floor is constructed with 4½ inch by 3 inch plates, 9 in. by 2 inch joists, 9 inch by 3 inch trimmer and trimming joists and 1 inch solid strutting.

There is a well hole 4 feet square, between trimming joists in the centre of the half floor.

Indicate on one half of the plan between walls the carpentry construction and on the other half of plan the manner of finishing the 1 1/4 inch flooring about the well hole which has 9½ inch by 1 inch tongued linings, 3 inch by 1-inch architrave on plastered ceiling and 4 inch by 1 1/4 inch mitred margins to flooring.

Dimension all members and parts.

Draw to half full size scale an isometric projection of the joint used to secure the ends of the trimmer joists to trimming joists, name and give proportions of all parts of this joint.

Mark in coloured pencil where the following occur:

- Dovetailed halving, key, mitre, trimmer joist, tusk tenon joint.
25. An upper floor for a building is to be constructed with 9 inch by 2 inch timber joists and 1 inch floor boarding. Give sketches showing

(a) the method of supporting the ends of the bridging joists;
(b) the method of stiffening the floor by herringbone strutting;
and (c) the joint between the trimmer and the trimming joist.

26. Give sketches showing the construction of two types of hollow block floors. Show the arrangement of steelwork that may be necessary, and give dimensions.
CHAPTER XV
Plastering, Pointing, White-washing and Colour-washing

1 PLASTERING

Plastering is the art of covering rough walls and uneven surfaces in the construction of houses and other structures with a plastic composition, called plaster. Sometimes the term "rendering" is used for the process of applying plaster or cement to the external surfaces of walls either to improve the appearance or to prevent damp rising.

The principal objects of plastering are

(i) to provide a true, even, smooth and finished surface to the work and improve the appearance,
(ii) to preserve the surfaces from atmospheric influences,
(iii) to cover defective workmanship,
(iv) to cover up the unsound and porous materials,
(v) to give a suitable ground for white or colour-wash, distemper or paint.

Good brickwork, made of well-burnt bricks and good mortar, or neat stone masonry, constructed of durable stones and good mortar, does not require plastering in general either to preserve or beautify it.

Plaster is a fine paste (or mortar) made by working with water a mixture of cement and sand or lime and sand. When cement forms the binding material, the plaster is called cement plaster and if lime is the binder, it is called lime plaster. Mud plaster, made of clay and sand, is also used. Fine sand is generally used for making
the plaster, but it should not be so fine as to pass more than 5 per cent through a 100 mesh sieve or more than 20 per cent through a 50 mesh sieve. A good plaster should be smooth, non-absorbent, washable, sound-deadening, fire-resisting, and not affected by temperature changes.

For lime plaster, fat or pure lime is the best. If hydraulic lime is to be used, it should be either (a) ground dry to a fine powder and then mixed with sand and water, and used, or (b) it should be twice ground, i.e., ground first time, then left for two or three weeks in a heap to slake, after that period reground, and used. If hydraulic lime is not prepared as mentioned above for plastering, the unslaked particles contained in the lime might slake in the course of time absorbing moisture from the atmosphere—even after six months or a year—and the surface of the plaster may be damaged by blisters called blowing. Surkhi plaster\(^1\) should never be used for external work since surkhi\(^2\) is likely to disintegrate after a time.

Sometimes a suitable quantity of cement is added with lime plaster to improve its strength, and this plaster is mainly used for external work. To improve the building properties of lime mortar for plaster work, gugal (Amyres agallocha—a sort of fragrant gum), 10 lbs. to every 100 cubic feet of mortar, is added when the mortar is being ground. Very often a solution of gur or jaggery, about 1 lb. to every 4 gallons of water, is added to the mortar to assist adhesion. Sometimes small quantities of

1 Surkhi plaster is usually a fine mixture of lime, surkhi and sand, which are generally used in equal proportions.

2 Surkhi is usually made by pounding bricks, brick-bats, or clay balls burst in kilns. Like sand, it is used as an adulterant in mortar, but unlike sand, surkhi imparts strength and hydraulic property to the mortar.
chopped hemp or vegetable fibres are added to the mortar to improve its adhesive and tensile properties. In England, ox-hair is mixed with plaster to assist adhesion. Small quantities of ghee (clarified butter), whites of eggs, linseed-oil, etc., are often added to produce a fine polish.

Cement mortar forms an excellent material for external plaster, the proportion of cement to sand being generally one to four. Cement mortar is not generally used for internal work, except where it is necessary from the point of view of water-tightness, such as in bathrooms, water cisterns, etc. The reasons for this are that it is difficult to drive nails or make any fixtures in cement-plastered walls and that distempers, paints and varnishes, white and colour-washes, etc., do not stick so well to cement-plastered surfaces.

Plaster may be applied in one, two or three coats, but the thickness of a single coat should not exceed ½ in. The setting coat should not be applied until the previous coat is almost dry. When applying another coat of plaster, the previous plastered surface should be scratched or roughened to form a key. To ensure even thickness and a true surface, strips of plaster about 6 in. wide should be formed on the wall, about 4 to 8 ft. apart to act as gauges. The trowels for plastering should have faces measuring about 10 in. by 4½ in.

**Lime plastering** —Lime plaster is composed of lime and sand in various proportions according to the nature of the work and the number of coats to be applied. Sometimes sufficient quantity of Portland cement is added with lime plaster, mainly for external work. The following proportions are generally used for either external work or internal work:
Only fresh water and clean sand should be used. Care must be taken to see that there is no salt in the sand or water, otherwise the plaster will not dry. For superior work, the ingredients should be mixed with jaggery water. Before the plastering is commenced, the surface should be prepared as described below.

(i) **Preparation of surface for plastering:** When a wall has to be plastered, the mortar joints are left rough and projecting, to give a key or hold to the plaster. All the joints and surfaces of the masonry are well cleaned with a wire brush, and care is taken to see that they are free from oil, grease, soot, etc. The projections which are more than half an inch beyond the general surface of the wall are knocked off so as to present a uniform surface of the wall. Similarly, holes and hollows, if any, are properly filled up in advance. If the surface is smooth or the wall is an old one, the mortar joints are raked out at least to a depth of half an inch to give a key to the plaster. All woodwork to be plastered is roughened. In the case of old brick walls, the bricks are picked over so as to expose a new and rough surface.

<table>
<thead>
<tr>
<th>1st coat</th>
<th>2nd coat</th>
<th>3rd coat</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Lime plaster if applied in one coat</td>
<td>1 part lime and 1_4 parts river sand.</td>
<td>...</td>
</tr>
<tr>
<td>(b) Lime plaster if applied in 2 coats.</td>
<td>-do- 2 parts lime and 1 part white sand.</td>
<td>...</td>
</tr>
<tr>
<td>(c) Lime plaster if applied in 3 coats.</td>
<td>-do- 1 part lime and 1 part sand. 4 parts lime and 1 part fine white sand.</td>
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Finally the mortar joints and surfaces of the wall are well washed, wetted with clean water and kept wet for at least 6 hours before the plaster is applied. A groundwork is required for the application of plaster, which is briefly described below.

(ii) Groundwork for plaster:—To serve as a guide for the thickness of the plaster, vertical strips or ledges of plaster, called screeds or bands, are formed at the ends of the surface to be covered and at intervals of a few feet (about 5 feet) across it, and levelled up to strings stretched at the distance from the masonry. The width of the screeds are usually about 6 in. and the screeds extend from the top of the wall to the bottom. The screeds thus formed form the groundwork for the application of plaster.

(iii) Application of plaster coats (a) First coat or Rough Course of plastering:—Lime plaster may be applied in one, two or three coats. The average thickness of first coat of plaster, called rough course, is generally 1 in. on brick or ashlar masonry and $\frac{1}{2}$ in. on rubble masonry, the larger thickness of rubble masonry being due to the roughness or unevenness of its surface and the necessity to ensure at least 1/4 in. of mortar covering to the rubble. The first coat of plaster is usually applied by dashing it against the wall surface between the screeds mentioned above. It is frequently sprinkled with sufficient quantity of water and rubbed well with floats applying pressure with the hand during the rubbing. If a second coat, called floating course, is to be applied, the surface of the first coat is left exposed to air to set and harden for about 2 days, but not to dry, and after this period, the surface of the first coat is sprinkled with water and is either freely scored all over with the edge of the trowel or well beaten with a thin
cane. The surface of the first coat is kept wet till the second coat is applied.

(b) Second coat or floating course of plastering:—
Before applying the second coat, the first coat is allowed to set, but not to dry, and roughened if the scoring with the edge of the trowel or beating with the cane had not been done as described above. The second coat is then applied with mason’s trowels, fairly spread out, tested, pressed and rubbed with the straight edge. Water is slightly sprinkled over the plastered surface and rubbed well with floats. The thickness of the second coat is usually 1/4 in. to 3/8 in.

(c) Third coat or Final coat or Finishing coat:—
About five days after the second coat is applied, the final or finishing coat which is usually of cream of white or fat lime, called neera or plasterer’s putty, is applied in a thin coat of 1/8 in. thick, with a perfectly straight plane, and the paste well rubbed with a straight edge. It is then floated with a wooden float, and polished with a trowel till no trowel marks are seen on the surface. A soapstone or polishing stone is very often used to obtain a fine polished surface. Sometimes a small quantity of mica powder is added to the mixture of the final coat, the particles of which shine in strong light.

For very fine work, a little powdered soapstone may be used with the plaster during the finishing to increase its whiteness and polish. Surfaces to be papered, white or colour-washed, or painted should not be finished off with a polish.

2. Madras chunam plastering:—Madras chunam plaster is a very fine, but expensive, plaster used for interior work in the Madras State. It is usually applied in 3 coats. The first coat, about half an inch thick.
consists of shell lime, sand and jaggery water; the second about one-eighth inch thick, made of sifted shell lime and fine sifted white sand without jaggery; the third or finishing coat, about one-sixteenth inch thick, consists of lime from selected white shells mixed with one-fifth part finest white sand, the ingredients being ground to the consistency of cream; to every eight gallons of this paste are added the whites of twelve eggs, half a pound of ghee, and two-and-a-half pounds of sour curdled milk. The final or finishing coat is laid on very thin and before the second coat is dry. It is then sprinkled with finely-powdered soapstone and rubbed with soapstone or agate until the required polish is produced. The moisture, which exudes from the plaster for several days, must be continually wiped off. Excellent examples of this type of plaster may be seen in the Cathedral and Banqueting Hall, Madras.

3. Cement plastering: (a) First coat.—The cement plaster may be applied either in one or two coats. The first coat or rough coat of plaster usually consists of 1 part of Portland cement and 3 or 4 parts of sand by volume. The average thickness of the first coat of plaster is generally 1/4 in. on brick masonry or ashlar masonry and 1/2 in. on rubble masonry. On concrete masonry, the thickness of the first coat varies from 3/8 in. to 5/8 in. depending upon the nature of the work. The wall surface is first prepared as described above for lime plastering, and 6 in. wide vertical screeds are formed on the wall surface at suitable intervals. After the screeds are made, the spaces or bays between them are applied with cement plaster with mason's trowels and the plaster is levelled by means of flat wooden floats and wooden straight edges. Finally the surface is polished with a trowel without sprinkling water. If a second or fine or flushing coat is to be
applied, the surface of the first coat is not polished, but roughened to give a key to the second coat of plaster.

(b) Second or fine or flushing coat.—Prior to the application of the second coat of plaster, the first coat is allowed to set but not to become dry, and is roughened to give a key to the second coat. A paste of pure Portland cement mixed with sufficient quantity of water is used for the second coat. The fine or second plaster coat is applied in a thin layer not exceeding 1/8 in. thickness over the moist and damp first coat, well trowelled and rubbed perfectly smooth.

The finished plastered surface, whether one or two coats, is kept wet by sprinkling water for at least seven days in order to develop strength and hardness.

4. Moghul (or Moghal) plastering.—To prepare the Moghul plaster, 4 parts lime, 3 parts sand and 1 part surkhi are ground in a mortar mill and mixed with some jaggery (coarse sugar), glue, powdered gall-nut (soaked in water for about 12 hours) and finely chopped fibres of old rope or gunny. Moghul plaster is generally applied in two coats. For plastering roofs, the surface is first well wetted and the first coat of plaster, about 1/2 inch thick, is applied. This coat is gently beaten with wooden tappers, jaggery water being sprinkled in small quantities, till it hardens. The second coat of plaster, about 1/4 in. thick, is then applied and rubbed perfectly smooth, jaggery and gall-nut water being added freely as the rubbing goes on. The finished plastered surface is kept wet for about three weeks in order to obtain a hard, glossy and crack-proof surface.

5. Stucco plastering.—Stucco is an excellent decorative plaster used on both interior and exterior walls. Stucco is usually laid in three coats: the first is a scratch or
rough coat which bonds with the wall and provides the strength; the second is a finer coat (sometimes called brown coat), which straightens and trues up the surface; and the third is the final or finishing coat, which provides the texture and a smooth and decorative surface. The total thickness of these three coats is about 1 in.

For interior walls, the scratch or rough coat for stucco is a \( \frac{3}{4} \) in. thick coat of lime plaster; the second coat, called finer coat, which is richer in lime, is \( \frac{3}{8} \) in. thick and forms a smooth, true surface; and the finishing coat, \( \frac{1}{8} \) in. thick, consists of a mixture of finest lime and well powdered white stone (marble or quartz). The last or finishing coat is well polished with a bag of linen containing moist chalk, then with oil and chalk and finally with oil only.

For exterior walls, the rough coat is about \( \frac{3}{4} \) in. thick and is made up of 1:3 cement mortar with 10 per cent by weight of hydrated lime; the second coat is about \( \frac{3}{8} \) in. thick and has the same composition as the first or rough coat; the finishing coat is about \( \frac{1}{8} \) in. thick and is of 1:2 or 1:2½ cement mortar. Coloured cement may be used in the final coat, if a coloured finish is desired. The compositions given for exterior walls may also be used for interior walls, if desired.

Sometimes, in laying stucco, whites of eggs, ghee and sour curdled milk are added in sufficient quantities to the finishing coat, which is rubbed for several hours with the smooth surface of a piece of soapstone or agate to produce a polish. This practice is usually adopted in the Madras State.

Madras chunam is a very fine stucco.

6. Mud plastering:—This is used on walls of
temporary sheds and country-side buildings. This keeps the room cool, besides being cheap. The mud plaster consists of clay to which is added an equal volume or bulk of chopped straw, hay, loose coir or hemp and cow-dung, the whole being thoroughly mixed and flooded with water and left for about seven days. For plastering, the wall surface is first prepared by knocking off projections, raking joints, wetting with water, etc., as in the case of lime-plastering, and 6 in. wide vertical screeds are formed on the wall surface at suitable intervals. After the screeds are formed, the spaces between them are evenly filled with mud plaster and worked with a straight edge and a wooden float. This first coat is left exposed for about 24 hours for the mortar to harden, and then it is tamped and close dents are made with a suitable edged instrument. Tamping compacts the layer and drives it home into the joints; it also helps to avoid cracks and hollows. After tamping, water is sprinkled slightly and the surface is polished with a trowel. A thin wash of cow-dung is then given and tamping done again at the places where small cracks have formed. Finally the surface is given a wash of fine white earth, cow-dung and cement in the proportion of 3:2:1.

Plaster on laths:—The laths are generally used for ceilings, partitions, etc. They may be broadly divided into two classes, viz. wood laths and metal laths.

The wood laths are generally used for plastering the sides of timber partitions and ceilings of timber floors. They consist of thin strips of specially selected well-seasoned wood. The strips are usually about 1 in. broad and 3 ft. to 4 ft. long. The strips are generally made in three sizes, namely, 'single' (average 1/8 in. to 3/16 in. thick), 'lath and half' (average 1/4 in. thick), and 'double' (3/8 in. to 1/2 in. thick). The thicker strips, because of
the strain upon them, should be used in the ceilings, and
the thinner laths should be used in vertical partitions, etc., where the strain is but small. Some walls and partitions have to stand rough usage; in such cases the thicker strips are necessary. The strips are nailed in parallel lines on the surfaces to be plastered so as to form a groundwork for the plaster. The strips are usually spaced with about $\frac{3}{8}$ in. between them for plaster, and galvanised iron nails are used for fixing them. Every strip is nailed at each end, and also at the place where the lath crosses a joist or stud. The strips are best nailed so as to break joint entirely, because, for various reasons, there is a tendency to crack along the line of the joints if the laths are nailed with the butt ends in a row. After the strips are nailed, the plastering work is carried out in the usual manner.

Wood laths are subject to the attack of white ants and fungi. They should not be used in the fire-resisting construction.

Metal laths are of several types and most of them are the subjects of patents. The following types are generally used in India: Ermet, Brickett, Hy-rib, Shamil, Trussit, Self-centering, Trus Con, B. R. C. Fabric (British Reinforcing Company's Fabric), Woven wire, Herringbone, etc. The sheets are drawn taut and fixed by galvanised iron staples driven into wooden supports. If the latter are not available, wooden fillets or plugs are embedded in the concrete or masonry. The laths should be as stiff as possible, and they should be joined by a reasonable lap and should be fastened by lacing with a galvanised wire run through the meshes. Care should be taken to see that joints are not formed at corners; where two surfaces, 1 B. R. O. Fabric consists of high tensile steel wire made into fabric by welding.
either vertical or horizontal, meet, the lath should be bent at the junction.

Special finishings to plastered surfaces:

Rough-cast or Spatter-dash:—The wall surface is first pricked up with a layer of coarse stuff upon which a coat of similar composition is uniformly spread while this is wet and as fast as it is done in small portions. Over this, a mixture of cement and coarse-grained sand (one part cement to 3 parts coarse-grained sand) is evenly applied with the aid of a large trowel and the surface is roughly finished by means of a wooden float. A waterproofing compound and some colouring pigments may be added with cement mortar if desired.

Smooth-cast:—In this, the base coat is as in rough-cast, and in the final coat, fine-grained sand is used instead of coarse-grained sand.

Sanded surface:—To get the effect of a sanded surface the final or finishing coat is finished by rubbing clean and washed sand by means of a wooden float. Lime plasters, when wet, receive the sand-surface well and represent a uniform yellow shade.

Floated surface:—To obtain this type of surface, the final coat consisting of cement or lime mortar is allowed to set partially and then the surface is rubbed with a wooden float till the sand comes to the surface. It is then slightly rubbed with a moist sponge to remove float marks.

Pebble-dash:—This is a form of rough cast, and to obtain such an effect, the wall surface is given a rendering coat of coarse sand and cement (1:3), about 1 in. thick, and against this, cleaned and washed pebbles of the required size are thrown and tamped with a broad wooden float. The pebbles may also be dashed against the rendering coat by means of a scoop.

Depeter:—This is another form of rough-cast. To obtain this effect, the wall surface is given a ½ in. thick rendering coat of coarse sand cement (1:3) as in the case of pebble dash and pieces of gravel or flint of different colours are pressed by hand while the rendering coat is
still wet. Thus various beautiful and ornamental patterns may be produced in colour.

Glazed cement finish:—The final coat is finished smooth by means of a wooden float, and it is then given a glazed cement finish. Three coats of cement gauged to the consistency of a thick paste with a patented liquid, which controls the set, are applied. The first two coats are brushed and the last or final coat is finished with a rubber stippler and then sprayed twice with cellulose.

Painting in Fresco:—Painting in fresco is a system of decoration in which desired figures are carefully painted on the stucco plastered surfaces while freshly laid and still wet, with earth colours ground with water and mixed with lime. Painting in Fresco is mostly used for internal work.

Various beautiful and ornamental patterns may be produced on the rendering coat with ingenuity. The tools shown in Figs. 1257 to 1262 are generally used by the plasterers.

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**Figs. 1227 to 1262.**
Trowels, Floats and Straight Edge.
Gunite and Guniting:—Cement and sand mortar applied by air pressure is commonly called "gunite", and the operation is known as "guniting". Actually such mixture of cement and sand is termed "shot concrete" or "shotcrete" in general and "gunite" is only a trade name for the product of Cement Gun Company. Gunite is used with or without reinforcement for many purposes, the most important being

(i) Repairing masonry or concrete structures.
(ii) Construction of water tanks and cisterns.
(iii) Waterproofing the surfaces.
(iv) Lining of canals, reservoirs, tunnels, sewers, etc.
(v) Protection of steel from fire, corrosion, etc.
(vi) Roof and rib protection in mines.
(vii) Walls and roofs, etc. of buildings.

The outstanding features of gunite are (a) rapidity and ease of execution, (b) high adhesion, (c) high impermeability, and (d) increased compressive strength. The usual thickness of gunited plaster is ½ in. The gunited walls for building are normally 2 in. thick and are shot on chicken netting stretched against plywood forms. Roofs of buildings are 2 to 3 in. thick. Wire mesh is generally used for reinforcing the works. Gunite is used for reinforced concrete domes also.

Guniting or application of gunite or shotcrete:—An intimate mixture of cement, sand and water is forced or ejected through a machine called cement-gun and shot into place by means of compressed air. The usual equipment consists of a compressor of a capacity of about 200 cub. ft. per minute spray nozzle and 1½ in. to 2 in. flexible hose pipe which is about 100 to 200 ft. long. At the end of the hose there is a nozzle to which water under pressure by a separate connection is supplied. A uniformly graded dry mixture of cement and sand is loaded in the gun and shot under a pressure of about 35 to 40
lbs. per sq. in. by compressed air. The usual proportions of cement and sand are 1 : 3; sand is of size 3/16 in. downwards. Slightly moist sand, with about 3 to 8 per cent of moisture, works better. About 3 gallons of water per cwt. of cement are generally sufficient for ordinary works. A very wet mixture does not stick well. With considerable practice, a mixture of the proper consistency can be easily formed and forced or ejected in a layer of any desired thickness. As the material is shot into place with great force, the plaster is compacted, and results in a very impervious layer and makes it unnecessary to add a cement waterproofer, even when a deep water reservoir or tank is to be rendered watertight. From experience and experiments it is found that 5/8 in. and 3/4 in. gunite slabs stand about 700 ft. and 1,600 ft. head of water respectively.

While shooting, the gun should be held at a distance of 30 in. to 36 in. from the surface to be treated, and the material should be shot at right angles to the surface. A thin edge should be left at each day's work. The surface to be treated must be thoroughly cleaned of any dirt, grease or loose particles and should be fully wetted with clean water. If a smooth polished surface is required, the gunite surface should be polished by means of a trowel immediately after shooting as gunite hardens within a short time. The correct No. of gun should be secured for the maximum size of aggregate or sand to be used, and the compressed air entering the gun must be dry and free from oil.

It is advisable to provide expansion and contraction joints in large exposed surfaces treated with gunite as in the normal concrete works.

The following points should be noted in the case of various works:
1. **Steel encasing:**—The wire netting should be fixed at about \( \frac{1}{2} \) in. from the surface. All the paint, rust, and loose sand deposits should be removed and gunite 1:3 mix by volume should be applied.

2. **Floors:**—Gunite 1:3 mix by volume should be applied in one coat up to \( \frac{3}{4} \) in. thickness. For greater thickness, the gunite should be applied in two coats. As a rule, the final coat should always be more than 1 in.

3. **Wall slabs and panels:**—The thickness of the wall slabs and panels should be \( 1\frac{1}{4} \) in. up to 4 ft. span and 2 in. up to 7 ft. span. The steel fabric reinforcement should not be more than 4 in. mesh and the area should be 3 per cent of wall cross section in each direction.

4. **Water-proofing of walls:**—The surface to be treated must be thoroughly cleaned of any dirt, grease, oil, or loose particles and should be fully wetted with clean water. Upon the surface thus prepared, \( \frac{3}{4} \) in. thick gunite (1 part cement and 3 parts clean sand) is applied.

**Special materials used in plastering:**

1. **Plaster of Paris:**—This is obtained by grinding *gypsum* (a soft stone of crystalline texture consisting of hydrated sulphate of lime), and then calcining it in iron vessels until nearly all the water of combination is driven off. It is then in the form of a fine powder like wheat flour in appearance, but heavier. It is used alone or as addition to other materials. When mixed with water, it sucks up a large quantity without perceptible heating and sets hard in a few minutes, expanding in so doing. Mixed with ordinary lime it is used for repairing holes and cracks in plastered surfaces and for ornamental work. Plaster-of-Paris, being very soluble in water, can only be used for interior work.
If a small quantity of Plaster-of-Paris is added to hydraulic lime, selenitic lime is formed, and its mortar sets very quickly.

2. Coarse stuff is a rough mortar containing 1 to 1 1/2 parts of coarse sand to 1 of slaked lime by measure, and 1 lb. of finely chopped hemp or old coir to every 2 to 3 cub. ft. of stuff.

3. Fine stuff is pure lime slaked to paste and afterwards diluted to the consistence of cream. It is then allowed to settle, the water rising to the top is run off, and the stuff is left till it is thick enough for use. Sometimes a small quantity of finely chopped hemp is added with the stuff to increase the adhesive power.

4. Plasterer's putty is pure lime slaked with water, brought to a creamy consistence, strained through a fine sieve and allowed to evaporate until stiff enough for use. It is the last coat applied to internal walls that are to be coloured.

For a plastic and adhesive plaster, 1 part of lime putty to 3 parts of cow-dung by volume are mixed with enough water and applied immediately. This is chiefly used for plastering chimney flues.

5. Gauged stuff is plasterer's putty with a portion of plaster-of-Paris mixed with it, the proportions being 3 parts putty to 1 part plaster-of-Paris when required to set quickly, and gauged in small quantities.

6. Keene's cement is plaster-of-Paris, calcined with alum. It sets hard within a few days and is suitable for

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1. Bricklayer's putty is made by reducing ordinary good mortar to a cream by the addition of water. This is chiefly used for gauged brickwork. Mason putty for stonework is formed of pure lime, whitelead, and a little fine washed silver sand or marble dust.
angles, skirtings, etc., in internal work. It is chiefly used for internal plastering and surfaces intended to be painted.

7. **Parian cement** is also plaster-of-Paris, calcined with borax. It is cheaper than Keene’s cement and is chiefly used for interior work. It would be used in preference to Keene’s cement when it is desired to paint the surface as soon as possible, also when the surface to be plastered is large.

8. **Martin’s cement** is also plaster-of-Paris, calcined with pearl ash. It sets quickly and dries with a hard, white surface. It is also used for internal work.

9. **Sirapite** is also plaster-of-Paris slaked in petroleum, and is used for internal work. It is easy to work with and sets quickly. It has high fire-resisting properties and dries with a hard, white surface.

10. **Thistle hardwall** is a product of high grade gypsum and is mainly used for internal work. It sets rapidly and gives an excellent polish.

11. **Barium plaster**: This is employed as a final coat to the walls of X-ray rooms.

12. **Granite silicon plaster**:—Granite silicon plaster sets hard quickly. It possesses considerable elasticity and hence it is not liable to crack.

13. **Asbestos-marble plaster**:—This consists of finely crushed marble and asbestos mixed with cement. It is mostly used for the finishing coat as it is costly. It gives a beautiful marble-like polish.

14. **White cement**:—This is a variety of ordinary Portland cement and is pure white in colour. White cement is made from pure white chalk and clay-free iron oxide. It is used for both internal and external work. It
is sold under the trade names "Snowcrete", "Atlas" and "Silvicrete".

15. Coloured cement:—This is produced by mixing very intimately 10 to 15 per cent of a suitable mineral pigment with ordinary Portland cement or white cement. The pigment to be used in cement must be durable against the action of light and weather, must be free from soluble salts, must be in a fine state of division and must not affect the quality of the cement nor be affected by it. Red, yellow and brown colours are obtained by using various percentages of iron oxide. Manganese dioxide gives black or brown colour. Chromium oxide gives a green colour and cobalt oxide a blue colour. White and coloured cements are more costly than ordinary Portland cement, the blue and green cements being the most costly. Coloured cement is used mostly for the finishing coat.

Coloured cement is sold in the market under the trade names "Colorcrete" and "Rainbow". White and coloured cements in a wide range of colours under the trade name "Snocem" are also available in India.

16. Scagliola:—This is an imitation marble, which is made from dissolving Keene’s cement mixed with colouring pigments in glue. This is used for pilasters, columns, panels, etc.

17. Marezzo:—This is also an imitation marble formed of Keene’s cement, coloured and formed upon a smooth surface. This is used for panels, pilasters, columns, etc.

18. Acoustic plasters:—A hard, dense and well polished surface is unsuitable for theatres, music-halls, churches, and the like, as it causes reverberations and interferes with clear bearing. There are a few proprietary acoustic plastering materials (available in the
illarket), which, when mixed with water and applied to the surfaces of walls, undergo a chemical reaction by which gas-bubbles are produced. These gas bubbles make the surfaces honey-combed, which in their turn absorb sound waves.

Defects that may arise in plastering: Normally the following defects may arise in plastering.

1. Cracks on plastered surface: Cracks may be caused by injudicious hurry in attempting to lay one coat before the previous one has sufficiently set (but not dry).

2. Blistering of plaster: Blistering is a defect to which internal plastering is subject. It takes the form of small patches swelling out beyond the plane of the plastered surface, and is due to the slaking of particles of the lime after the plaster has been applied. To prevent blistering, the slaked lime should be left for some weeks to cool before use and it should be sifted.

3. Efflorescence on plastered surface: Efflorescence is the whitish substance that appears on the surfaces of walls due to the presence of salts in the lime, cement, sand and bricks which (salts) are dissolved by moisture drawn through the pores to the surface of the wall, and left in thin layers on evaporation of the moisture. It produces ugly damp patches and gradually disintegrates the structure. It is normally of a temporary nature, disappearing during wet weather and reappearing during dry weather. Efflorescence or salting often occurs on new brickwork, but seldom on plaster; on old work efflorescence occurs on both brick and plaster when the place is damp and ill ventilated.

Efflorescence may be removed with scrubbing brushes and a solution of 1 part hydrochloric or sulphuric acid and 5 parts clean water. Before applying
the solution, the wall should be well wetted. After scrubbing, the solution should be applied and finally the surfaces should be well washed with clean water. Salts from brickwork can also be removed with a solution of zinc sulphate and clean water. The surface should be brushed off when dry.

A mortar can be made as follows which will be waterproof and will also be useful in preventing efflorescence:

One part of fresh Portland cement is mixed with 2 parts of fine white sand. To this is added about \( \frac{1}{2} \) lb. pulverized alum for each cubic foot of sand. To this dry mixture is then added sufficient quantity of clean water in which has been dissolved \( \frac{1}{2} \) lb. soft soap per gallon of water, and mixed well. This mortar is applied as plaster about 1 in. thick.

To avoid efflorescence, the following precautions should be adopted in new buildings:

1. Cement gauged lime mortar, moderately hydraulic lime mortar or cement mortar containing a small proportion of pounded alum and some soft soap should be used throughout the work.
2. Only well-burnt bricks should be used in the construction.
3. Damp-proof courses should be provided wherever necessary.
4. Only clean water (free from salts) should be used.
5. The works should be properly covered at night and during rain in order to exclude superfluous water.

**Wall boards** :— Though plaster forms the best
covering on walls, it is not a very satisfactory material for the following reasons:

(1) Due to temperature changes cracks appear on the plastered surfaces.
(2) Plaster does not stick well to woodwork.
(3) The operation of plastering takes considerable time.
(4) The plastered surface takes considerable time for setting and drying.
(5) A hard, dense and smooth surface is ideal for decoration, but it is very bad for insulation against heat and sound.

In modern practice, to overcome the above defects, a variety of wall boards is used. These wall boards are usually sheets of wood fibre (shavings) cemented together under pressure, 1/8 to 1 in. thick, 3 ft. to 6 ft. wide and 6 to 16 ft. long; these wall boards are called wood fibrous boards or fibre boards. Various kinds of wall boards are now available in the market and most of them are the subjects of patents. Masonite, Essex board, Fiberlic, Venesta, Celotex, Insulite, Lloyd board and Tentex are examples of wood fibrous wall boards, and these boards are not only lighter, stronger and more decorative than plaster, but are sufficiently resilient, non-absorbent and sound-deadening. Wall board composed of asbestos-cement is an excellent fire-resisting material, and is suitable for fire-resisting construction. Plaster boards (plaster sandwiched between two layers of cardboard), plaster lath boards (these are similar to plaster boards, but smaller in size and the surfaces are made rough to take plaster), fibrous plaster boards (these are plaster lath boards reinforced with fibre) and plywood boards are also used as wall boards. The wall boards are fixed to masonry and concrete surfaces on a groundwork of
teakwood furring. The groundwork of furring is not necessary when wall boards have to be fixed to wooden joints, rafters or studs of timber partitions.

2. POINTING

Pointing is the art of finishing the mortar joints of the walls or similar structures with either cement mortar or lime mortar in order to protect the joints from atmospheric influences and also to improve the appearance of the structure. It may be noted here that mortar joints are only the weak spots in a structure (provided the materials used in the continuation are of good quality) and hence they should be properly protected from the disintegrating effects of sun, rain and frost. The mortar joints alone are pointed, instead of plastering the entire surface, in the following cases:

(a) Where a smooth and even surface is not required.

(b) Where the natural beauty of the materials (viz., stone blocks, bricks, etc.) used in the construction are to be exhibited to view.

(c) Where the materials (viz., stone blocks, bricks etc.) used in the construction can stand the action of the weather.

(d) Where the workmanship is neat and good.

Method of pointing:—Pointing may be done either as the work proceeds or after the completion of the work; the former is the stronger and more durable, while the latter is cleaner and has a better appearance. It is necessary to remember that the pointing work does not last permanently and hence pointing requires replacement.

1 Furring is a term which is applied to the use of framework of wood or metal to provide an air space for insulation and to provide a finished level surface.
from time to time by repointing. Before pointing, all the mortar joints on the face are raked out by a special pointing tool to a depth of about \( \frac{1}{2} \) in, in order to give an adequate key for the fresh mortar used for pointing. All the loose mortar and dust are then brushed out of the joints, and the joints and the wall surface are well washed, wetted with clean water and kept wet for a few hours. After the joints are thus prepared, they are carefully filled with lime or cement mortar with a small trowel and the mortar is well pressed into the joints with the trowel in order to obtain a solid contact with the internal old mortar joints. All excess mortar sticking to the sides are carefully scraped away. The finished pointing is kept wet for about 3 days for lime pointing and 10 days for cement pointing. Lime pointing is done with lime mortar made with equal parts of lime and fine white sand, carefully ground in a mortar mill. Cement pointing is done with cement mortar made by mixing equal parts of cement and fine white sand, using it quickly before it begins to set. Blue or black pointing is sometimes used with red brickwork and is made by mixing the mortar with fine ashes instead of sand to give a dark colour.

Pointing must not be done during the frost weather as the expansion of the moisture in it by freezing would tend to throw out the pointing and disintegrate the joint. In ordinary circumstances a neat struck pointing (see below) is the best. This pointing may be advantageously done as the work proceeds. In frosty weather no brickwork should be allowed to proceed.

Types of pointing: There are many types of pointing, and the following is a brief description of them. The selection of a particular type of pointing depends upon the types of bricks (or stone blocks) used and the appearance required.
Figs. 1263 to 1273.
Different types of pointing
1. **Flush or flat pointing** (Fig. 1263):—This is the simplest type of pointing and is probably more extensively used than any other. Though the appearance is not very satisfactory, the pointing is very durable and does not afford a lodging place for dust. In this type, the joints are filled up flush (with mortar) with the face of the wall, and the edges are neatly trimmed with a trowel and straight edge.

2. **Struck pointing** (Fig. 1264):—This is a good type of pointing as it permits of the ready discharge of water and is very commonly used. In this type of pointing the upper sides of the mortar joints are kept about \( \frac{1}{4} \) in. inside face of masonry, and bottom flush with exterior or face of masonry. This type is also known as ruled pointing, and is usually done with cement mortar as the work proceeds and before the mortar in the joints sets.

3. **Overhand struck pointing** (Fig. 1265):—This is similar to struck pointing, but the lower sides of the mortar joints are kept about \( \frac{1}{4} \) in. inside face of masonry and the upper flush with face of masonry. This type is sometimes adopted, but it is not recommended as water collecting on the ledges may pass through the mortar and cause dampness on the inside.

4. **Recessed pointing** (Fig. 1266):—This type of pointing is used for facing work of good textured bricks and good quality mortar. The face of the pointing is pressed behind the plane of the wall by means of a suitable tool and is left vertical instead of being made inclined. This is not recommended.

5. **Keyed or grooved pointing** (Figs. 1267 and 1268):—This type of pointing gives an attractive appearance to the structure and is generally used for superior work. In this type, the joints are first filled up flush
(with mortar) with the face of the wall, and then the bent end of a small steel or iron tool, called pointer or naila, is pressed and rubbed in the middle of the joints frequently until a uniform semi-circular notch is formed. Two types of keyed or grooved pointing are shown in Figs. 1267 and 1268.

6. Vee-pointing:—This type of pointing is shown in Fig. 1269, and is made as described for the Keyed or grooved pointing and with a steel or iron jointer having its lower edge suitably shaped.

7. Beaded pointing:—This type of pointing is shown in Fig. 1270 and is formed, in conjunction with the pointing rule, by a steel or iron jointer having a concave edge. This type has a good appearance, but it is liable to be damaged.

8. Weather pointing:—In this type of pointing each joint is finished with a V-shaped raised band of mortar as shown in Fig. 1271. This type is mostly used for brickwork.

9. Tuck pointing (Fig. 1272):—This type is used for new or old work, but more often for the latter. For tuck pointing, the mortar joints are raked out, brushed and well watered as described before. The joints are then filled flush with coloured mortar to match the brickwork, or rubbed over with a piece of soft brick of similar colour. A 3/16 in. or 1/4 in. wide by 1/8 in. deep groove is immediately and carefully formed along the centre of each joint, and the groove is filled, or tucked in (hence the name given to the pointing) with white lime putty to which a small amount of silver sand has been mixed. The lime putty is given a maximum projection of 1/8 in. and both top and bottom edges are neatly trimmed off by means
of a frenchman. Tuck pointing has a neat and attractive appearance, but the band of lime putty, called ridge or fillet, is not durable and in course of time becomes defective.

Fig. 1274.
A Frenchman

10. Bastard or half-tuck pointing:—This type of pointing is shown in Fig. 1273 and is similar to that of tuck pointing but the band which projects consists of the same pointing material. Though the appearance of bastard tuck pointing is not so good as the true tuck pointing, it is more durable than the latter.

3. WHITE-WASHING AND COLOUR-WASHING

Plastered walls and ceilings are very often either white-washed or colour-washed for appearance and sanitary reasons. Lime is said to possess antiseptic and disinfectant properties.

Preparation of white-wash:—The white-wash is prepared from fresh burnt shell lime or pure stone lime mixed with water. Shell lime is generally used as it is whiter and slakes more perfectly and to a smoother paste than stone lime. The fresh burnt lime, either shell lime or stone lime, is put in a tub with a sufficient quantity of clear water and the whole well mixed until it attains about the consistency of thin cream. The diluted paste is then strained through a clean cloth and clean gum

1. Frenchman is a discarded table knife, the blade of which is cut to a point which is bent about 3/8 in. at right angles to the blade. This is used for tuck pointing only. See Fig. 1274.
arabic dissolved in hot water is added to the mixture in the proportion of 2 oz. gum arabic to 2 cub. ft. of lime to improve its adhesiveness. Rice size (a mixture of rice flour and hot water) may be used instead of gum arabic. A small quantity of blue or tootia (copper sulphate) is sometimes added with the diluted paste in order to prevent glare and to give a pleasing effect.

**Preparation of colour-wash**—The colour-wash is usually prepared by adding the necessary colouring pigments in suitable quantities to the liquid mixture prepared for white-washing. The colour-wash should be stirred continually during use, and only sufficient quantity of wash for the day’s work should be prepared each morning.

For a **buff** colour-wash, add sufficient quantity of brown earth, called Peeli or Maltan mitti or Remrai in Northern India, with the white-wash solution; or add raw umber and lamp black with the white-wash solution. Stir the whole mixture and strain through a clean cloth before use.

For a **green** colour-wash, boil about 10 lbs. of fresh mango bark in 4 pints of water (1 pint = 1/8 gallon) for 5 minutes, and mix this water with the white-wash solution together with a solution of 2 lbs. of tootia (copper sulphate) in 3 pints of water.

For a **slate** colour-wash, add lamp black and blue in suitable quantity with the white-wash solution.

For a **yellow** colour-wash, add yellow earth or ochre with the white-wash solution.

For a **blue** colour-wash, add burnt coconut shells with the white-wash.

For a **pink** colour-wash, add vermillion with the white-wash.
For a fawn colour-wash, add umber, Indian red and lamp black with the white-wash solution.

An excellent white-wash or colour-wash that will not easily rub off may be prepared as described below:

About 1 cwt. (= 112 lbs.) of burnt shell lime is slaked thoroughly with hot water in a covered vessel. With this mixture are added about 1½ lbs. salt dissolved in hot water, about 8½ lbs. pounded rice mixed in hot water and about 2 lbs. glue dissolved in hot water. The whole mixture is then stirred well and thinned by adding hot water to a consistency of cream, and put over a fire for a few hours. Finally, the hot liquid mixture is strained through a clean cloth and applied hot (in the usual manner). For colour-wash, the desired pigment in suitable quantity is added to the liquid mixture prepared for white-washing.

Whiting is made by reducing pure white chalk to a fine powder. It is mixed with water and rice size and used for whitening ceilings and inside walls. It will not stand the weather well.

Application of white-wash or colour-wash:—Before white-wash or colour-wash is applied to the surfaces of new walls, the surfaces should be well cleaned and brushed. The surfaces should also be in dry condition. If the surfaces are extra smooth, white-wash or colour-wash will not stick well to them, and hence, in that case, they should be carefully rubbed with sand paper. For re-white-washing or re-colour-washing, the surfaces should be cleaned of all loose old wash, and sand papered, all nails removed, and holes filled with lime putty in which a small quantity of fine silver sand and some gur (jaggery) are mixed. All greasy spots should be given a coat of rice water and fine sand in order to give an adequate key.
to the wash. If the surfaces are discoloured by smoke, they should be given a wash made of fine wood ashes and water before the application of the wash. Cement plastered walls should be washed with a weak solution of soap, and should be given one coat of sodium silicate and water 1:5. There will be no scaling or flaking off after this treatment. After the preparation of the surfaces, the white-wash or colour-wash should be applied with a brush.

Three coats of wash are generally required for new work and for work on scraped surfaces. The coats are given alternately, vertically and horizontally. One stroke is given from the top downwards and the other from the bottom upwards over the first stroke and similarly, one stroke from the right and another from the left over the first brush before it dries. Each coat should be allowed to dry before applying the next coat. Annual white-wash or colour-wash may consist of one coat only, applied first in vertical strokes of the brush, followed immediately by horizontal strokes.

Wall tiling:—Walls are sometimes lined with some special types of tiles either partially up to 2 to 4 ft. above the floor level or up to the ceiling, in passages, kitchens, bath-rooms, fire-places, staircase walls, boiler rooms, and sometimes on the exterior of the buildings for decorative effect or protection from atmospheric influences.

Most of the tiles used for wall tiling are either of terracotta, faience, china clay or marble. These tiles are usually about 3/8 in. or ½ in. thick, and are available in a very wide range of colours and sizes. Rounded angle tiles and corner tiles are also available.

The wall surface is first plastered with good lime
mortar in the usual manner, and then each tile is covered with a paste of Portland cement on the back and laid flat against the surface true to line and plumb, and pressed with light strokes of a wooden mallet. The tiles should be kept immersed in water for about two hours in advance. The joints should be very thin, i.e., as thin as paper.
CHAPTER XV

QUESTIONS FOR REVISION

1. What are the objects of plastering? Describe any three of the following:
   (a) Lime plastering,
   (b) Stucco plastering,
   (c) Cement plastering,
   (d) Mud plastering.

2. What is pointing? Describe the different types of pointing with sketches.

3. What are the objects of white-washing and colour-washing?
   How are they prepared and applied on new and old walls?
   The answer should not exceed 40 lines.

4. Write short notes on any five of the following:
   (a) Depeter
   (b) Wall boards
   (c) Blistering of plaster
   (d) Plasterer's putty
   (e) Efflorescence
   (f) Pebble-dash.

5. State the different types of plaster adopted for internal and external finishing of buildings.
   What do you understand by waterproof plaster?
   What type of plaster would you adopt for (i) an ordinary residential building of a middle-class family, (ii) a big insurance building, and (iii) a modern cinema-house.

   (Gujarat University, 1953).
6. Write short notes on any three of the following:
   (i) Fibrous plaster,
   (ii) Guniting,
   (iii) Terrazzo paving,
   (iv) Cement rendering.
   (Gujarat University, 1954).

7. What do you understand by Guniting? What is its speciality?
   (Karnatak University, 1955).

8. Why is plastering done in more than one coat? How is lime mortar prepared for plastering a wall surface? What is Neeru and how is it applied?
   (Karnatak University, 1954).

9. Write short notes on:
   (1) Tuck pointing. (Karnatak University, 1955).
   (2) Waterproof plaster. (Guniting operation).
   (3) Guniting operation.
   (Bombay University, 1954 and Gujarat University, 1952).
   (4) Fibrous plaster. (University of Sind, 1950).
   (5) Pointing. (Guniting operation).

10. Describe the following constructions, indicating the important points to be attended to very carefully in order to produce a first class job:
   (a) Plastering work of brick walls. (University of Bombay, 1953).
   (b) Guniting operation.
      (University of Poona, 1956, University of Baroda, 1953, Gujarat University, 1952, and Bombay University, 1953 & 1954).
   (c) Rough cast plaster. (University of Poona, 1956).
11. A residential building in heavy rainfall area is constructed in first class coursed rubble stone masonry for the front and rubble backing behind. The walls are to be plastered on the internal faces, while external faces are to be pointed.

Specify the quality of mortar you would prepare for plastering and pointing and describe the methods of carrying out these works. (Bombay University, 1954).

12. One room with a verandah is to be added to an existing structure. Inside work is to be plastered and outside to be pointed. Describe how the work of these items is actually carried out. (University of Baroda, 1952).

13. (a) What is guniting? What are its advantages and in what situations is it used in building construction?

(b) What is the use of paint? What are its constituents and what are their functions? (Karnatak University, 1952).

14. Write short notes on

(a) Guniting
(b) Pointing
(c) Stucco
(d) Terrazzo.

(A. M. I. E. (India) 1950 and 1952.)
CHAPTER XVI

Painting, Varnishing and Distempering

1. PAINTS & PAINTING

Objects of paints and varnishes.—Paints and varnishes are used in building and other engineering works for covering the surfaces of wood and metal (a) to protect them from atmospheric influences and other agencies and to preserve them from decay or oxidation and corrosion respectively and (b) to improve their appearance.

Ingredients of a paint (or oil paint).—A paint essentially consists of (1) a base and (2) a vehicle or carrier. A paint may also contain (3) an inert filler or extender or a dilutent, (4) a drier, (5) a solvent or thinner and (6) one or more colouring pigments.

(1) Base.—A base (sometimes called pigment) is a solid in a fine state of division and it is the principal ingredient in a paint. It (a) gives body to the paint. (b) reinforces the film of paint after it has dried, i.e., makes the film of paint harder and more resistant to abrasion and (c) minimises shrinkage cracks usually formed in drying. The character and durability of a paint largely depend on the base. The bases generally used are white lead, red lead, zinc oxide or zinc white, iron oxide, titanium dioxide or titanium white, antimony oxide or antimony white, and lithophone.

White lead or basic carbonate of lead.—This is the base most extensively used for all ordinary purposes. White lead ground in linseed oil is the usual product on the market. It is also available in the form of powder. It is cheap, durable, easily applied, works well, has good
covering properties and density, combines easily with the vehicle, has great tenacity and offers a range of coloured paints to be built up. It is waterproof and has a good body to obscure the surface, and weathers well. But white lead is poisonous and smelly. Further it has the disadvantage of turning black when exposed to sulphur vapours. White lead base dries soft. It is not suitable for delicate work but is often used as undercoat with finishing coat of white zinc. White lead improves by keeping. Old white lead of good quality lasts better. For surfaces of wood it affords, in most cases, the best protection. It is not used for ironwork as it does not stop rusting.

Venetian white or Venice white is a mixture of 1 part of white lead to 1 part of barium sulphate.

Dutch white is a mixture of 1 part of white lead to 3 parts of barium sulphate.

Red lead:—It is an oxide of lead. It is generally used for the first or priming coat on wood and ironwork. It sticks well and gives good protection. It is a strong drier of linseed oil, solidifying it in a short time. It is available in a powder form in the market.

On account of the poisonous effect of lead, lead paint produces injurious effect upon those who use it. Entering the pores of the skin it is absorbed by the system, which leads to numbness and a kind of paralysis. It is also the cause of a complaint known as “painter’s colic.” Hence precautions should be taken while scraping old dry painted surfaces or while painting with spray machines.

Freeman’s non-poisonous white lead is prepared by grinding, under considerable pressure, a precipitated sulphate of lead with 25 per cent of oxide of zinc.

B. C. — 25
Zinc oxide or Zinc white:—It forms the base for all zinc paints. It is transparent, non-poisonous, smooth, unaffected by fumes of sulphur, has no smell and amalgamates readily with the binding oil during oxidising and drying, but it is costly. It does not combine with oil so readily as white lead, and hence its covering properties are inferior and it takes a long time to harden. The acids in unseasoned wood have a great effect upon it. It also weathers badly. Zinc white paint retains its colour well and stands washing for many a year without losing any freshness. When dry, it becomes very hard and takes a good polish.

Iron Oxide:—It forms the base for all oxide of iron paints and is obtained by roasting and grinding brown haematite ore. It combines freely with the vehicle and prevents rust. The tints obtainable vary from yellowish brown to black. Iron oxide paint is cheap and durable and is mainly used for the priming coat on ironwork. The best known paint of this class is Oliphert’s Oxide of iron paint, which is largely used for painting ironwork.

Titanium dioxide or titanium white:—It is very white, non-poisonous, unaffected by heat and acids and has excellent body and density. Titanium white base dries soft. Titanium paint is generally used as an undercoat to enamel, as it supplies a very white body to the thin, transparent film of enamel. It keeps the colour in industrial areas. Titanium white paint is sold under the proprietary name “Titanox.”

Antimony oxide or Antimony white:—It is similar to titanium dioxide. Antimony white paint is sold under the proprietary name “Timox.”

Lithophone: It is cheap, non-poisonous, white and dense. It is used in gloss paints and many water paints
It has a good body to obscure the surface and can be applied with great ease. It is discoloured when exposed to daylight. Lithophone paint is mostly used for interior work. It is not suitable for ironwork. It should not be allowed to come in contact with water.

2. Vehicle or carrier:—A vehicle or carrier is a liquid matter, which (a) holds the ingredients of the paint in liquid suspension, (b) helps the ingredients to spread evenly over the surface to be painted, and (c) acts as a binder for the ingredients and causes them to adhere to the surface. The vehicles or carriers commonly used are linseed oil, tung oil, poppy oil and nut oil.

(i) Linseed oil.—This is extracted from flax seeds and is the vehicle most generally used for all painting works. Linseed oil of good quality is limpid, pale, transparent, and brilliant, almost free from smell and sweet in taste. Linseed oil oxidises and becomes thick on exposure to air. It is used either raw or boiled.

Raw linseed oil is thin, odourless, transparent and brilliant. It is suitable for delicate tints and interior painting work. Raw linseed oil takes a long time for drying. The drying power of raw linseed oil may be improved by adding about 1 lb. of white lead to every gallon of oil and allowing it to settle for at least a week. Linseed oil should not be used within six months of its extraction from the seed.

Boiled linseed oil is called drying oil and is prepared by boiling the oil alone or with some drier (red lead or litharge). It is thicker and darker in colour than raw linseed oil and dries more rapidly. It is also more durable than raw oil. It is used for external work. It is not suitable for delicate or indoor work, nor will it do for grinding colours, as it clogs and thickens too rapidly.
Pale boiled linseed oil is better than raw oil and is the same as ordinary boiled oil except that it is not dark in colour. It is very suitable for painting plastered or metal surfaces.

Double boiled linseed oil dries very quickly and is very suitable for external work. It generally requires a thinning agent like turpentine.

(ii) Tung oil:—This is much superior to linseed oil and is used in making superior paints and varnishes.

(iii) Poppy oil:—This is extracted from common poppy seeds and is used for very delicate colours. It is paler in colour than linseed oil and is inferior to linseed oil as regards its drying qualities though its colour stands longer.

(iv) Nut oil:—This is extracted from walnuts. It is nearly colourless and dries more rapidly than linseed oil, but is less durable. It is very suitable for white and light tints.

3. Inert filler or Extender or Adulterant:—This is an inert material usually mixed with the base (a) to make the paint lighter or heavier to the desired extent, (b) to increase its durability and (c) to lessen the cost of the base used. The inert fillers commonly used are barytes, silica, charcoal, silicates of alumina and magnesia and whiting (powdered chalk).

(4) Drier:—A drier is a substance which acts as a catalyst and quickens the drying (by oxidation) of the vehicle or carrier used in a paint. The drier absorbs oxygen from the air and becomes a higher oxide and then

1. A catalyst is a substance which helps or encourages a chemical reaction but does not itself take part in it.
parts with the oxygen to oxidise the vehicle into drying. Driers are classified as: (i) **Soluble or liquid driers**: Driers dissolved in linseed oil or some other good oil; and (ii) **Paste driers**: Driers mixed with inert fillers (see above) ground in linseed oil or some other good oil. The driers generally used are *litharge*, *massicot*, *red lead*, *lead acetate* or *sugar of lead*, *sulphate of manganese* and some *cobalt compounds*.

- **Litharge** (oxide of lead) is the drier most generally used, ½ lb. of the substance being added to every gallon of oil. It has, however, a tendency to injure the colour of paint; hence it should not be used for the final or finishing coat.

- **Massicot** is a yellow powder. On melting and cooling, massicot is converted into litharge.

- **Red lead**, which is also an oxide of lead, is used when its colour does not interfere with the desired tint of the paint. It acts slower than litharge.

- **Lead acetate or sugar of lead** is used as a drier for lighter tints only.

- **Sulphate of manganese** is very often used with zinc paints to avoid the risk of discolouration of a lead drier. It is very suitable for deep tints.

- Several **patent driers** are now available in the market, which are convenient for immediate use.

Driers should not be used unnecessarily, nor in excess, especially in the finishing coat as they have a tendency to destroy the elasticity of the paint and cause the paint to peel off in scales. They should not be added to paints until they are about to be used. More than one kind of drier should not be used with a paint. They should not be used with colouring pigments that dry well in oil.
5. Solvent or Thinner:—A solvent or thinner is a liquid which is mixed in a paint to make the paint thinner and flow freely under the brush, to facilitate spreading the paint evenly over the surface. The solvent or thinner, largely used, is spirit of turpentine obtained by distilling the resinous exudation of some kinds of pine trees. Turpentine is called turps by the workmen, and is much cheaper than oil. Turpentine evaporates very quickly, and while doing so, facilitates the drying of the oil. Turpentine diminishes the tendency of the paint to turn yellow, especially in rooms kept closed for a considerable time. If turpentine is used in excess, colours will be flattened and will also not be durable, as the turpentine evaporates leaving an excess of colour unmixed with the oil. Pure spirit of turpentine does not leave any residue on evaporation. Turpentine is generally affected by weather and is used only in interior work and in making varnishes. If used at all in external work, it should only be added in a small quantity, just sufficient to make the paint run readily with the brush. Sometimes the painted surface is required to present a glossy or shining finish, at other times a dull or dead one is required. An oil paint will generally present a shining or glossy appearance, provided no more turpentine has been used for thinning than the oil. The dead or dull finish is obtained by using no oil, but turpentine alone, for the last or finishing coat. The finishing coat, in this case, is called a flatting coat.

English turpentine is too pungent for indoor work.

Turpentine is often adulterated with mineral oils and some of them have higher penetrating values but are otherwise inferior. Benzine and Naphtha are generally used as substitutes.
Colouring pigment:—When the required final colour of the paints is different from that of the base used, the required tint is obtained by adding a colouring pigment to the mixed paint. The pigments may be divided into five divisions:—

(i) Natural earth colours, such as umbers, siennas, ochres, iron oxides, etc. These are beautiful and durable pigments which readily intermix with other paint compositions.

(ii) Calcined colours, such as lamp black, Indian red, venetian red, carbon black, etc. In general, these pigments are durable.

(iii) Precipitates, such as Prussian blue, chrome yellow, chrome green, etc.

(iv) Lakes, obtained by precipitating some organic colouring matter (usually a coal-tar type) upon some suitable mineral base, like barytes.

(v) Metal powders, such as bronze powder, zinc powder, aluminium powder, powders of lead and lead alloys, copper powder, silver–bronze powder, gold–bronze powder, etc. These are used in protective and decorative paints. They require a minimum amount of vehicle for suitable dispersion, and hence the film formed is made up largely of the metal used.

The following colouring pigments are in general use:

(a) Blacks:—Lamp black, vegetable black, ivory black, graphite.

(b) Blues:—Prussian blue, Cobalt blue, ultramarine, indigo.

(c) Browns:—Prince's mineral, raw umber, burnt umber, vandyke brown.

1. Gold–bronze consists of copper, zinc and tin.
(d) **Greens**—Paris green, Chrome green, Verdigris.
(e) **Reds**—Indian red, Venetian red, Vermillion, carmine, red lead.
(f) **Yellows**—Chrome yellow, zinc chrome, raw sienna, yellow ochre.

**Proportion and nature of ingredients in paints**—The exact proportions and nature of the ingredients in mixing paints vary according to circumstances. They should be governed by the following factors:

(a) Nature of material to be painted. Paints for protecting wood and metal respectively differ considerably.
(b) Kind of surface to be covered. A porous surface requires more oil than an impervious surface.
(c) Nature and appearance of work to be done. Delicate tints require colourless oil. When a dull or dead appearance is required only turpentine is added, and no oil is added to the paint for the final or finishing coat. If the painted surface is to be varnished the paint should contain only a small quantity of oil.
(d) Climate and the degree of exposure to which the work will be subjected. For external work, boiled linseed oil is used as it weathers better than raw linseed oil. Turpentine evaporates rapidly and does not last; hence it is avoided as far as possible. But for work exposed to the sun, turpentine is necessary to prevent the surface from blistering.
(e) Quality of the ingredients used.
(f) Number of coats to be applied. The different coats of paint vary in composition. The first coat on new work requires more oil to soak into the material. On old work, the first coat requires turpentine to make it
adhere. The colouring pigment is added to the final coat to get the desired tint.

(g) Skill of the painter. A good workman can lay on even coats with a smaller quantity of oil and turpentine than an unskilful workman.

Preparations of paints: The usual method of preparation of paints is as follows: The base (usually white lead) is first thoroughly ground by machinery in a small quantity of oil (usually in linseed oil). The paste thus formed is softened and made smooth by adding a small quantity of oil and working it well with a palette knife. The colouring pigment, well ground and mixed with some oil, is then added with the base that has already been prepared, and the whole mixture is brought to the consistency of cream by adding sufficient quantity of oil. The paint is then strained through a fine canvas or a fine sieve. When about to be used, the paint is thinned to the required consistency by adding oil or turpentine, or both, and the drier, well ground and mixed with some oil, is also added. To prevent mixed paints from skinning over or drying up, they should be kept constantly covered with water or a thin film of linseed oil.

For thinning the paints, a mixture of 14 parts boiled linseed oil and 1 part turpentine may be used. For white

1. Many bases are now available in the market either in a powder form or in a paste form.

2. For grinding the colouring pigment, a colour mill or a grindstone and muller may be used. The grindstone is a smooth flat slab of granite, about 3 ft. by 3 ft. and the muller is a hard conical stone whose flat end has a diameter of 4 to 6 in. The colouring pigment is first pounded, sifted and mixed with a small quantity of oil. Successive small lumps of the size of an egg are then placed on the stone and thoroughly ground with the muller. After grinding, it is mixed with some oil.
paint raw linseed oil should be used as boiled oil turns it yellow.

A large number of proprietary ready-mixed paints, such as Shalimar paints, Carson’s paints, Solignum paints, Hubbons paints, Nagrath paints, Nerolac paints, etc., are now available in the market. These paints are sold in various colours in tins or drums, and they are applied exactly as received in tins or drums. If the ready-made paints are too thick, they may be thinned by the addition of a small quantity of oil and stirring. Ready-made paints are expensive in general. A good paint, whether ready-mixed or mixed at the work spot with ingredients, should flow freely from the brush when dipped in the paint and held vertically.

**Characteristics of good paints:**—A good paint should have the following characteristics or qualities:

(a) It should have a good body or spreading power.
(b) It should work freely and smoothly under the brush.
(c) It should easily spread on a surface in a thin and uniform film and it should not show brush-marks when dry.
(d) It should become surface dry in about 9 hours.

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1. Solignum paints are made by Messrs. Solignum Ltd. and are available in various colours such as brown, green, white, etc. These paints contain ingredients which act as effective preventive against attack by white ants. They are more costly and hence they are often used only as a finishing coat for woodwork.

2. Spreading or covering power of a paint is its capacity to spread over an area to be painted. Covering power is generally measured in sq. ft. per gallon. The spreading power of the paint depends upon (1) the quality of the base used in the paint, (2) the nature of the surface to be painted (wood, metal or plaster), and (3) the nature of the coat (priming or second).
and hard dry and in a condition to take another coat in about 24 hours.

e. It should not crack in drying.

f. It should form a hard, resistant-to-wear and durable film when dry.

g. Its colour should not be affected by atmospheric influences, i.e., its colour should not fade or change.

**Different kinds of paints**: The following is a brief description of different kinds of paints:

1. **Priming paint**—This contains an excess of oil and a pigment of pronounced drying action like red lead.

2. **Gloss paint**—This is prepared by adding a mixture of 4 parts of oil and 1 part of drier with previously mixed paste paints. It is used for both internal and external work.

3. **Flat paint**—This is similar to gloss paint, but is made by the addition of 1 part of oil and 4 parts of drier with the previously prepared paste paints. It has high penetrating power, good flow, and gives a smooth mat finish. It should be applied only to clean and dry surfaces.

4. **Luminous paint**—This is a preparation of Calcium sulphide made up with varnish. This paint represents a luminous surface for hours or even days, after the source of light has been cut off, just as radium dials of watches and clocks do. Oil destroys its properties, and it should be applied only to clean surfaces free from lead paint or corrosion.

5. **Inodorous paint**—This paint is mixed without any turpentine or turps. The ordinary white lead or zinc white, well ground in oil, is mixed with methylated spirit in which shellac has been dissolved together with some
linseed oil and castor oil. The methylated spirit evaporates very rapidly, leaving behind shellac which acts the part of the film of varnish left by the oil and turpentine in the ordinary method. As this paint dries very quickly, a three-coat work can be finished in one day. The rapid drying makes it difficult to paint a large uninterrupted surface evenly. This paint may be advantageously used in places where rapidity in execution is required. But this paint is not so durable as oil and turpentine mixed paint.

6. Aluminium paint:—This paint is made by suspending very fine powder of aluminium in either spirit varnish (quick-drying) or oil varnish (slow-drying), according to the purpose for which the paint is required. On the evaporation of the spirit or oil, the particles of aluminium form a thin, metallic coating on the surface painted. Aluminium paint has the advantage of being visible in the dark. It does not oxidise and fade. It has a high covering capacity, i.e., one gallon of aluminium paint will cover at least 10,000 sq. ft. of surface. Aluminium paint protects iron and steel far better than any other paint and also resists heat to a certain extent. It is widely used for painting marine piers, gas tanks, oil storage tanks, radiators, hot water pipes, etc.

7. Enamel paint:—This paint consists of white lead or zinc white ground with a little oil, and mixed with petroleum spirit, holding resins in solution. Enamel paint is now available ready-made in different colours. It dries slowly and produces a hard, impervious, brilliant, elastic film which is smooth, glossy and durable. Enamel painted surface is washable and is not affected by hot and cold water, steam, acids, alkalis, or fumes of gas.
It is used for both internal and external work. Very often a coat of titanium white in pale linseed oil is applied before the application of the enamel paint to improve the appearance.

**Synthetic enamel paint** is a variety of enamel paint, which is made from a synthetic resin. This paint is superior to the ordinary enamel paint in several respects. It dries quickly, leaves no smell, and gives a durable film.

8. **Cellulose paint**—This paint is made from nitro-cotton¹, celluloid sheets, photographic films, etc. Nitro-cotton is used for making superior paint. This hardens by the evaporation of the ingredient used for thinning, and thus it dries very rapidly. It can be more easily worked and cleaned, and possesses greater hardness, smoothness and flexibility, and stands extreme degrees of heat and cold, and is not affected by contact with hot water. Thus it is far superior to ordinary paint, though a little more costly.

9. **Bituminous paints**—These paints are prepared from vegetable bitumen, asphalt, and mineral pitches dissolved in petroleum, paraffin or naphtha, various oils, etc. They are also prepared from the products of coal and other mineral oils. These paints are very suitable for painting iron water mains, and other iron work fixed under water. These paints present a black appearance.

**Siderosthen paint** is a well known proprietary ready-mixed paint, which has a bituminous base. It is available in different colours, such as red, green, black, grey, chocolate, etc.

¹ For use in making paints, natural cellulose (i.e., cotton), is chemically treated to form a nitrate or acetate or to convert it into methyl or ethyl cellulose.
10. **Coal tar paint**:—This is prepared as follows: Good coal tar is heated nearly to boiling point, and thinned by the addition of 1/16 gallon of common country spirit to every gallon of tar. Two pounds of good quicklime are also mixed with each gallon of tar. The mixture is applied hot to the surface. The addition of spirit and quicklime neutralises the free acids in the tar, and also prevents its running.

11. **Ordinary tarring**:—This is prepared by boiling 6 gallons of coal tar with 1 lb. of resin and 1 lb. of pitch. This should be applied hot to the surface.

12. **Anti-corrosive paint**:—This paint consists of oil, a strong drier and a pigment such as lead or red lead or zinc chromes or chromium oxide mixed with some very fine sand. This paint lasts longer than white lead, costs less, and is mostly used for the preservation of iron and steel. This paint presents a black appearance.

13. **Graphite paint**:—This paint is very suitable for iron and steel work in contact with sulphur gases, ammonia, chlorine, etc. It lasts 7 to 10 years, especially in mines, underground railways, etc. This paint presents a black appearance.

14. **Silicate paint**:—To prepare this paint, very pure silica, usually found in the West of England, is calcined and finely ground. The silica powder is then mixed with resinous substances. This paint has no chemical action on metals, and is not affected by alkalis. It has a good covering power, stands a high heat, sets quickly and dries with a hard surface. It is durable and adheres well to brickwork. It should be used with a special silicate drier.

15. **Bronze metallic paint**:—This paint is made by adding finely ground bronze powder to hardened resin or
ester gum in white spirit for internal work and to elastic oil varnish mixed with free lime for external work. It has high covering power, reflects light very well and forms a durable film.

16. Colloidal paint:—This is mixed without any inert filler. The colloidal paint settles very slowly over long periods of time and penetrates the surface of the materials to which it is applied. It is used for both interior and exterior work.

17. Asbestos paint:—This is suitable for places exposed to steam and acid gases.

18. Cement paint:—This is made with good cement (ordinary, white or colour cement) and boiled linseed oil. Four pounds of cement are usually mixed with 2½ lbs. of boiled linseed oil. The cement and the boiled linseed oil should be well mixed, and the mixture should be kept constantly stirred during use. A mixture of 4 lbs. of cement and 2½ lbs. of boiled linseed oil will cover about 100 sq. ft. of corrugated iron sheets. The cement paint is used for both external and internal work. The paint bleaches eventually to a greyish-stone colour, being thus less unsightly than coal-tar paint.

APPLYING PAINTS TO SURFACES

Painting new woodwork: General:—New woodwork usually requires 4 coats of paint. In superior work 5 or 6 coats of paint are applied, and in inferior work 2 or 3 coats are used. The painting on new woodwork is usually done in the following stages:

1. Preparation of woodwork:—The woodwork should be thoroughly seasoned and absolutely dry before being painted. The surface to be painted should be carefully cleaned without any dirt, dust, etc., and rendered
smooth. All nails should be punched in so that their heads are about 1/8 in. below the surface.

2. Knotting or Killing Knots:—The surface is then Knotted. Knotting consists in ‘Killing’ or covering all the knots with a substance through which the resin cannot exude, as red-lead and size, shellac dissolved in methylated spirits, or lime. The three methods of knotting in general use are (a) Ordinary or size knotting, (b) Patent knotting and (c) Lime knotting, and either of them may be used,

(a) Ordinary or size Knotting:—This consists in applying first a hot coat of red-lead ground with strong glue size¹ in water, and when this coat is dry, applying a coat of red-lead ground in oil and thinned with boiled oil and turpentine.

(b) Patent Knotting:—This method consists in applying two coats of a varnish made by dissolving shellac in methylated spirits or naphtha.

(c) Lime Knotting:—In this, the knots are kept covered with hot lime for about 24 hours, and then they are scraped off. After scraping, the surface is given a coat of red-lead ground with strong glue size in water, and when this coat is dry, a coat of red-lead ground in oil and thinned with boiled oil and turps is applied. If this does not ‘Kill’ the knots, the knots may be coated with red-lead and white-lead ground in linseed oil, and when quite dry rubbed smooth with pumice-stone, or after the application of the lime they may be ironed with

¹. Glue size or size is made from finest animal glue, one pound of glue yielding about one gallon of size. Size is largely used in distempers to make the colouring matter adhere to plastered surfaces.
a hot iron and then painted smooth. In superior work the knots may be cut out to a slight depth, and the holes filled up with putty made of white-lead, Japan and turpentine.

3. Priming or first coat:—After knotting, the priming or first coat of paint is applied to the whole surface of the wooden article to be painted. It forms a hard and opaque covering, filling the pores of the wood. The paint for the priming or first coat may consist of the following ingredients.

For Internal work:—White-lead 8 lbs., Red-lead ½ lb., Boiled linseed oil ½ gallon, Raw linseed oil ½ gallon, and Litharge ½ oz.

For external work:—White-lead 10 lbs., Red-lead 10 oz., Raw linseed oil ½ gallon, and Litharge 2 oz.

The priming coat is usually applied before the woodwork is fixed in position.

4. Stopping:—After the application of the priming or first coat, stopping is done. Stopping consists in rubbing down the dried primed surface well with either pumice-stone or glass-paper or both and filling up nail holes and other holes, dents and cracks with putty (called painter's putty) or muck, which, when dried and hardened, should be rubbed down with pumice stone. As

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1. See page 410.

2. Painter's putty consists of ground whitening (powdered chalk) mixed with as much raw linseed oil as will make a stiff paste. The paste is well kneaded and left for about 12 hours, and then it is worked up until quite soft and smooth. If the putty becomes dry, it can be restored by heating and working up.

3. "Muck" is made by mixing fine shavings of wood with painter's putty. This gives better results than putty. It is generally used for concealing all defects in woodwork.

B. O.—28
already stated, 'stopping' should be done only after priming. If the putty is applied before the priming, it will be liable to fall off, because the wood would absorb the oil in the putty and the putty would then shrink.

5. The second and succeeding coats of paint are then applied to the surface prepared by knotting, priming and stopping, one after the other. The paint is laid on evenly with a good brush, the brush being held at right angles to the face of the work, which is being painted, so that the ends of the hairs only touch it. Each coat must be allowed to dry perfectly before the next coat is laid on. All successive coats of paint, except the last, should be gently and slightly rubbed down with fine glass-paper and rendered smooth. The coats of paint should be spread as smoothly and evenly as possible, and no hair marks from the brush must be left on the work. The finished painted surface should be perfectly smooth and even, without any brush marks being left visible.

Repainting old woodwork: Before repainting, the old painted surface must be thoroughly cleaned, or, if greasy, with lime and water, rubbed down with pumice, and all cracks, dents and holes filled with either putty or muck. If the old paint has blistered, the surface must be rubbed down and scraped. If necessary the old paint may be removed by a mixture consisting of 1 part soft soap and 2 parts potash, to which 1 part quicklime is afterwards added. The mixture is applied hot and left on for about 24 hours, after which washing with hot water will completely remove the paint. A mixture of 2 lbs. of washing soda and 2 pounds of quicklime (brought to the consistency of cream by adding water) may also be used for removing old paint. The mixture is spread on the old painted surface and kept on for an hour. The old paint
can then be washed off with water. A solution of caustic soda (2 lbs. caustic soda to a gallon of water) will also remove the old paint from wood or iron-work. But it should not be touched by hand and it should be used with great care, as it is dangerous to human beings. The above three solutions, used for the removal of old paint, are called paint solvents.

The old painted surface having been prepared in one of the above ways, 2 or 3 coats of an oil paint are applied carefully so that no brush marks are left on the surface, each succeeding coat being applied only after the previous coat is perfectly dry.

Surfaces marked by smoke or otherwise dirty should be given a coat of 3 lbs. glue and 3 oz. unslaked lime boiled in one gallon of water prior to the application of the paint.

Painting new iron and steel work:—Painting the ironwork or steelwork is usually done in the following stages:

1. Preparation of ironwork or steelwork:—Before applying paint to a new iron or steel surface, it must be carefully cleaned of all dirt, loose scales, rust and grease. All dirt and loose scales are removed by means of stiff wirebrushes, scrapers or other effective methods. The grease is removed with lime and water or caustic soda and water. Petroleum solvent may also be used to remove grease. The cleaned metal surface is then treated with phosphoric acid, which forms an adherent film protecting the surface from rust and giving a surface to which paint will adhere better.

2. Application of coats of paint:—After cleaning the surface of the metal and when the metal is perfectly
dry, the priming or first coat of paint is applied with a good brush. This coat is allowed to dry thoroughly and then the outer or second coat of paint is applied with brush (or by spraying). The paint used for the outer or finishing coat should be of an elastic and durable character. The finished surface should be perfectly smooth and even.

Painting new galvanized ironwork: Galvanized iron should not be painted until it has been exposed to the weather for a year, as paint does not adhere well to new galvanized iron. If necessary to paint sooner, the surface should be given a wash composed of 8 oz. of copper acetate added to a gallon of water, or 2 oz. of muriatic acid added to a mixture of 2 oz. of copper chloride, 2 oz. of copper nitrate and 2 oz. of ammonium chloride (sal-ammoniac), dissolved in a gallon of soft water, to which a small quantity of hydrochloric acid has been added. This is sometimes called "Mordant solution." The solution should be prepared in a glass or earthenware vessel to prevent precipitation of copper salts. The mixture turns the galvanized iron black, the treated surface should be left for at least 12 hours before being painted. The mixture will cover about 3000 sq. ft. of the surface. Alternatively, the new galvanized iron surface may be washed with dilute zinc sulphate, washing soda or vinegar before the application of paint. Paint will adhere well to the treated G.I. surface. After the wash has

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1. The paint for the priming or first coat is usually made by dissolving 33 lb. of fine red-lead powder in one gallon of boiled linseed oil.

2. The second (or outer) coat may consist of 6 lbs. of red oxide paint, 1 lb. of lamp black and 1 gallon of boiled linseed oil. In superior work a third coat may be required, and, in that case, it may consist of 7 lbs. of red oxide paint and 1 gallon of boiled linseed oil.
dried, a priming or first coat, consisting of red-lead mixed with equal parts linseed oil and turpentine, may be applied; on this priming coat, when perfectly dry, any good oil paint may be applied.

Paints containing red-lead and litharge have been in use for a very long time and have given excellent results. There is nothing to compare with red-lead for a priming or under-coat on iron or steel where there is no abrasion. Red-lead primer followed by a finishing coat of red oxide paint, aluminium paint, graphite paint, oxide of iron paint or cellulose paint has been found very satisfactory. Red oxide is usually grouped up with boiled linseed oil. Red-lead guards against rust while white-lead does not stop rust. The white-lead paint or zinc oxide paint should not be applied directly to the iron or steel as it encourages galvanic action which destroys the paint. Zinc white paint does not adhere well to galvanized iron.

Repainting old iron and steel-work:—Before repainting, the old painted surface must be thoroughly cleaned with soap and water, and the grease should be removed with lime and water. If necessary the old paint may be removed either by burning, preferably with a blow lamp, and scraping, or with a paint solvent (see pages 402 and 403). If the old painted surface has blistered, it must be rubbed down and scraped. The surface having been prepared in one of the above ways, one or two coats of paint are applied as in the case of painting new iron and steel-work.

Painting plastered surfaces:—The free alkalies in new lime and cement plaster will destroy the oil in paint and prevent the paint from drying. Further, the alkalies in the plaster will bleach and discolour the paint. Hence painting should be avoided on a freshly plastered surface for at least six months and in such cases the plastered sur-
face should be white or colour-washed in the first instance. New cement plastered surface should be given a wash composed of 5 lbs. of zinc sulphate added to a gallon of pure water and when dry given a coat of pure raw linseed oil. Alternatively, the surface may be treated with dilute sulphuric or hydrochloric acid (1 part acid to 50 parts pure water) and then washed down with water. The acid should be added to the water and not water to the acid.

The plastered surfaces and brickwork should be given a coat of sizing (glue mixed with water) before applying paint. It will fill up all the cracks and dents, and reduce suction. Otherwise, the oil in the paint would be sucked up and dry patches left on the surface. The plastered surfaces may also be given a coat of boiled linseed oil prior to the application of paint. The surfaces should generally be given four coats of oil paint.

The first two coats of paint may consist of white-lead and boiled linseed oil. The third coat may be of white-lead tinted to approach the desired colour and mixed with raw or boiled linseed oil and a small proportion of turps. The fourth or last or finishing coat may contain a large proportion of turps with a little varnish to serve as a binder and applied when the previous coat is still tacky. Paints are now available in the market which can be applied directly on new plastered surfaces.

Painting damp walls: Put 2½ gallons of paraffin, 2 gallons of benzoline and 14 lbs. of pale resin in a vessel, when completely dissolved, add 24 lbs. of whiting (powered chalk) and grind the whole mixture well. Keep the mixture air-tight to prevent drying. Apply on damp walls as ordinary paint one or two coats according to
dampness. It will dry hard. Paint can then be applied on it in the usual manner.

The surface to be painted should, as a rule, be clean and thoroughly dry. The surface to be ultimately painted should not be tarred. A coat of tar, even though very old, bleeds through the paint and spoils it. If it is unavoidable, two coats of good shellac knotting varnish should be applied after scraping the tarred surface, and then the paint should be applied carefully.

The painting work should be commenced from the top and should progress downwards. The brush should be of good bristles. The brush should be held at right angles to the surface and only the ends of the bristles should touch it. The work should be carried out as fast as possible so that one portion of a surface will not have dried before the next is commenced.

**Brushes for Painting work:** For painting work, only bristle brushes should be used; horse hair brushes should not be used as they are inferior in all respects to bristle brushes. Bristles can be distinguished by the fact that each bristle is split at ends. Further, horse hair curls up, whereas a bristle remains straight. A good brush should have springiness in the bristles. A round brush is usually considered the best for painting. The following sizes of brushes are in common use:

(a) For dusting large flat surfaces, size 12 or 14.
(b) For girder work, size 8.
(c) For woodwork, size 6.
(d) For fine work, sizes 2 and 4.

New brushes should be kept in water (covering the bristles only) for about two hours and then allowed to dry for one hour before use. After use, the brushes should be carefully cleaned with the aid of kerosene oil. Old
brushes should be kept either in raw linseed oil or water (covering the bristles only) when not in use.

Spray painting:—Spray painting is done by spraying an atomised paint with a spraying pistol, worked by compressed air, so as to form a thin, uniform coat of paint on the surface. A spray-painted surface gives an elegance and perfection, which cannot be easily achieved by hand-painting with brushes. Further, the work can be executed at a greater speed and very artistic effects can be produced on the surface by spray-painting. Two coats of spray are sufficient where three or even four of brush painting are required. All high-class painting on metal or wood is done by spray-painting. Special paints suitable for spray-painting are now available in India in different colours and most of them are the products of English and American companies.

2. VARNISHES AND VARNISHING.

Varnish:—This is a solution of resin (or resinous substance) in either oil, turpentine or alcohol. The liquid dries or evaporates (oil dries and turpentine and alcohol evaporate) and leaves a hard, transparent, glossy film of resin on the varnished surface.

Uses of varnish:—Varnish is applied (a) to give brilliancy to the painted surfaces and to protect them from atmospheric influences, and (b) to intensify and brighten the ornamental appearance of the grains of wood on unpainted wood surfaces and to protect the wood from atmospheric action. At present, painted surfaces are rarely varnished. Varnish is most generally applied to ornamental woods.

Characteristics of a good varnish:—A good varnish should have the following characteristics:—

(a) It should dry rapidly.
(409)

(b) It should form a hard, tough, resistant-to-wear and durable film when dry.
(c) It should not crack in drying.
(d) Its colour should not fade or change under atmospheric action.
(e) It should give gloss.
(f) It should appear uniform and pleasing, when dry.

**Ingredients of a varnish:**—The following are the ingredients of a varnish:

(a) **Resins or resinous substances**—The quality of resin greatly influences that of the varnish. Amber, common rosin, copal, gum dammer, mastic and lac (or shellac) are some of the principal resins. Common rosin, lac or shellac and copal are most generally used in varnishes. *Common Rosin* or *Rosin* is obtained from the exudation of some varieties of pine trees. *Lac* or *shellac* is made from the exudation of a kind of insects which grow on some kinds of trees in India. *Copal* is a hard, lustrous resin, which is sometimes colourless and transparent but often of a bright, yellowish, brown colour. The best copal, called *ripe copal* or *fossil copal*, is found embedded in the earth in places, where forests of trees of pine variety existed. The *raw copal*, obtained from standing pine trees, is used to make inferior varnishes.

(b) **Solvents**:—Boiled linseed oil, turpentine, methylated spirits of wine and wood naphtha are examples of solvents. The solvent used must be suitable to the resin it has to dissolve. Thus, *boiled linseed oil* is used to dissolve copal or amber; *turpentine* for common rosin, mastic and gum dammar; and *methylated spirit of wine* for shellac or lac. *Wood naphtha* is used for cheap varnishes. It is less brilliant and has an offensive smell.
(e) **Driers**—The driers commonly used in varnishes are litharge, sugar of lead or lead acetate and white copperas.

**Different kinds of varnishes**—Varnishes are classified as **oil, turpentine, spirit or water varnishes**, according to the solvent used.

(a) **Oil varnishes**—These varnishes are made from the hardest resins such as amber, copal, etc. dissolved in linseed oil with turpentine. *English copal* is considered to be the best. Oil varnishes take some time to dry, but are the hardest and most durable of all varnishes. They are very suitable for exposed works or those which require polishing or frequent cleaning. They are used for the joinery and fittings of houses and for all outside work.

If the oil varnishes are too thick, they may be thinned by means of spirits of turpentine.

**Superfine copal varnish** is an oil varnish which is considered to be the best as it produces a higher gloss and smoother finish. *Copal Varnish* is made by dissolving copal in linseed oil and mixing some turps. It is used for superior work and dries in about 24 hours.

**Flatting varnish** is an oil varnish with a high proportion of resin. It dries glossy, but brittle. Hence the finishing coat should be gently rubbed with waterproof sand-paper to obtain a smooth surface.

**Japan** is white or coloured lead paint ground in oil and mixed with copal varnish. It is applied in several successive coats, each coat being allowed to dry before the next coat is applied. The surface is finally treated with several coats of superfine varnish to obtain a smooth and brilliant finish. It stands a high temperature and is used in baths and other metalwork subjected to heat.
(b) Turpentine varnishes:—These are made from soft resins such as gum dammar, mastic, common resin, etc. dissolved in pure spirits of turpentine. Turpentine varnishes are cheaper, more flexible, dry quicker and are lighter in colour than oil varnishes. But they are not as tough and durable as oil varnishes.

(c) Spirit varnishes or Lacquers:—These are made from soft resins such as shellac, etc. dissolved in methylated spirits of wine. They dry quicker and become harder and more brilliant than turpentine varnishes, but are apt to crack and scale off and do not stand weathering. They are mostly used for furniture. French polishes and shellac varnishes belong to this class.

French polish.—This is a high-class spirit varnish, and is made by dissolving 1½ lb. of black or light brown shellac in 1 gallon of methylated spirit without heat. The polish may be coloured with some colouring pigment. French polish dries within a few minutes and gives a fine glossy finish. It is used on superior woodwork, hand-rails, furniture, etc.

French polishing is done as follows:—The wood surface to be French polished is first cleaned of all dirt and dust, and then sand-papered. The prepared surface is then given a coat of one of the filler compounds given below.

(i) Whiting mixed with either water or methylated spirit.
(ii) Linseed oil and beeswax (3:1) boiled.
(iii) Plaster of Paris in either water or raw linseed oil.

The filler coat is allowed to dry thoroughly and the surface is rubbed down with sand-paper. The French
polish is then applied sparingly with a suitable rag. It dries up in three or four minutes. The surface is then lightly rubbed with very fine used sand-paper and wiped with a clean dry cloth, and the process is repeated several times in succession until the required finish is achieved. The rag may be dabbed with a drop of olive or mustard oil after each coat to allow a smooth working and finish.

**Furniture polish**—The following composition will make an excellent furniture polish:

- 4 gallons of linseed oil
- 1/4 gallon of methylated spirit
- 1/4 gallon of vinegar
- 1/4 gallon of turps
- 1/4 gallon of Copal varnish
- 3/16 gallon of hydrochloric acid.

The linseed oil should first be heated and the whole mixed up.

**Lacquer for brass** is made by dissolving with agitation 1 1/2 lbs. of pale shellac in 1 gallon of methylated spirit.

**(d) Water varnishes**—These consist of shellac dissolved in hot water mixed with just so much ammonia, borax, potash or soda, as will dissolve the shellac. Water varnishes are used for varnishing wall-papers, maps, pictures, etc.

**Stains** are liquid preparations applied to cheap light-coloured woods to give them the appearance of highly coloured woods of superior quality. The colouring pigments and proportions vary according to the shade of colour required.
Incombustible varnish for wood—Wood cannot be made fire-proof, but it may be made fire-resisting to a certain degree. An application of equal parts of alum and isinglass to the place exposed to the flame prevents ignition, but not transmission of heat. By coating wooden vessels with this varnish fluids may be boiled in them over an ordinary fire.

Varnishing or application of varnish.—Before applying varnish to any woodwork, it must be thoroughly seasoned, and the surface to be varnished must be made perfectly smooth with sand-paper. The woodwork when prepared should be sized with a coat of thin, clear glue to which a little brown earth and ochre should be added if the wood is of oily nature and the varnish does not readily dry from this cause. The glue size should be applied hot and rubbed down smooth. A second coat of thin clean glue (in which some desired colouring matter should be added) should then be applied, allowed to dry perfectly and rubbed down smooth with fine sand-paper. One lb. of glue will make about a gallon of glue. Sizing is done to close up the pores and to prevent the varnish being readily absorbed. Two coats of boiled linseed oil can be given instead of glue size. Everything should be quite clean and the work protected from dust and smoke. Varnish should be applied uniformly in very thin coats, and sparingly at angles or corners. Each coat of varnish should have thoroughly dried before the next coat is applied. The finished surface should be even and glossy. One gallon of varnish will cover about 1200 sq. ft. of surface, single coat.

Varnish applied to painted surfaces is liable to crack if the paint contains inferior oil or too much oil; cracking is due to unequal drying of the paint and the varnish and consequent unequal contractions. Good varnish should
dry hard within 2 days, and be free from stickiness. Varnishing and painting should be avoided on stormy and rainy seasons. Varnishing is generally prescribed for interior works and painting for exterior works.

**Graining** is imitating the colour and grains of wood upon any painted surface.

### 3. DISTEMPERS AND DISTEMPERING

Distempers are paints consisting of whiting (powdered chalk) and some colouring pigments and size mixed in water. **White distempers** are made by mixing only whiting and size. **Coloured distempers** are prepared by tinting the whiting with the required colouring matter before mixing it with size. Distempers are cheaper than paints and varnishes and are used as a finishing coat over plastered and white-washed interior walls. They present a smoother and more agreeable appearance than ordinary wash and are more durable. High-class distempers may be used externally on cement or brick surfaces.

The following is a recipe for distemper: Take 6 lbs. of whiting and soak it in soft water sufficient to cover it for several hours. Pour off the water, stir the whiting into a smooth paste, strain the material and add 1/4 gallon of size in the form of weak jelly. Mix carefully not breaking the lumps of jelly, then strain through muslin, and use after adding colouring matter as desired. Keep the distemper in a cool place and dilute with water if required.

Ready-mixed distempers are available nowadays, with directions for use. They are sold in tins in the form of a stiff paste or dry powder. All prepared distempers are mixed with water before use. **Hall's, Shalimar, and Muraline** distempers are generally used. Muraline distempers have the greatest covering capacity and can be applied to wood also with good results.
Distempering or application of distemper:—Distempering should be done in the following stages:

(a) Preparation of surface:—The surface to be distempered must be carefully cleaned of all dust, dirt, etc., and it should be absolutely dry. New plastered surfaces should be allowed to dry for at least two months prior to the application of distemper and they should be washed either with a solution of 1 part vinegar to 12 parts of water, or with a solution of 1 part sulphuric acid to 50 parts of water and left for about 24 hours, after which the surfaces should be thoroughly washed with clean water. If the plaster contains cement, the surface should be washed over with a solution of 1 lb. of zinc sulphate in one gallon of water and then allowed to dry; before distempering, it should be wiped with clean cloths to remove any efflorescence. Old distempered walls should be well cleaned and brushed and should be thoroughly washed with water; non-washable distempers should be carefully removed. All nails should be carefully removed without damaging the plaster, and all holes and cracks should be filled with lime putty. If the surface to be distempered, whether new or old, is rough, a coat of whiting mixed with a solution of glue should be applied.

(b) Application of coats of distemper:—The surface having been prepared above, a priming coat should be applied and allowed to dry. For local-made distempers a priming coat of milk is generally used. For ready-mixed distempers, the priming coat should be as recommended by the makers. Over the priming coat, coats of distemper of good quality should be applied uniformly in succession. The second coat should be applied only after the first coat had become hard. Distempers should be applied with broad stiff brushes in dry weather. On new plastered
walls distempers should be applied in two or three coats over one coat of priming. On old lime-plastered walls, covered with one or two coats of hard dry white-wash, one coat of distemper without priming can be used, but a coating of warm glue is useful.

In applying the distemper, the brush should first be applied vertically and then immediately crossed off horizontally. Brushing should not be continued too long as the distemper becomes sticky and brush marks result. After each day's work the brushes should be thoroughly washed in hot water.

Distempers give poor results in damp places; alternate wetting and drying cause peeling, flaking and blistering. Distempering should not be done in damp weather.

4. WAX POLISHING, PAPERING, GLAZING, ETC.

(1) **Wax polishing or waxing**—Wax polish is made by dissolving 1 part of beeswax in 2 parts of spirits of turpentine. The woodwork should be smeared with wax polish, and allowed for about 12 hours to soak into the pores of the wood, superfluous stuff should then be wiped off with clean flannel-like cloths, and rubbed with a soft flannel until the required finish is obtained. Before wax polishing, all dirty spots should be well cleaned with clean soft cloths, soaked with benzine. The whole surface to be waxed or wax polished should be dusted with a dust mop before attempting to apply the wax polish.

(2) **Wood oiling**—Wood oiling is sometimes done as a substitute for painting on woodwork not exposed to weather. It consists of linseed oil with a small quantity of *gum dammar* or red ochre boiled up in it. Other recipes for wood oil are given below:
(417)

(a) Linseed oilling:—1 lb. of beeswax and 3 lbs. of double boiled linseed oil are heated in a vessel over a slow fire till the beeswax is melted; this mixture is allowed to cool, and then 1 lb. of turps is added to it and applied in two coats. This will cover about 850 sq. ft. of surface.

(b) Sweet oilling:—Equal parts of common vinegar, country sweet oil and spirits of turpentine are mixed and used. This gives a darker effect than the linseed oilling.

A mixture of oil and water should never be used. Only well-seasoned wood should be oiled or painted.

(3) Coal tarring:—The coal tar is heated nearly to boiling point, and thinned by the addition of 1/16 gallon of common country spirit to each gallon of tar. Two pounds of quick lime should also be mixed with each gallon of tar to prevent its running. The mixture should be applied hot. If possible, the ironwork would be heated to less than red heat and then tar brushed over. Before coal-tarring, the woodwork or ironwork should be well cleaned of all dust, dirt, etc., and the surface should be completely dry. Ten pounds of coal-tar should be applied for every 100 sq. ft. of surface.

(4) Whitening:—Whitening mixed with size and water is used for whitening walls and ceilings. As already mentioned, whitening is made by reducing pure white chalk to a fine powder.

(5) Papering:—The surface to be papered must be scraped and rubbed down free of white or colour-wash or dirt before paper is applied. Adhesive paste should be made of the best flour with water and a little size or glue. The addition of a small quantity of alum makes the paste flow more easily, while a little blue stone (copper sulphate) prevents the attack of insects. A brush should be used
to coat the paper with paste; as the paper is put on the wall, it should be smoothed with a roller covered with clean flannel, and not by hand. If expensive paper is issued, the surface should first be covered with a coating of lining paper which should be quite dry before the costly or high-class paper is put on. The papers used for papering are Common or Pulp paper, Satin paper and Flock paper. The first type is most generally used for ordinary purposes. The second type can be kept clean, but is affected by damp. The third type looks nice, but easily catches dust. Papering is not suitable in damp climates and places infested with white-ants. It is not much used in this country.

(6) Glazing—Glazing is the work of fixing panes of glass in window, door and other frames. The glass can generally be obtained from the manufacturers, but if not so available, can be cut with a glazier’s diamond (see Fig. 1275). Sheet glass is generally used for all ordinary purposes. Ordinary window glass is generally 1/16 in thick, weighing 21 oz. per sq. ft., known in the trade as “seconds”. The glass panes are usually fixed in the framing by glazier’s putty, made of finely powdered white chalk and raw linseed oil, kneaded into a stiff paste which will just not adhere to the fingers. All glass should be properly bedded to the frame with putty; i.e., there should be putty on both sides of the glass. If the weight of a pane of glass is considerable, small pieces of wood or lead may be inserted to prevent it settling while the putty
is soft. Before fixing the glass panes, the frames should be primed and prepared as for painting, as otherwise the bare wood will absorb the oil in the putty, and the putty will be liable to shrink and fall out. Common glazing with putty is shown in Figs. 1276 and 1277.

![Diagram of glass pane with putty](image)

Figs. 1276 and 1277.

Common putty glazing.

Canada balsam, which dissolves readily in alcohol and sets firm by exposure to air, is an excellent adhesive for glass. It is colourless and has the same refractive index as glass.

To soften putty to remove glass panes:—To 3 lbs. of quicklime, slaked in water, 1 lb. of pearl ash is added, and the mixture is well stirred and brought to the consistency of cream by the addition of water. The mixture is applied to both sides of the glass panes and left for about 12 hours when the putty will be softened. Then the glass panes may be removed easily.
CHAPTER XVI

QUESTIONS FOR REVISION

1. Write short notes on the following —
   (i) Constituents of a paint and their function.
       (University of Baroda, 1954).
   (ii) Distempers. (Karnatak University, 1954).
   (iii) Oil painting of walls plastered with cement mortar and neeru finish.
       (University of Bombay, 1953).
   (iv) Characteristics and uses of varnishes.
       (University of Bombay, 1954).

2. Give a brief account of the materials used for chief components of paints, and explain the purpose of each component in the painting process.
   (University of Bombay, 1953).

3. What is the use of a paint? What are its constituents and what are their functions?
   (Gujarat University, 1954 and A.M.I.E. 1950 and 1951).

4. Write short notes on —
   (a) Distempers. (Karnatak University, 1954).
   (b) Constituents of a paint and their function.
       (University of Baroda, 1954).
   (c) Varnishes. (University of Bombay, 1954).
Compositions and relative merits of dis­
tempers and colour washes.

(A. M. I. E., 1953).

5. Enumerate the precautions to be taken (i) in
painting the outside surface of a new wall exposed to
weather, (ii) in painting old ironwork which is blistered
and shows signs of rust.


6. Give the relative merits of (i) oil, (ii) turpen­
tine, (iii) spirit and (iv) water varnishes.


7. How would you remove the old paint from an
ironwork?


8. In painting by brush, would you prefer two or
more thin coats, or one thick coat of similar thickness?
Give reasons.


9. (a) Where would you specially recommend the
following paints:—

(1) Solignum, (2) Graphite.

(b) What is the effect of painting over unsea­
soned wood?

(c) What are the advantages and disadvantages
of hand painting and spray painting?

(A. M. I. E., 1951).

10. What is paint? State the function of the pig­
ment in a paint.

(A. M. I. E., 1951).

11. What is the difference between a paint, a varnish
and an enamel?


1. Pigment is often called "base" and should not be confused
with colouring pigments.

13. (a) What is varnish and why is it used? What are the qualities to be sought for in a good varnish? (A. M. I. E., 1951 and 1952).

(b) Classify the different kinds of varnish and give a description of each. (A. M. I. E., 1952).

14. How would you proceed to paint (a) a new wooden panelled door, and (b) a new steel roof truss of a workshop? (A. M. I. E., 1952).

15. (a) What are the characteristics of a good paint?

(b) Describe in detail the method of removing old paint from woodwork and repainting it. (A. M. I. E., 1953).

16. Give the compositions of a French polish and explain how it is applied. (A. M. I. E. 1953)
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<td>Solutions of Problems in Irrigation Engineering</td>
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<tr>
<td>37</td>
<td>Irrigation Engineering in Questions &amp; Answers</td>
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<td>Civil Engineering Drawing &amp; Design</td>
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<td>39</td>
<td>Solutions of Problems in Structural Drawing &amp; Design</td>
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