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This volume is the second in the series of three textbooks covering Building Construction.

This book is designed primarily for Building students studying externally through the TAFE External Studies College, but its wider usefulness to students in the Building Studies area throughout TAFE W.A. will quickly become apparent.

Volume 2 deals with the more specialised techniques required in the construction of large domestic and smaller commercial buildings, and general construction on difficult sites. It therefore fits in well between Volume 1 - which deals mainly with domestic construction - and Volume 3 - which covers multi-story (including 'high-rise') and other sophisticated building techniques.

As pointed out in the Introduction to Volume 1, new ideas, materials and methods are continually coming onto the market. Students should therefore obtain any new information they can acquire and incorporate it in this text - which can be placed in a loose-leaf file if desired.
Chapter 1

DEMOLITION

1.1 INTRODUCTION

1.2 PRELIMINARY APPLICATIONS AND APPROVALS
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1.7 PUBLIC SAFETY
   INTRODUCTION
   NUISANCES
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   REMOVAL OF DEBRIS

1.8 FURTHER READING
1.1 INTRODUCTION

Many builders may feel competent to undertake the simple demolition of low-rise buildings. However, the limited range of experience possessed by some builders may be inadequate for the safe and economical demolition of larger structures involving more complex designs.

Demolition firms specialise in the operations and techniques involved in the removal of structures. As nominated or general sub-contractors, they may be engaged on sites in accordance with the conditions of specific contracts. Usually the demolished materials become the property of the demolition contractor, but sometimes fittings and fixtures may be removed by the owner for re-use or for sale.

During the sequence of demolition operations, essential procedures and limitations must be strictly enforced to ensure the safety of nearby properties, the workmen, and the general public. The following publications stipulate the principal hazards involved in the demolishing of buildings and the safe-working practices required on demolition sites:

- The Uniform Building By-Laws
- The Construction Safety Regulations
- Standards Association of Australia codes of practice
  
  AS 2436: Demolition of Buildings, and Noise Control
  AS 2601: Demolition of Structures.

1.2 PRELIMINARY APPLICATIONS AND APPROVALS

Prior to any demolition work being carried out the contractor must submit an application for a demolition licence - see Appendix A (U.B.B.).

Then, bait the entire building for possible vermin habitation and leave for seven days. A demolition licence will be issued when proof of rat baiting has been shown - see Appendix B (U.B.B.).

THE LIABILITIES OF THE CONTRACTOR

1. The contractor must take out all necessary Insurance policies, especially:
   
   (a) Public Risk                      compulsory
   (b) Workers Compensation            compulsory.

2. The contractor must pay all fees and charges, including:
   
   (a) Footpath deposit
   (b) Parking meter fees (removed or hooded).
3. Clauses within the Uniform Building By-Laws and the
Construction Safety Regulations of the Department of Labour
and Industry (cl. 79, 92, 133-140) clearly outline the
responsibilities of the contractor, with respect to proposed
demolition of existing buildings.

DESTRUCTION LICENCE (FORM 7)

The application for a demolition licence (Form 3) must be accom-
panied with full particulars of the location of the building, and
the extent of demolition intended.

Form 3
Local Government Act 1960
Application No..................................................
..................................................................................
(Name of Municipality)
APPLICATION FOR DEMOLITION LICENCE

To the Building Surveyor:
Application is hereby made for a licence to demolish/remove the building referred to in
the undermentioned particulars:
Situation: Ward........................................Street..................Street No..............
Town Lot.............................................Subdivision...........................................
Type of Building.................................................................................................
(Here describe type of construction, i.e., Brick, Timber Frame, etc.)
Number of Storeys....................
(Note: If demolition is of part of building only, applicant should set out particulars of
demolition work to be performed.)
Owner's Name And Address .................................................................
Demolition Contractor's
Name And Address ..............................................................................

Signature of Applicant...........................................................................
Date..................................................19........
Form 7
Local Government Act 1960
Licence No ........................................ Date ............ 19.......
__________________________________________
(Name of Municipality)
DEMOLITION LICENCE

Granted to (Owner’s Name) ..........................................................
Address .............................................................................
Contractor ............................................................................
The abovenamed is hereby authorized to demolish the building or part of the
building situated in .................................................. Street,
Town Lot ................................ Subdivision .................................. particulars
of which proposed demolition work are set out in Application No..

This licence is issued subject to the Uniform Building By-laws 1974, and more
particularly to the following conditions—
1. Before any demolition work commences a certificate shall be obtained from the
Health Surveyor of the council certifying that the building to be demolished has been
treated so as to ensure that it is not infested by rodents.
2. Where the building to be demolished comprises more than one storey, the demolition
shall be effected by the complete removal of one storey after another, commencing with
the uppermost storey and proceeding with the successive removal of the storeys in
descending order.
3. No part of an external wall abutting on a street or road shall be demolished, except
during such hours as are permitted by the Building Surveyor.
4. Unless otherwise authorized by the Building Surveyor, any material removed or
placed from the building shall not be placed upon a floor of the building but shall be
immediately lowered to the ground and thereafter removed from the site, but in no case
shall loading be such as to cause a floor to collapse.
5. Materials removed or displaced from the building shall not be placed in any street,
road or right of way and, before commencing work, as the case may require, shall be
kept sprayed with water so as to prevent any nuisance from dust.
6. Materials removed or displaced from the building being demolished or materials left
standing shall not be burned on the demolition site.
7. Council shall be notified of the existence of any septic tank(s) on the demolition site
seven days prior to the emptying and filling of such tank(s).
8. Any septic tank(s) on demolition site must be emptied and filled with clean sand or
removed entirely and any soakwells, leach drains or similar apparatus must be removed
or filled with clean sand.
9. Notification, within seven days of date of issue of this licence, shall be given to the State
Energy Commission and Postmaster General’s Department now Telecom and
arrangements made for disconnection of these services.
10. Where the building being demolished is more than one storey in height, a hoarding
and an overhead gantry shall be provided to protect pedestrians.
11. A footpath deposit shall be lodged with the council to cover the cost of any
damage caused to footpaths during the demolition operation, against which the actual
cost of repairing any damage will be charged and any unexpended balance refunded to
the person taking out the licence. In the event of the cost of repairs being in excess of
the deposit lodged, the person holding the licence shall, on demand, pay the amount of the
excess to the council.
12. Where necessary, the holder of a licence shall construct a temporary crossing place
over the footpath as specified by the council.
13. Demolition site shall be cleared, and left clean and tidy to the satisfaction of the
Building Surveyor within 90 days of the date of commencement of the demolition work.
14. Fee for this licence;
   Fee for structure of not more than 2 storeys—
   Fee for structure of more than 2 storeys—

..........................................................
Building Surveyor.

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NOTE: A demolition licence (in the form illustrated above) is
void if the work detailed in the application has not
commenced within twelve months from the date of issue of
the licence.

1.4
1.3 AUTHORITIES

One essential condition involved in the issue of a demolition licence is the necessity to notify all relevant statutory authorities and instrumentalities.

The following statutory authorities must be notified, and where applicable, all fees paid and licences obtained, prior to commencement of work:

(a) LOCAL GOVERNMENT AUTHORITY

- Application for demolition licence
- Demolition Licence.

(b) HEALTH DEPARTMENT OF W.A.

- Certificate of vermin eradication
- Disconnection - etc., septic tank systems.

(c) WATER AUTHORITY OF W.A.

- Disconnection - sewer
- Disconnection - water.

(d) STATE ENERGY COMMISSION

- Disconnection - electricity
- Disconnection - gas.

(e) DEPARTMENT OF OCCUPATIONAL HEALTH SAFETY AND WELFARE

Safety standards, Catch boards, scaffolding, etc.

(f) TELECOM AUSTRALIA

Disconnect telephones.

(g) WESTERN AUSTRALIAN FIRE BRIGADES BOARD

Disconnect fire alarm systems and fire fighting equipment

(h) DEPARTMENT OF MINES

- Removal of flammable liquid storage
- Use of explosives in demolition.

(i) COUNCIL PARKING

Removal or hoisting of parking meters.

(j) ROAD TRAFFIC AUTHORITY

Re-routing of traffic.
1.4 SEQUENCE OF OPERATIONS

PRIOR TO STARTING DEMOLITION

1. Arrange temporary services.

2. All gantries, hoardings, fans and scaffolding to be erected, and approved, to protect workers, public and adjoining buildings.

3. Erect signs.

4. Adjoining buildings - check these for any existing defects and:
   (a) verify with owners in writing
   (b) mark and record defects
   (c) photograph, if possible, then if necessary (and quite probable) shore-up and underpin adjoining buildings to prevent collapse - which may not be necessary until demolition is near ground level.

MATERIALS

Unless specified, all materials arising from the demolition, become the property of the demolition contractor.

METHODS - GENERAL

These depend largely on the type of building but during demolition:

(a) remove all debris as demolition proceeds
(b) keep dust nuisance down to a minimum
(c) tone noise down by "hooding" jack hammers
(d) apply all safety precautions.

METHODS - SPECIFIC

1. Remove all glass, doors, sashes, fittings and fixtures, noting and carefully handling re-saleable items.

2. Remove chimney stacks.

3. Remove roof coverings, roof timbers.

4. Then remove most of floor, internal walls, external walls, rest of floor and floor framing.

1.6
5. Continue this sequence floor by floor, making sure each floor is not overloaded if demolishing **inwards**.

6. If possible, demolish outwards using chutes directly into trucks or waste bins.

7. If basements occur, demolish and remove rubble completely to ground floor level.

8. Remove basement structure after assessing construction of adjacent buildings and, if necessary underpin, and shore up, or use chemical injection prior to removing basement structure in case of possible collapse of adjacent building.

1.5 METHODS OF DEMOLITION

The Demolition Code (AS 2601-1983) lists the various methods adopted for demolishing structures, under the following headings:

(a) Hand Demolition

(b) Mechanical Demolition

(c) Demolition by Explosives

(d) Other Methods of Demolition Involving Sophisticated Techniques and Equipment.

Table 1.1 sets out various types of buildings for demolition and recommends the various methods included above. The following legend is utilized.

**LEGEND:**

A denotes hand demolition

B denotes mechanical demolition by pusher arm

C denotes mechanical demolition by deliberate collapse

D denotes mechanical demolition by demolition ball

E denotes demolition by explosives
<table>
<thead>
<tr>
<th>Type of Structure</th>
<th>Type of Construction</th>
<th>Location of Site 1</th>
<th>Location of Site 2</th>
<th>Location of Site 3</th>
<th>Location of Site 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small and med. 2-storey buildings</td>
<td>Load-bearing walls</td>
<td>ABCD</td>
<td>ABD</td>
<td>ABD</td>
<td>AD</td>
</tr>
<tr>
<td>Large buildings 3-storeys and over</td>
<td>Load-bearing walls Load-bearing walls with W.I. and C.I. members</td>
<td>ABDE</td>
<td>ABDE</td>
<td>ABDE</td>
<td>AD</td>
</tr>
<tr>
<td>Framed structures</td>
<td>Structural steel</td>
<td>ACE</td>
<td>AE</td>
<td>AE</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>R.C. in situ</td>
<td>ADE</td>
<td>ADE</td>
<td>ADE</td>
<td>AE</td>
</tr>
<tr>
<td></td>
<td>R.C. precast</td>
<td>ADE</td>
<td>ADE</td>
<td>ADE</td>
<td>AE</td>
</tr>
<tr>
<td></td>
<td>R.C. prestressed</td>
<td>See text</td>
<td>See text</td>
<td>See text</td>
<td>See text</td>
</tr>
<tr>
<td></td>
<td>Composite - structural steel and R.C.</td>
<td>ADE</td>
<td>ADE</td>
<td>ADE</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Timber</td>
<td>A</td>
<td>A</td>
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<td>A</td>
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<tr>
<td>Cantilevers (canopies, balconies and staircases)</td>
<td>(independent of a framed structure)</td>
<td>ADE</td>
<td>ADE</td>
<td>ADE</td>
<td>ADE</td>
</tr>
<tr>
<td>Bridges</td>
<td></td>
<td>ACE</td>
<td>ACE</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Masonry arches</td>
<td></td>
<td>ACDE</td>
<td>ACDE</td>
<td>ACDE</td>
<td>ACDE</td>
</tr>
<tr>
<td>Chimneys</td>
<td>Brick or masonry</td>
<td>ACDE</td>
<td>A</td>
<td>ACDE</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Steel</td>
<td>ACE</td>
<td>A</td>
<td>AE</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>R.C. in situ and precast</td>
<td>ADE</td>
<td>A</td>
<td>ADE</td>
<td>A</td>
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<tr>
<td></td>
<td>Plastics reinforced</td>
<td>A</td>
<td>A</td>
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</tr>
<tr>
<td>Spires</td>
<td></td>
<td>ACDE</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Pylons &amp; masts</td>
<td></td>
<td>ACE</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Petroleum tanks</td>
<td></td>
<td>See text</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special structures</td>
<td></td>
<td>See text</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HAND DEMOLITION

Confined sites and saleable materials demand a substantial amount of hand work involving the use of portable electric and pneumatic tools and oxy-acetylene equipment.

Roof sheeting, plate glass, joinery, structural timber trusses, rolled steel sections all have salvage value and usually warrant due care. This must include lowering to the ground rather than dropping. (See Figures 1.1, 1.2 and 1.3).

**Figure 1.1**

**Sequence of Operations**

1. Ensure all loads, other than self-weight, are removed from beam.
2. Secure rope to end of beam.
3. Expose reinforcement at ends A and B.
4. Cut reinforcement at positions 1, 2 and 3 respectively.
5. Lower beam to floor.
6. Refix rope to end B, cut at position 4 and lower beam to floor.
REINFORCED CONCRETE FLOORS

Hand Demolition of In-situ Reinforced Concrete Structures

Figure 1.2

REINFORCED CONCRETE COLUMNS

Sequence of Operations

1. Ensure all loads, other than self weight, are removed from column.

2. Secure and tension two wire guy ropes to the top of the column. Rope 'X' is to prevent unintentional collapse in the wrong direction and finally for pulling column over. Rope 'Y' is to prevent unintentional collapse in the direction of winch.

3. Expose reinforcement on side opposite to required direction of fall. The height of concrete cut, dimension A, should be restricted to a minimum to prevent the possible uncontrolled collapse of the column.

1.10
4. Cut reinforcement at position (1) on side opposite to required direction of fall.

5. With all workers in positions of safety, release the anchorage of rope 'Y' and pull the column over with rope 'X'.

**REINFORCED CONCRETE WALLS**

![Diagram of reinforced concrete walls]

*Figure 1.4*

**Sequence of operations**

1. Ensure all loads, other than self-weight, are removed from wall.

2. Cut slots in wall.

3. Proceed as for R.C. Columns; see Figure 1.3.

**MECHANICAL METHODS OF DEMOLITION**

1. **Deliberate Collapse and Felling**

   Isolated buildings, towers, pylons or chimneys may be demolished by these methods.

   They must have a clear space on all sides of at least one and a half times the height of the structure to be demolished.

   The structure is usually first weakened at the base as much as is safe, especially on the side of the desired fall. It is then collapsed or overturned by means of a winch, a rope or the remotely controlled removal of the remaining supports by explosives or other means. (See Figure 1.5).
Demolition of Masonry and Brick Chimneys

Figure 1.5

2. Wire Rope Pulling

A well-anchored winch provides a versatile and highly controllable method of demolishing sections. However, apart from the obvious risk of flying debris, there is the particular hazard of the rope snapping under tension and behaving like a stock-whip out of control. Another risk is the need to manually connect the rope to the structure: an unsuccessful attempt to pull part of a structure may render it unsafe for personnel to approach. Refer to Figure 1.6.

Sequence of Operations

1. Fix spreader.
2. Take up slack on rope.
3. Partially cut posts at (A).
4. Completely cut posts at (B).
5. Pull over.
Demolition of Pylons and Masts

Figure 1.6

3. Demolition Ball

A cast steel weight suspended on a slewing-jib crane facilitates rapid demolition of masonry. The height limit for this method is about 30 m and a surrounding clear space of 6 m or half the height of the building is essential. The ball may be dropped onto horizontal members. For walls and columns, the ball may be slewed or swung in line with the jib.

4. Pusher Arm

This is a steel jib arm fixed to a track or wheel-mounted tractor. The arm is used to push over small sections of masonry and must be applied to the structure within 600 mm of the top of the wall. It is useful for demolishing buildings up to 10 m high with a surrounding clear space exceeding 6 m.

DEMOLITION BY EXPLOSIVES

The well-known means of rapid demolition by explosives, presents a number of problems in confined sites and built-up areas.
Flying debris must be contained by blast mats, while the size of charges should be kept down to limits dictated by the likely nuisance or damage effects.

OTHER METHODS OF DEMOLITION

There are a number of other highly specialized techniques that can be used when normal methods would be unsuitable because of nuisance or other reasons. The oxygen lance (also called a thermic lance) is one which utilizes the oxygen-cutting principle on a large scale. It is capable of piercing thick concrete. C.C.R. "an explosive that is not classified as an explosive", is another: it is used in a similar manner to normal explosives; however it is safer, causes less noise and has no shock wave. Refer to Figure 1.7.

Post-tensioned Structures

Figure 1.7
1.6 SAFE WORKING PRACTICES

SPECIALIST CONTRACTORS

Many operations require special consideration or expertise. Where any doubt exists, a chartered engineer should be consulted, or experienced specialist contractors employed.

FUEL TANKS AND LINES

The danger that fuel tanks and lines may explode from a spark may be reduced by filling them with water or inert gas. Another convenient method is to insert 'dry ice' (solid carbon dioxide): 2 kg should be used for every 200 litres of tank capacity and at least 12 hours allowed before sealing the tank. To prevent sparks, only non-ferrous tools should be used.

CELLARS

There are two potential problems associated with cellars. First, their ability to collect water which may be overcome by cutting holes through the cellar floor for drainage. Second, a high water table may cause flotation when the weight of the super structure is removed; this, too, may be prevented by cutting holes to allow water to penetrate.

UNSTABLE STRUCTURES

Where possible, these may be collapsed by safe or remote means. Otherwise, they must be scaffolded and shored to facilitate progressive hand demolition.

PLANNING

From the survey information gained it is possible to formulate a safe, efficient schedule of work. This will take into account:

- the materials to be salvaged, equipment to be used, the techniques available, the type and size of the structure, any especially hazardous aspects, the size and expertise of the crew, restrictions on contract time, proximity and nature of adjacent buildings, the need for shoring and the materials to be re-used.

SHORING AND UNDERPINNING

Any parts of the structure that may be subjected to excessive loads or stresses during demolition, must be shored up. Lower floors and beams, for example, may have to support heavy plant and equipment or accumulated debris. Shoring or other forms of
strengthening must also be provided for parts of the building which are to be left and for adjoining buildings made unstable by the work. See Figure 1.8.

Left, Building Prepared for Demolition and Right, Demolition in Progress

Figure 1.8

1.7 PUBLIC SAFETY

INTRODUCTION

All necessary precautions must be taken to ensure the safety of the public and to avoid inconvenience to them. Measures usually required are fans, nets, gantries and hoardings. These deflect falling debris inwards and contain it; they also prevent public access to the site. (See Figures 1.8 and 1.9.)

Any obstructions such as gantries should be painted white or a bright colour and be illuminated at night.

NOTE: The construction safety regulations contain full details of requirements for construction of fans, hoardings and gantries.
SIDE ELEVATION - VIEW X
All bolts to be 12 Ø

SECTION
FREE-STANDING TIMBER GANTRIES

Figure 1.9
(Reproduced by courtesy of the Attorney General)
NUISANCES

Dust, noise, vibration and smoke are common sources of complaints from nearby occupants. Some techniques used to alleviate these problems are:

- spray debris with water
- use tarpaulins
- demolish progressively inwards
- always leave external walls until last
- use chutes or other methods to lower material from upper floors
- use suitable mufflers on equipment
- adjust working hours so that nuisance operations are carried out before or after working hours, or at weekends.

INCLEMENT WEATHER

It is often necessary during demolition operations to expose sections of a building to be retained, or valuable objects, or materials which would suffer damage from rain. At other times unstable portions of the structure will not withstand winds. These contingencies should be planned for. Weather forecasts are often a sufficient guide to the necessary action. When doubt exists, the schedule should be changed or suitable protective measures taken.

REMOVAL OF DEBRIS

Debris must not be allowed to build up on floors or against walls, but should be removed as it accumulates. Lateral pressure on lower walls could easily result in collapse.

1.8 FURTHER READING

- *S.A.A. Demolition of Buildings - Noise Control AS 2436/1* by the Standards Association of Australia.
Chapter 2

SHORING

2.1 INTRODUCTION

2.2 TYPES OF SHORING
   DEAD SHORES
   RAKING SHORES
   FLYING SHORES

2.3 TUBULAR STEEL SCAFFOLDING

2.4 PREPARATION OF BUILDING FOR SHORING

2.1 INTRODUCTION

Shoring is the means of providing temporary support to a structure until it is made stable by permanent structural work. It is necessary whenever there is a possibility of collapse, overturning or subsidence.

Subsidence of foundations can be caused by earth tremor, adjacent excavation, lowering of the water table, and so on. Shoring prevents further subsidence and resists any tendency of the building to overturn.

The removal of a wall, or part of a wall, to be replaced by a beam requires that floors, roofs and remaining sections of the wall be supported to avoid collapse. Here the main task is to support dead weight although it is also wise to stabilize the wall laterally.

This chapter describes the principles of shoring. For simplicity, timber will be considered because timber has several characteristics that ensure its continued use for this purpose, but steel is being used increasingly. Steel shoring is often purposely built from suitably-sized tube or universal beam sections or fabricated from standard scaffolding. There are also patented steel shoring systems and you should seek further information about these from manufacturers or suppliers. Adjustment of steel is usually achieved by screw jacks, whereas timber is invariably wedged.

No attempt will be made to explore the many individual problems that occur in special situations; in any case, major shoring jobs would have to be engineer-designed, and erected by specialist sub-contracting firms.
2.2 TYPES OF SHORING

There are two types of shores: those that support the dead weight of a structure, and those that provide lateral stability. In practice, however, it is normal to speak of three types:

- **dead shores** - to support dead load
- **raking shores** - to give lateral stability by shoring from the ground
- **flying shores** - to give lateral stability by shoring from an adjacent building.

(a) **DEAD SHORES OR VERTICAL SHORES**

When a beam, floor or roof is to be supported, it is usually possible to erect vertical shores immediately below them and bearing directly on the underside of the member. Walls or columns are not so simple because the load must be transferred downward alongside the wall or column and outside the centre of gravity.

The common method is to pass horizontal beams - called *needles* through prepared holes cut in the wall. These are propped on both sides of the wall with vertical (dead) shores.

Columns may be supported in a similar fashion by clamping (or bolting, welding, etc.) the needle to the column. Alternatively a collar can be attached or clamped to the column and supported by inclined struts.

*Sole plates*, in all cases, must be of stout section, continuous and bedded evenly over their whole bearing surface and borne on undisturbed or compacted soil or other suitable foundation; for example, concrete floor.

All members must be strongly braced in both directions to prevent any lateral movement. Joints between members must be securely fastened by dogs, fish plates, welding, etc.

Figure 2.1 shows a typical method of shoring a building for the purpose of cutting an opening in a wall. Holes for needles are first cut through the wall at intervals not exceeding 1800 mm and above the position ultimately to be occupied by the permanent beam.

In walls with window openings above, needles must be positioned under the piers. Also, the windows must be firmly strutted to resist deformation.

Once the needles are positioned, vertical shores are erected directly beneath them and resting on folding wedges on the sole plate.
Before tightening the wedges, a bed of cement mortar should be rammed between the upper surface of the needle and the underside of the brickwork to ensure a full solid bearing. Immediately after driving the wedges the whole of the temporary structure must be firmly secured and braced.

The shoring is usually nailed to lock it in place, and, preferably, left to settle for a few days before the demolition begins.

Shoring is dismantled in a definite sequence: first, the shores supporting the floors; second, those under the needles and finally, the rakers.

Imposed loads, such as floors, roofs or beams must be independently shored. They must usually be supported floor by floor, ensuring that the vertical shores are positioned directly above each other, with the weight taken right down to the ground.
Size of Timber Shoring

Many factors must be considered in determining the section sizes of the members. The most obvious is the mass to be supported. Others are:

- the length of shore or needle
- the species of timber and its grading
- whether or not the timber is seasoned
- and the effectiveness and position of bracing to shores.

Axially-loaded sections such as shores and struts are most effective when approximately square. Beams such as needles gain strength mainly with depth, while thickness is important for stability.

Effective Length of Shores

Table 2.1 shows that the load-carrying capacity of a shore varies in inverse proportion to its length (i.e. a longer shore is weaker). As an example, a 2.4 m shore of 125 x 125 section will support 4000 kg, whereas one of the same section but 4.8 m long will support only 1100 kg. If the latter shore is firmly braced at its centre, the effective length (unsupported length) is reduced to 2.4 m, and its capacity is increased to 4000 kg.

![Diagram of shoring](image)

Dead Shores
Buckling Under Load

Figure 2.2

<p>| TABLE 2.1 |
| SUPPORTING CAPACITY OF JARRAH AND KARRI SHORES |</p>
<table>
<thead>
<tr>
<th>SECTION</th>
<th>2.4 m long</th>
<th>3.0 m long</th>
<th>3.6 m</th>
<th>4.2 m</th>
<th>4.8 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 x 100</td>
<td>1 800</td>
<td>1 000 kg</td>
<td>700</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>125 x 125</td>
<td>4 000</td>
<td>3 000 kg</td>
<td>2 000</td>
<td>1 400</td>
<td>1 100</td>
</tr>
<tr>
<td>150 x 150</td>
<td>8 000</td>
<td>6 000 kg</td>
<td>4 000</td>
<td>3 000</td>
<td>2 200</td>
</tr>
<tr>
<td>200 x 200</td>
<td>20 000</td>
<td>16 000 kg</td>
<td>12 000</td>
<td>9 000</td>
<td>7 000</td>
</tr>
<tr>
<td>250 x 250</td>
<td>40 000</td>
<td>35 000 kg</td>
<td>26 000</td>
<td>21 000</td>
<td>17 000</td>
</tr>
<tr>
<td>300 x 300</td>
<td>65 000</td>
<td>53 000 kg</td>
<td>44 000</td>
<td>40 000</td>
<td>32 000</td>
</tr>
</tbody>
</table>
(b) **RAKING SHORE SYSTEMS**

These consist of inclined members called "rakers", supporting the walls at angles of approximately 60° to 75°. The purpose of raking shores is to prevent the wall buckling or overturning.

In large structures, raking shore systems support the walls at each floor level, and are described by the number of rakers in a system:

- **that is:** Single
- Double
- Triple
- Quadruple.
Riding-raking shores occur when the top shore is supported on a short "Jack" shore, to reduce the total length of a single member or to obtain a more structural sound support. Refer to Figure 2.5.

Raking Shores

Figure 2.5

2.6
A wall piece is used to distribute the pressure of the head of the rakers against the wall. The wall piece is 50 - 75 mm thick and about 75 mm wider than the raker and is held in position by mild steel wall-hooks. (See Figures 2.5)

The needles also provide a seating for the rakers and prevent the wall piece from moving; but because of the shear forces involved they must be neatly cut to fit through mortices in the wall piece and into a one course 110 x 110 mm hole in the brickwork. The shearing forces between the needle and the outside face of the wall piece are resisted by a cleat about 100 x 75, housed into the plate as shown. (See Figures 2.5 and 2.6.)

![Diagram of a Needle Joint]

**Detail at a Needle Joint**

*Figure 2.6*

**Position of Rakers**

The thrust from a raking shore imposes a force that tends to bulge or overturn the wall. Rakers are therefore positioned so that they act directly against the floors of the building. Figure 2.7 shows the positioning of the raker.

(a) when joists are at right angles to the wall, and
(b) when joists are parallel to the wall.

If there are no floors it is necessary to erect shores from the inside.
ANGLE OF RAKERS

The effectiveness of a raker against a wall decreases as it nears vertical; the ideal position is horizontal; that is, at a 90° angle to the wall. If the angle to the ground is below about 45° there is danger of failure by soil displacement. Because of this and the need to restrict the space taken up by the shores, the accepted optimum angle is between 45° and 70°. (See Figures 2.8 and 2.9.)

BRACING

Raking shores are seldom required to exert or resist great pressure. However, their length allows them to bend easily and thus they must be firmly braced in both directions.
To prevent sinking, a stout sole plate is bedded into the ground to take the feet of the rakers. It is set at a slope so that it will form an angle of slightly less than 90° to the outside raker. This enables the rakers to be tightened by levering their feet along the sole plate, a method which gives greater control than the use of wedges. Refer to Figure 2.9.
Sole Plate Detail

Figure 2.9

(c) HORIZONTAL OR FLYING SHORES

On small and congested sites it may be possible and convenient to stabilize a wall by means of flying shores braced against an adjacent building. In its simplest form this procedure consists of a beam wedged between the buildings. (See Figure 2.10(c).)

Where several floors are involved raking struts are added, and at least one beam is used. (Figure 2.10(a).) Note that struts are always in pairs to equalize any bending stress in the beam. (See Figure 2.10(b).)

Different floor heights require raking shores of different dimensions, (See Table 2.3).

**TABLE 2.3**

<table>
<thead>
<tr>
<th>Ht. Wall m</th>
<th>Rakers per set</th>
<th>Size of rakers mm</th>
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<tbody>
<tr>
<td>4.50</td>
<td>1</td>
<td>125 x 125 or 150 x 100</td>
</tr>
<tr>
<td>6.00</td>
<td>2</td>
<td>125 x 125</td>
</tr>
<tr>
<td>7.50</td>
<td>2</td>
<td>150 x 150</td>
</tr>
<tr>
<td>9.00</td>
<td>3</td>
<td>200 x 125</td>
</tr>
<tr>
<td>10.50</td>
<td>3</td>
<td>175 x 175</td>
</tr>
<tr>
<td>12.00</td>
<td>3</td>
<td>200 x 200</td>
</tr>
<tr>
<td>13.50</td>
<td>4</td>
<td>225 x 225</td>
</tr>
<tr>
<td>15.00</td>
<td>4</td>
<td>300 x 225</td>
</tr>
</tbody>
</table>

2.10
The same principles apply to flying shores as to taping shores: wallpieces, needles and cleats have the same application, although adjustment is made by folding wedges. (See X, Y and Z on Figure 2.10(a).)

![diagram of flying shore]

(a) single flying shore

Single Flying Shore

Figure 2.10(a)
Flying Shores

Figure 2.10(b)(c)(d)
2.3 TUBULAR STEEL SCAFFOLDING

Shores may be built up of tubular scaffolding provided they are properly designed and braced.

Raking Shore

Figure 2.11

Flying Shore

Figure 2.12
2.4 PREPARATION OF BUILDINGS FOR SHORING

1. Carry out a thorough site investigation to determine:
   (a) number of shores required by ascertaining possible loadings
   (b) bearing capacity of soil and floors
   (c) location of underground services which may have to be avoided or bridged.

2. Fix ceiling struts between suitable head and sole plates to relieve the wall of floor and roof loads.

3. Strut all window openings within the vicinity of the shores to prevent movement or distortion of the opening.

4. Prepare walls, where rakers and struts intersect walls, by packing the cavities.
Chapter 3

UNDERPINNING

3.1 INTRODUCTION

3.2 PRELIMINARY PROCEDURES

3.3 METHODS OF UNDERPINNING
   (a) CONTINUOUS
   (b) PILED UNDERPINNING
   (c) UNDERPINNING FOR FRAMED STRUCTURES

3.4 STOOL AND BEAM

3.5 CHEMICAL INJECTION OF SOILS

3.6 TERMINOLOGY
   GROUT
   PINNING UP
   PRE-COMPRESSION
   RE-COMPRESSION
   UNDERPINNING

3.1 INTRODUCTION

Underpinning is the term applied to any new, permanent supporting structure, for an existing building, that:

- replaces existing footings
- strengthens existing footings
- increases the bearing capacity of existing footings
- lowers footings.

Underpinning is usually applied to the installation of new footings, but correctly includes associated temporary works such as shoring and timbering, as well as inserting a new beam in a wall.

Underpinning becomes necessary when:

- failure of foundations has occurred (subsidence)
• the footings for a new building must be taken lower than those of an adjacent existing building; in this case the existing footings must also be lowered

• an extra storey is added to an existing building because this increases the dead load.

3.2 PRELIMINARY PROCEDURES

Before commencing any underpinning, the structure of the building should be thoroughly examined for weaknesses. It may be necessary, at this stage, to strengthen the building by grouting cracks or inserting tie rods.

Adjoining properties should be inspected to record any existing cracking or damage, and to avoid claims for rectifying any faults which were obvious prior to underpinning.

Careful records are vital in case a dispute should arise. These should show the exact condition of floors, walls, etc., including the levels of floors and walls, the plumb of walls, the existence of cracks, their position and size, and any other defects. Tell-tale marks each side of cracks will help to show the extent of any movement.

![Diagram of underpinning](image_url)

*Typical Method of Needling prior to Underpinning*

*Figure 3.1*

3.3 METHODS OF UNDERPINNING

• Continuous

• Piled

(a) CONTINUOUS UNDERPINNING

The underpinning of a strip footing is carried out in short sections. The length of these (usually 900 - 1500 mm) will depend on the condition of the structure, the type of existing footings and the nature of the foundations.
The same considerations will also govern the number of sections that can be unsupported: never more than one-third of the length should be left unsupported at one time. On heavily-loaded or weak structures, the unsupported length should be restricted to one-fifth of the total length.

To ensure a minimum of disturbance, it is necessary to observe a strict sequence of operations. First, the wall to be underpinned is divided into a suitable number of sections. (See Figure 3.2.)

Sequence of Underpinning

Figure 3.2

The sequence should be such that no section is excavated immediately adjacent to one that has just been completed. It is desirable that construction work should start as soon as the excavation is completed. If delay is likely, the last 200 - 300 mm of the excavation should be held over or, alternatively, a concrete screed poured.
Either brickwork or concrete may be used; each has its special advantages. In either case, provision must be made for joining succeeding sections.

![Diagram of Lowering Existing Footings](image)

**Lowering Existing Footings**

*Figure 3.3*

Brickwork must be in cement mortar and toothed at the ends for bonding with the next section. Concrete should be grooved, to provide a key, and horizontal reinforcement which must project, must be turned up against the sides until the adjacent section is excavated. It is then turned down to be spliced with the steel in the next section.

Concrete is poured to about 75 mm below the existing footings or wall; it is then left to gain the necessary strength and also to permit shrinkage before final pinning up. Brickwork is carried up leaving it 3 or 4 courses low and time is allowed for mortar to set and shrink before final pinning up.

**Pinning Up**

Brickwork is completed by building up and pinning up the courses in the sequence shown in Figure 3.4.

![Diagram of Order of Pinning Up](image)

**Order of Pinning Up**

*Figure 3.4*
Special wedge-shaped bricks have been used for pinning up. Alternatively half dry cement mortar should be packed in tightly by means of 25 mm thick board and hammer. It has now become standard practice to use an expanding mortar for this purpose. This is mixed with either expanding metal aggregate or expanding cement. It is essential that the existing footing or wall is thoroughly cleaned before pinning up.

**Backfill/Timbering**

The normal practice is to remove timbering and backfill as construction proceeds. Where removal is not possible, precast concrete must be used. This may be used for permanent formwork where concrete underpinning is used. Backfilling beneath the building is often impossible: in this case, suitably placed holes must be left in the underpinning to permit grout to be pumped into place.

**Soil Re-compression**

This is done to restabilise or compress the disturbed soil beneath the new sections of build-up. This is achieved by either:

1. Using a hydraulic jack whilst building up the section, or
2. Using Freyssinet 'flat jacks' which are inserted in the 'pinning' gap, forced to expand by hydraulic action, and in so doing, push the 'block' down. The gap is then filled with an expanding mortar and the flat jacks are removed.

![Freyssinet Flat Jack](image)

_Freyssinet Flat Jack

Figure 3.5

(b) **PILED UNDERPINNING**

Continuous underpinning as described above may in some circumstances be impracticable or uneconomic. The presence of subsoil water with certain types of soil might make the work extremely difficult, or when the load has to be transferred to a great depth, the cost of continuous underpinning might be excessive. In such circumstances, piles may be used with the load from the wall transferred to them by beams or needles. In order to avoid vibration which would be undesirable in many cases of underpinning, bored or jacked-in piles are used.
The arrangement of beams and piles depends on many things, including the state of the structure and the necessity or otherwise of avoiding disturbance to the use or contents of the building. The most straightforward method is probably to sink pairs of piles at intervals along the wall, one on either side, connected by a needle or beam passing through the wall just above or immediately below the foundation.

Figure 3.6

As an alternative to cantilevered supports, jacked-in piles can be used immediately under the existing foundations in order to avoid internal work.
Refer to Figure 3.6 (b). It is, of course, essential that the weight of the structure be sufficient to provide adequate dead weight as a reaction to the jacks as the piles are being forced down.

(c) UNDERPINNING FOR FRAMED STRUCTURES

In underpinning framed structures, the main problem is to provide satisfactory support to the columns while they are being underpinned. Before excavation is begun, these must be relieved of their load by dead shores under all beams bearing on them.

Reinforced concrete columns and brick piers can be supported by means of a horizontal yoke formed of two pairs of steel beams and transverse tie rods. (Figure 3.7.) The pair of steel beams are large enough and long enough to act as needles to transfer the load to temporary support.

![Diagram of U.B. Yoke to Brick Pier]

**U.B. Yoke to Brick Pier**

**Figure 3.7**

An alternative method is to grip the column or pier in a heavy steel cramp designed to grip more tightly as it takes up the weight of the column (Figure 3.8).

![Diagram of Steel Cramp to RC Column]

**Steel Cramp to RC Column**

**Figure 3.8**

3.7
Steel columns can be supported on steel needles by steel angles or channel cleats welded to the beam flanges. Look at Figure 3.9.

![Diagram of MS channel cleats welded to stanchion and UB needles extending to supports]

Cleats Welded to Beam Flanges

Figure 3.9

3.4 STOOL AND BEAM

When a beam must be inserted in a wall such as would be required over a new opening, steel or precast concrete stools may be used to eliminate the need for shoring.

Holes are first cut in the wall to accommodate the stools which are of the same height as the depth of the beam. Spacings will be determined by the stability of the wall in much the same way as if they were needles.

The stools are then inserted and pinned up. Reinforcement is next threaded through the stools, formwork erected and concrete poured. This, too, is allowed to attain strength and is pinned up, as described earlier.

At this stage the wall is fully supported by the beam, allowing the wall below to be removed. Refer to Figure 3.10.
3.5 CHEMICAL INJECTION OF SOILS

Suitable soil such as gravel and sand may be strengthened, or its permeability decreased, by pressure grouting, and water in sand and silts can be frozen by refrigeration. The task of underpinning can often be simplified by the application of these processes to the soil and in some circumstances they can be used as an alternative to underpinning. In the latter case, where permanent effects are required, grouting would be used, since freezing is only practicable as a temporary measure. Grouts may be solutions of various chemicals which gel in the soil or suspensions of cement, fly-ash or bituminous emulsion.


3.6 TERMINOLOGY

**GROUT:** A non-shrink mortar compressed into the joint between the existing structure and the underpinning structure, in the pinning-up operation.

**PINNING UP:** The process of consolidating the joint between the existing structure and new underpinning, and the insertion under pressure of non-shrinking grout.
**PRE-COMPRESSION:** The compression of a foundation under a building prior to applying the load from underpinning, to avoid settlement.

**RE-COMPRESSION:** The application of pressure from hydraulic or flat jacks to consolidate the underpinning structure and foundation, before the pinning-up process is completed.

**UNDERPINNING:** The construction of continuous or intermittent footings and supporting structures under the footings of an existing structure which has failed, or may fail.
Chapter 4

FOUNDATIONS

4.1 INTRODUCTION

4.2 RELATIONSHIP OF FOUNDATION, FOOTING AND STRUCTURE SETTLEMENT

4.3 TYPES OF FOUNDATIONS
   ROCK
   NON-COHESIVE SOILS
   COHESIVE SOILS
   ORGANIC SOILS

4.4 BEARING CAPACITIES OF FOUNDATIONS

4.5 FOUNDATION BEHAVIOUR
   SAFE BEARING VALUE
   GENERAL SHEAR FAILURE
   SUBSIDENCE
   DISTRIBUTION OF PRESSURE
   MOVEMENT OF CLAY
   UNSTABLE SLOPES
   POOR SOIL COMPACTION

4.6 REASONS FOR SITE INVESTIGATIONS
   INFORMATION NEEDED
   SOURCES OF INFORMATION
   SITE EXPLORATION

4.7 ON-SITE TESTING OF FOUNDATIONS
   SAMPLING
   EXTENT OF INVESTIGATION
   STANDARD PENETRATION TEST
   PENETROMETER
   DUTCH CONE TEST
   SHEAR VANE TEST
   PILE TEST
4.1 INTRODUCTION

In Australia, the term "Foundation" means the material soil or rock supporting a building or structure.

Students must not use the broader meaning usually conferred on the term in overseas textbooks.

A thorough knowledge of the underlying foundations is necessary to design suitable footings. For minor works, it is possible that a cursory glance may yield all the information necessary; alternatively, it may reveal the necessity for further investigation. Where major structures are concerned, however, extensive investigations are absolutely essential.

4.2 RELATIONSHIP OF FOUNDATION, FOOTING AND STRUCTURE

Any foundation will be compressed under load and the resultant downward movement, called "settlement", is no cause for concern. What does present difficulties is differential settlement; that is, one part sinks further than another, or at a different rate.

Strip and isolated pad footings are the most economical. However, they do not provide a rigid chassis, and any differential movement is transmitted to the main structure (See Figure 4.1). Framed structures (those supported by columns) can withstand some distortion. The limit is about 20 mm difference between adjacent columns 7 m apart. Infill panels must, of course, also be able to accommodate the racking. Other structures are more sensitive to distortion.

Whenever differential movement exceeds the acceptable limits, special footings must be used. These include cellular rafts which act as a rigid chassis and so eliminate distortion, and piles which can be sunk to better foundations at whatever depth they occur.

![Frame Distortion](image)

*Figure 4.1*
SETTLEMENT

Mass rock provides an excellent foundation because there is no settlement and (normally) a high safe bearing value (S.B.V.). Compact, coarse, granular soils also present little problem because settlement is comparatively uniform. Any uneven settlement which does occur is finished before the job is completed and measures can be taken to rectify it.

Differential settlement is common in clay soils. The problem is aggravated by the extended settlement period which may continue long after the building is occupied.

As well as differential settlement resulting from foundation behaviour, there is also the factor of uneven loading. Figure 4.2 illustrates a common design problem. The foundations beneath the taller - and therefore heavier - section will obviously settle far more than the lower one. A settlement joint is essential between the two sections but this only partly solves the problem.

![Design to Accommodate Differential Settlement](image)

**Figure 4.2**

4.3 TYPES OF FOUNDATION

It is convenient to classify foundations into four basic types which exhibit distinctly different characteristics:

- Rock
- Non-cohesive soils (sands and gravels)
- Cohesive, plastic or reaction soils
- Organic soils.
<table>
<thead>
<tr>
<th>Rock</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Igneous</td>
<td>Negligible compression under load can be fissured. S.B.V from 0.1 - 4 MPa</td>
</tr>
<tr>
<td>Sedimentary</td>
<td></td>
</tr>
<tr>
<td>Gravels</td>
<td>May be uniform or graded, compact or loose, rounded or angular. Easily dug.</td>
</tr>
<tr>
<td>(over 2 mm)</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>Non-cohesive. Non-reactive (does not swell). Compression under load is small and</td>
</tr>
<tr>
<td>(0.06 - 2.00 mm) visible</td>
<td></td>
</tr>
<tr>
<td></td>
<td>rapidly completed. Sand and fine gravel bulks when dug, especially when moist</td>
</tr>
<tr>
<td>Silt</td>
<td>The particle size is intermediate between clay and sand and has similar</td>
</tr>
<tr>
<td>0.002 - 0.06 mm barely visible to invisible</td>
<td>characteristics - for example:</td>
</tr>
<tr>
<td></td>
<td>fairly permeable</td>
</tr>
<tr>
<td></td>
<td>slightly cohesive</td>
</tr>
<tr>
<td></td>
<td>slightly reactive</td>
</tr>
<tr>
<td>Clay</td>
<td>Cohesive - plastic, moulable. Reactive - swells according to moisture content.</td>
</tr>
<tr>
<td>below 0.002 mm invisible</td>
<td>Compressible under load. Compaction difficult and slow. Low permeability. S.B.V. variable according to M/C (moisture content).</td>
</tr>
<tr>
<td>Peat</td>
<td>Found in pure beds or mixed with clay, silt or sand. Very spongy. Combustible.</td>
</tr>
</tbody>
</table>

| 4.4 |
(a) **ROCK**

The two significant characteristics of most types of rock are high S.B.V. and minimal deformation under load.

(b) **NON-COHESIVE SOILS**

Compact granular soils are subject to a small amount of compression when loaded. This settlement stops on completion of the building.

(c) **COHESIVE SOILS**

The compressibility of clay is considerable, and, in contrast to sand, settlement may continue for years. The reason for this is that the reduction in volume is due largely to the expulsion of water from the pores which is a slow process because of the low permeability of clay. Another phenomenon is the swelling which accompanies a rise in moisture content, but this problem decreases with depth and is usually limited to the upper 1 - 2 metres, however, in the black soils found in N.S.W., Queensland and some parts of W.A. it can extend more than 4 metres down. Vertical movements of up to 100 mm are not unknown with upward pressures of over 600 kg/m² (14 MPa).

As the moisture content of clay increases, the bearing capacity decreases because of loss of cohesion. Clay has no friction between the particles and relies on cohesion to resist movement. The extreme example is mud, which is clay with high water content - so high that the bearing capacity is nil.

(d) **ORGANIC SOILS**

Peat is sometimes found in beds of varying thickness: at other times it occurs mixed in varying proportions with granular soils which are then referred to as organic clays or silts. As a foundation it should be avoided because of its high degree of compressibility. It is also combustible and, if near the surface where it can become dry, there is danger of spontaneous combustion.

4.4 **BEARING CAPACITIES OF FOUNDATIONS**

The following table is only a guide for minor works where costly investigation is not warranted.
<table>
<thead>
<tr>
<th>TSF</th>
<th>MPa</th>
<th>t/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvial soil ¼</td>
<td>0.05</td>
<td>5</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>permanently dry 3</td>
<td>0.3</td>
<td>30</td>
</tr>
<tr>
<td>soft or wet 1</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>Loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>permanently dry 4</td>
<td>0.4</td>
<td>40</td>
</tr>
<tr>
<td>wet 2</td>
<td>0.2</td>
<td>20</td>
</tr>
<tr>
<td>Sand 2 - 2³/₄</td>
<td>0.2 - 0.3</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Local limestone and sandstone 1 - 6</td>
<td>0.1 - 0.6</td>
<td>10 - 60</td>
</tr>
<tr>
<td>Shale 8</td>
<td>0.8</td>
<td>90</td>
</tr>
<tr>
<td>Hard sandstone and igneous rock 20 - 40</td>
<td>2.0 - 4.0</td>
<td>200 - 450</td>
</tr>
</tbody>
</table>

4.5 FOUNDATION BEHAVIOUR

SAFE BEARING VALUE

The S.B.V. (safe bearing value) of a particular soil type is not constant but varies according to several factors. It increases with depth and footing area while moisture content influences both the S.B.V. and magnitude of the settlement.

Dampness in sand increases cohesion between particles and, consequently, the bearing capacity. When submerged, film cohesion is lost and buoyancy is imparted to the particles, reducing the bearing capacity. The cohesion of plastic soils will decrease with any rise in moisture content.

GENERAL SHEAR FAILURE

All soils are subject to shear failure which is the displacement of soil from beneath the footing, causing 'heave' nearby. Footings must be of sufficient depth so that shear failure is resisted by the weight of soil above each side of the footing, together with the shear resistance of the soil.

Shear Failure

*Figure 4.3*
SUBSIDENCE

Apart from the settlement induced by the weight of the structure compressing the foundation there are other agencies that can cause rapid or uneven settlement.

The collapse of mines or caves underneath footings is an obvious example. A less well-recognised source of movement is the lowering of the water table. This takes effect in two ways: first, by the shrinkage of clay soil; second, by the loss of buoyancy, both of the soil and the building.

The effective weight of a building is reduced proportionately by any portion of it below water level. Basements below water level are essentially empty tanks and are subject to tremendous upward pressure from the flotation tendency. A drop in the water table will then allow the full structural load to be taken by the foundation with consequent further settlement.

DISTRIBUTION OF PRESSURE

The arching effect which distributes a load throughout a masonry wall is well-known. Soils also exhibit this phenomenon: the distribution spreads out in a bulb form under the footing.

![Bulbs of Pressure](image)

*Bulbs of Pressure*

*Figure 4.4*

The load finally diminishes at a depth about three times the width of the footing where the load is one-twentieth the original load and compression of the foundation is negligible.

Where several footings occur in close proximity, the bulbs of pressure combine to form a common bulb of pressure.
MOVEMENT OF CLAY

It is commonly believed that Western Australia has no problem with clay soils. This is a fallacy. There have been numerous failures because of ignorance on the part of the building surveyors, builders and architects.

Clay defies effective compaction by normal methods; consequently, clay fill is rarely properly consolidated. As a consequence, surface water is readily able to percolate deeply into the soil causing a tremendous build-up of water content in the soil.

This is accompanied by both expansion and weakening through loss of cohesion.

Differential expansion of clay soils is frequently brought about by the protection of soil beneath a structure, while the surrounding soil is exposed to changes of moisture content (m/c). Thus, the external walls are subject to vertical pressures and movement while the internal walls are not.

The importance of drainage to dispose of surface water cannot be over-emphasised.

UNSTABLE SLOPES

These can occur naturally, such as where soil overlays a sloping rock stratum. Water collects and runs over the rock surface thereby reducing friction and sometimes allowing the soil to slide downhill. This is especially dangerous with clayey overlays which have no friction when waterlogged.

A not-uncommon cause of failure occurs when sloping clayey ground is built up, especially with clayey fill, which is seldom properly compacted. This allows surface water to percolate through to the natural surface which becomes a slip plane.
POOR SOIL COMPACTION

The need to consolidate made ground is well recognised, and yet is not an infrequent cause of failure. It is often wrongly assumed that virgin soil is naturally compact and therefore suitable as a foundation without further work. Nothing could be further from the truth. There are many occurrences of poorly consolidated and, worse, irregularly consolidated natural soil.

Another fallacy is the belief that the consolidation of the first 500 - 800 mm is all that is important for minor jobs. Soil technologists claim that loads of a single-storey cottage will exert pressures on foundations to over 1500 mm deep. Thus, compaction tests should always be taken to at least this depth and proportionately deeper where the structure exceeds one storey.

4.6 REASONS FOR SITE INVESTIGATION

A knowledge of the foundations will reveal the following:

(a) Type of footing most suitable (pile, strip, raft, etc.).

(b) Size of footings.

(c) Designs of the structure: a flexible structural design may be more economical than a rigid footing where differential foundation movement is anticipated.

(d) Need for preliminary work such as dewatering or compaction.

INFORMATION NEEDED

1. Type of foundation (its extent or depth) (rock, sand, clay, mixed, etc.)

2. Degree of compaction of soils.

3. Compressibility (initial and final settlement)

4. Permeability (for de-watering)

5. Water table:
   • natural water level
   • seasonal variations
   • possible need of drainage.

6. The existence of weaknesses:
   • unstable slopes
   • made ground
   • abandoned mines

7. S.B.V. (safe bearing value).

8. Possibility of lateral pressures.

4.9
**SOURCES OF INFORMATION**

The following sources provide a useful guide to the type and extent of foundation exploration.

- Local Government Authorities
- Water and Sewerage Authorities
- Local boring contractors
- Nearby road or railway cuttings
- Geological and Soil Survey Maps
- Atlas of Australian Resources.

The first three can frequently supply very accurate and detailed information.

**SITE EXPLORATION**

To obtain the data required for a final assessment, a subsurface investigation is essential for most works, and especially for those of a major nature. Some of the methods used are:

- post-hole auger - for shallow depths
- test pit or trench - shows soil profile and any zones of weakness
- machine drilling
- geophysical exploration.

**4.7 ON-SITE TESTING OF FOUNDATIONS**

1. **SAMPLING**

As test drilling proceeds, disturbed samples are automatically brought to the surface and will yield some information about the nature of soil or rock at known depths. However, at intervals, undisturbed samples must be taken by driving a sample tube into the soil or by core drilling the rock.

The resultant cylindrical core 40 - 75 mm diameter is removed for observation, testing and analysis.

Observation will reveal any changes in the type of soil or rock: comparison with cores from elsewhere will establish the extent of any stratum. Variations in level may indicate potential slip planes.
Testing and Analyses are carried out in a laboratory to produce a variety of information such as:

- bearing capacity
- moisture content (shrinkage)
- permeability (dewatering)
- density or compaction
- particle size and grading
- the presence of organic matter, salts or sulphates.

EXTENT OF INVESTIGATION

Heavy building loads, such as those from a high-rise building, stress the foundations to a great depth, therefore foundations must be explored to the full depth that is subject to stress.

Poor quality foundations will be more subject to deformation at lower stresses and, therefore, greater depths than others.

Variable foundations demand a larger number of test holes than if they were uniform. The exact nature and extent of any weak strata must be established.

For normal circumstances, foundations should be explored to at least 1½ times the width of the footings. Heavily loaded and closely spaced footings will combine their effects on the soil and so the required depth will be 1½ times the width of the building.

![Soil Sampling Tool](image)

Figure 4.6

4.11
2. STANDARD PENETRATION TEST

This is based upon the same principles that determine the 'set' of a pile. Unlike pile driving, however, this test utilizes only standard factors. A standard rod is driven to the required depth by a 60 kg hammer that drops 750 mm. The number of blows taken for the last 450 mm is compared with standard graphs to estimate the bearing capacity. The test is not reliable in clayey soils.

3. PENETROMETER

The instruments are basically miniature refinements of the Standard Penetration Test. A pocket-size one can be used for testing soil cores in the field. The model illustrated is commonly used in Perth sands to test compaction. Its useful depth limit is about 3 metres. An important point to note is that this instrument is designed and calibrated for Perth Metropolitan sand only; it cannot be used in other soils.

Penetrometer

Figure 4.7
4. DUTCH CONE TEST

A conical tool is pressed into the ground by a standard weight and the penetration is continuously recorded. The results are used to forecast the performance of piles in soft silts and sands.

5. SHEAR VANE TEST

To assess the shear strength of soft clay a standard four-bladed vane is pushed into the bottom of a bore hole and rotated by means of a torque wrench.
6. **Pile Test**

Wherever piles are used, one or more should be driven to the calculated 'set' or depth and loaded.

'Set' is the resistance of soil to the penetration of a pile. It is measured by recording the average penetration per blow and is used to indicate the bearing capacity of the pile.

![Pile Test](image)

*Figure 4.10*  
**Load Bearing Test**
Chapter 5

FOOTINGS

5.1 INTRODUCTION

5.2 APPLICATION OF FOOTING TYPES
   STRIP AND SLAB FOOTINGS
   RAFT FOOTINGS
   PILES

5.3 MAIN CLASSES OF FOOTINGS
   STRIP AND SLAB FOOTINGS
   RAFT FOOTINGS
   PILER FOOTINGS
   PIERS

5.4 STRIP FOOTINGS
   INDEPENDENT COLUMN FOOTINGS
   CONTINUOUS COLUMN FOOTINGS
   COMBINED COLUMN FOOTINGS
   CANTILEVER FOOTING
   BALANCED BASE FOOTING

5.5 RAFT FOOTINGS
   SOLID SLAB RAFT
   BEAM AND SLAB RAFT
   CELLULAR RAFT

5.1 INTRODUCTION

The portion of the building known as the footing is very often confused with the term foundation but, for clarity, we will refer to the Uniform Building By-laws:

Footing means the construction by which the weight of the building is transferred to the foundations.

This definition only identifies the footing. It is also essential that we understand the reason for and the requirements of a footing. The footing does more than transfer the weight of the building; it distributes the load to reduce the intensity of the
pressure of the building on the foundation. Footings should be
designed and constructed in such a way that settlement, particu-
larly uneven or relative settlement of the structure, is limited
and failure of the underlying foundations is avoided.

In Chapter Four, consideration was given to the resistance of the
foundation to the loads imposed by the building, to its behaviour
under load, and to the factors which determine the choice of
footing. This information is necessary in selecting the type of
footing used in the various circumstances to transfer load to
foundations. Footings are invariably made from concrete, either in
mass or reinforced and range from a simple strip to a deep-piled
footing.

The two major categories of footings used in building construction
are shallow footings and deep footings.

Shallow footings are used where safe bearing soil is located near
the foundation surface. Types of shallow footings include strip,
slab and raft footings. If there is a basement incorporated in the
construction the strip, slab or raft may in fact be located at
some depth below the surface.

Deep footings are used to transfer loads to the foundation far
below the basement or lowest floor. Deep footings include piles,
piers and caissons.

5.2 APPLICATIONS OF FOOTING TYPES

STRIP AND SLAB FOOTINGS

Strip and slab footings are designed to meet specific require-
ments; however they are mainly used where a stratum of strong
subsoil exists either near the surface of the ground or near the
level of the proposed basement floor.

RAFT FOOTINGS

Raft footings may be used:

- where firm strata does not exist near or at a reasonable
depth below ground level

- where wide distribution of building loads is necessary to
keep within bearing values

- to resist unequal settlement caused by differential movement
or foundations of unequal values

- as part of a basement to reduce the pressure likely to cause
shear failure.
PILES

Pile footings are used where it is necessary to:

- transfer loads to strata which are stable and can resist them
- go to depths far below the base of the structure to achieve a stable footing
- accommodate unequal building loads which make raft footings impractical and uneconomical.

5.3 MAIN CLASSES OF FOOTINGS

STRIP AND SLAB FOOTINGS

(a) strip footings
(b) independent column footing
(c) continuous column footing
(d) combined column footing
(e) cantilever footing
(f) balanced base footing.

RAFT FOOTINGS

(a) solid slab raft
(b) beam and slab raft
(c) cellular raft.

PILED FOOTINGS

(a) friction piles
(b) end bearing piles.

PIERS

(a) masonry
(b) mass concrete
(c) cylinders and monoliths.
Strip, slab and raft footings are (in general) spread footings, because their function is to spread the loads over an area and minimize the bearing pressure. In the design of spread footings, two essential factors must be borne in mind:

- the soil must not be over-loaded
- any settlement must be minimal and equal at all points.

Over-loading will cause soil failure and excessive settlement. Uneven loading will cause differential settlement. However, differential settlement can be avoided by arranging the centre of gravity of the loads to be in the same plane as the centre of area of the footing.

In Building Construction 1B, strip footings for continuous walls were considered and it was shown that, in the case of light loading on reasonably strong soils, a footing strip one and a half times the width of the wall it carries can, in some cases, provide sufficient width to avoid overstressing the soil or cause excessive settlement.

The Uniform Building By-laws include a table for 'cross-sectional dimensions of concrete strip footings' for Classes 1 and 1A buildings (single dwelling houses and duplexes) if constructed on stable soil foundations.

<table>
<thead>
<tr>
<th>Construction of wall</th>
<th>Nominal thickness of wall to be supported (including cavity) not more than (mm)</th>
<th>Size of concrete (width and depth in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry, single storey with wall height (according to sub-bylaw (2)) not exceeding 4 200 mm excluding any gable ..........</td>
<td>270 110</td>
<td>450 x 250 300 x 250</td>
</tr>
<tr>
<td>Masonry veneer single storey with wall height (according to sub-bylaw (2)) not exceeding 4 200 mm excluding any gable ..........</td>
<td>110</td>
<td>300 x 250</td>
</tr>
<tr>
<td>Timber frame, single storey - For foundation walling up to 1 500 mm high, measured from the top of the strip footing ..........</td>
<td>110</td>
<td>230 x 150</td>
</tr>
</tbody>
</table>
The load per unit of area should be such that it does not over-stress the foundation. This can be achieved by relating the imposed load to the bearing strength of the soil. In a strip footing this is considered in terms of width to give sufficient area per metre run; for isolated piers or columns, both width and length are involved.

Where the edges of a footing project beyond the faces of the wall or column it supports, the resistance of the soil will create a cantilever action and bending and shear stress will occur in the footing. Therefore, because of the low tensile strength of unreinforced concrete, the strip or slab must be of adequate thickness to resist failure. The thickness required to resist failure may make the footing uneconomical and impractical; thus, the thickness must be reduced by adding reinforcement to the concrete to take up the tensile stress. In extreme cases, shear reinforcement is added to the footing.

The detailed design of footings is well covered in textbooks concerned with reinforced concrete design. Footings will be considered here only in terms of their types and application.

5.4 STRIP FOOTINGS

A strip footing carries the load bearing walls and transfers and spreads these loads to the foundation. When the dimensions detailed in the Uniform Building Bylaws are used the height of the wall should not exceed 4.2 metres. Reinforcement of the bottom half of the strip footing is usually required to resist the stresses set up by the cantilever effects which were previously mentioned.

TYPES OF STRIP FOOTINGS

strip Footing

Figure 5.1 (a)
TYPES OF STRIP FOOTINGS

Deep Beam

Figure 5.1 (b)

Inverted "T" Beam

Figure 5.1 (c)

INDEPENDENT COLUMN FOOTINGS

This is the most commonly used type of footing in framed buildings. There are two methods of construction:

- reinforced concrete
- steel grillage.

The last is gradually being eliminated because of increasing costs of steel and the availability of high strength concrete.
Reinforced Concrete

Sometimes called "blob" footings, these are used under piers, columns and any isolated parts of a building. They may be square, rectangular or circular in plan and sufficiently thick to withstand the loads applied to them. Reinforcement is placed at the bottom in both directions to resist the bending stress set up on the double cantilever action of the slab about the column base.

![Independent Column Footing](image)

Figure 5.2

Steel Grillage

This form of footing incorporating universal beams on layers was used under heavily-loaded columns. However, the wide range of mild steel reinforcement has seen the abandonment of such footings. (Figure 5.3.)

CONTINUOUS COLUMN FOOTING

Because a strip of concrete is located under the line of columns uniting them to act on the strip it may be seen that there will be bending both longitudinally and transversely in the strip between the columns.

This type of footing is used where:

- the proximity of independent columns would unite their footings
- site restriction prevents an equal four-way horizontal design.

The loads are transferred from column to the base of the footing, and, as the complete footing can be considered as a column and floor beam in reverse, the tensile reinforcement will be positioned near the upper surface between columns. Shear reinforcement will be required as for a floor beam.
Steel Grillage Footing

Figure 5.3
Continuous Column Footing

Figure 5.4
COMBINED COLUMN FOOTING

The combined footing slab will be reinforced in much the same way as a continuous column footing to resist tensile stresses set up by the beam action between the columns and any cantilever action in the ends.

There are two variations of the common type of combined column footing:

- they may be constructed as a single or double tier steel grillage in conjunction with steel stanchions
- a combined footing may be provided for a number of adjacent columns where the size of independent footings would be such that they would over-lap.

Combined Column Footing

Figure 5.5

CANTILEVER FOOTING

This footing consists of a ground beam cantilevering over a footing slab to support a column. The ground beam has the supported column at one end and the counterbalancing column at the other end. The force on the counterbalancing columns must be at least 50% greater than the total loads on the supported column. This margin of safety must be maintained during construction.

When counterbalancing loads cannot be attained, tension piles or mass concrete can be used to resist the moments of force.

Diagonal ground beams may be used at corners where a corner column exists.
BALANCED BASE FOOTINGS

When an outer column is eccentrically laden it may be necessary to use a ground beam to balance the footing under the outer column. The balancing ground beam usually extends into the building as far as the next line of column footings. The inner footing slab must resist any moments set up by the length of the balancing beam and therefore will need to be wide enough to prevent overstressing of the foundation. When overstressing cannot be avoided it may be necessary to use a cantilever footing.

Balanced Base Footing

Figure 5.7

5.5 RAFT FOOTINGS

Basically a raft footing is a large slab which covers the whole of the site occupied by the building. Raft footing can be used in any of the following conditions:

• where the strata uppermost in the foundation are stable but have a low bearing value
where the loads of the building make it necessary to spread the weight over the largest possible area

where settlement is to be avoided

where differential movement is likely to occur from unequal loads or inconsistent foundations

where closely spaced column footings would contact one another

where a large proportion of the site is covered with footings.

The selection of a raft footing must be made after considering the depth to which the footings must be placed to reach a firm foundation; it may be cheaper to use piled footings. If, however, the depth of piled footings is too great then a raft can be used to 'float' on the foundation. The foundations may be treated to improve their bearing capacity.

The characteristics of the foundation, the load distribution of the building, and the type of structure will determine whether the raft needs to be a flexible or a rigid type. A rigid raft will minimize differential settlement by distributing the pressure over the site. Unfortunately, a very rigid slab is most expensive.

Where a hard area exists in an otherwise weak site it should be excavated, backfilled and compacted to a uniform bearing value.

Where subsidence is anticipated it can be overcome by using flexible raft footings. The flexibility of the footing must be matched by the building structure.

Footings may be divided into three main types according to their design and construction:

• solid slab
• beam and slab
• cellular.

Each of these footings consists of a slab covering the whole of the site occupied by the building; the thickness is governed by the loads and rigidity required.

**SOLID SLAB RAFT**

There are three variations of this raft which is solid and reinforced in both directions.

The light solid slab up to 300 mm thick has two-way reinforcement and where columns are located additional reinforcement is required. This raft is used in domestic buildings and where light-framed structures such as in small industrial buildings are incorporated.
Light Solid Slab Raft

Figure 5.8 (a)

Light Solid Slab with Edge and Stiffening Beam

Figure 5.8 (b)

Light Solid Slab Raft with Edge and Cross Beams

Figure 5.8 (c)

The slab with edge and stiffening beam is used to prevent erosion under the perimeter of the slab and to distribute the loads to a lower strata.

The slab with edge and cross beams is used where it is necessary to stiffen the slab as well as transferring loads to lower strata.

**BEAM AND SLAB RAFT**

Where the loads are great and a slab thicker than 300 mm is required it may be cheaper to use a thin slab with beam projecting up from the slab.

Beam and Slab Raft

Figure 5.9
CELLULAR RAFT

Where great rigidity is required and the depth of the beam exceeds 900 mm, a cellular form is used. It consists of a top and bottom slab separated by beams in both directions. In some instances the depth of the cellular raft may occupy a basement storey; this would severely restrict the use of the basement unless some heavy beams were used to span openings.

Cellular Raft

Figure 5.10
Chapter 6

PILED FOOTINGS

6.1 INTRODUCTION

6.2 METHOD OF PLACEMENT
   DISPLACEMENT
   REPLACEMENT

6.3 PILE MATERIALS
   REINFORCED PRECAST CONCRETE PILES
   STEEL PILES
   TIMBER PILES

6.4 PILE TYPES
   SHEET PILING
   CAST IN-SITU
   COMPOSITION PILE
   CONSOLIDATING PILING

6.5 CLUSTERS
   PILE CAPS

6.6 SHAPES OF PILES

6.7 PILE DRIVING METHODS
   DROP HAMMER
   STEAM AND COMPRESSED AIR
   DIESEL HAMMERS
   JACKED PILES
   PILE 'SET'

6.8 PILE TESTING

6.1 INTRODUCTION

The word 'piles' is used to describe columns, usually of reinforced concrete, driven or poured in-situ into the ground, in order to carry footing loads to some deep underlying firm stratum, or to transmit loads to the soil by the friction of their surfaces in contact with the soil.
Piles for FOOTING purposes are known as LOAD BEARING PILES, and are used to support bases of structures where S.B.V. is too deep for practical excavation.

As mentioned above, there are two classifications:

(a) Bearing Piles - those that mainly transmit loads by the bearing of the base of the pile on sub-stratums.

(b) Friction Piles - those that mainly transmit loads by the friction of their surfaces on the surrounding sub-soil.

6.2 METHOD OF PLACEMENT

(a) Displacement piles are driven so that the soil is forced aside or displaced. These can be further divided into large and small displacement types according to their cross-sectional area; that is, round, hollow sections, universal beams.

(b) Replacement piles are constructed by boring a hole of the required diameter and filling it with concrete; that is, the soil is removed and replaced with concrete.

These types may also be described as driven and bored piles.

![Diagram of Pile Cap and Base](figure_6_1)

*Figure 6.1*

![Diagram of Pile Cap and Base](figure_6_2)

*Figure 6.2*
6.3 PILE MATERIALS

REINFORCED PRECAST CONCRETE PILES

These provide a logical alternative material. Typical sections are square and octagonal. However, their use does present some difficulties:

- the weight and length of the piles cause problems in transport and storage
- the piles normally have poor beam strength and require careful handling in the horizontal position
- economics demand that their lengths must be fairly accurately pre-determined because of the wastage when they are shortened
- it is almost impossible to lengthen them efficiently.

STEEL PILES

These may be produced in large or small displacement types. They are exceptionally strong and durable provided they are of sufficient diameter. This enhances their bearing capacity and also their ability to be driven in difficult foundations. The 'H' section provides a large surface area, to obtain frictional support, while its small sectional area enables it to be driven through rock strata.

Hollow steel tubes (piles) are normally fitted with a conical shoe and they may be left empty or filled with concrete with or without reinforcing.

Steel piles are readily lengthened by welding and, for this reason, long offcuts are not necessarily wasted.
The most common use for steel is in re-usable casings for concrete piles cast in-situ.

TIMBER PILES

These have lost favour in recent years because of their poor durability. However, this is only a half-truth because the durability of timber which is below the low water table - and therefore continually saturated - is almost infinite. Venice, for example, stands on centuries-old timber piles. The use of timber is certain to increase with the advent of effective preservatives, e.g. creosote and copper-chrome arsenate (C.C.A.) and impregnation techniques.

The advantages of timber are its cheapness, its lightness for transport and handling, the ease with which it can be cut - with hand or chain saw - or lengthened (by bolting or splicing).

6.4 PILE TYPES

(a) SHEET PILING is used to either:

(a) enclose a site to prevent soil movement or retain stresses within the building site

(b) to act as a retaining wall

(c) to protect foundations from sub-soil water

(d) to act as a coffer dam for footings under water.

Usually these are made of steel up to 22 mm thick with a variety of profiles available, but precast concrete types may also be utilised.

The method of driving is similar to driven piles, and the piles are held vertically in a longitudinal frame.

![Profile of Steel Sheet Piling](image)

*Figure 6.4*
Long lengths of sheet piling provide retaining wall for deep excavation on large building site.

Figure 6.5

(Reproduced with permission of GFWA PTY. LTD.)

(b) CAST IN-SITU - (one version is known as FRANKI piling)

Variations in sub-soil conditions frequently make it impossible to pre-determine the exact length required, causing inevitable wastage of concrete, time and labour in cutting off surplus lengths.

This drawback is overcome by in-situ piling by two methods:

(i) Driven in-situ

(ii) Bored in-situ

both being developed by the Franki Pile Coy.; the bored in-situ type being used where there is an objection to vibration.

(i) Driven in-situ: when the piling frame is ready, a solid drawn tube is held vertically, the bottom resting on the ground. The bottom is then filled to 750 - 1000 mm with dry gravel or aggregate plug.
Driving Tube by Drop Hammer

FRANKIPILE SYSTEM

Figure 6.6
This plug is compressed inside the tube by a drop hammer, and when consolidated the friction between it and the inner wall of the tube allows the subsequent hammer blows to pull the tube down into the ground.

By this means, the sealed tube is forced down to the stratum in which it is anticipated that the pile will be founded.

A number of sets are then taken to obtain a measure of the piles carrying capacity, to confirm that the tube has been driven to a depth where a satisfactory enlarged base can be formed.

The friction between the plug and tube is broken by hammer blows and forcing the plug out of the bottom of the tube, while the tube is held to prevent it being driven down.

A head of semi-dry concrete is then forced into the ground to form a bulbous base, the size being determined by the nature of the soil. Compaction is continued until refusal is obtained under the blows.

When completed, the hammer is withdrawn, and a cage of steel reinforcement inserted.

The pile is built up by successive charges of semi-dry concrete in the tube, each charge being rammed, and the tube is gradually withdrawn, and the dual action forces the concrete down and outwards, which compresses the surrounding subsoil.

(ii) *Bored in-situ*: used to provide an economic pile for smaller jobs in restricted areas, with minimum vibration. A tube (or sections of one) is sunk into the soil and the soil is removed by an auger as the tube sinks. Depending on the circumstances, a bulbous base may be formed, then reinforcement inserted, and subsequent layers of concrete rammed as the tube is being removed.

(c) *COMPOSITION PILE*: where a steel shell is driven into the ground, from the top, or internally at the shoe, then filled with concrete and reinforcement as required; the steel shell remains in the strata permanently.

(d) *CONSOLIDATING PILING*: used to compress soil and improve the load bearing capacity of the foundation.

Two methods may be employed:

(a) *Sand Piles* - used in soft but not fluid grounds.

(i) Solid piles are driven in the ground forming a hole with compressed sides. The hole is filled with shallow layers of sand, which is consolidated,
(ii) Tube piles are driven in, the shoes become unattached, pile withdrawn in shallow lifts with layers of sand inserted and rammed. Used where possible collapse of walls of the hole will occur.

The purpose of the sand pile is to allow moisture to be removed from the soil through a permeable drain. The removal of moisture will compact the soil and increase its bearing capacity.

Consolidated Sand Piling

1. A tube is driven to the required depth (a hinged plate at the bottom prevents the tube being filled with mud).

2. The tube is raised as sand fill is deposited into the tube and consolidated.

3. The sub-soil water is drawn to the surface, through the permeable drain.

Figure 6.7

(b) Vibro-flotation - high pressure water is jetted from the bottom of a suspended vibrator, and whilst going down, flushes out soft and unstable soils, and simultaneously consolidates the sides of the hole. When it has reached the required depth, the water is turned off at the bottom jets, and water jets are opened at the top of the vibrator. The vibrator is then rapidly moved
up and down to remove any loose particles. Then the hole is filled in stages with granular fill and consolidated to ground level.

The depth could be up to 75 m and the centres as close as 2.5 m.

Figure 6.8

(Reproduced with permission of GFWA Pty. Ltd.)

Vibroflotation in progress on a home unit development in South Perth.

Figure 6.9

(Reproduced by Courtesy of GFWA Pty. Ltd.)

6.9
6.5 PILE CLUSTERS

Column loads, etc., frequently exceed the bearing capacity of a pile and a ‘cluster’ of piles becomes necessary. These clusters are symmetrically placed below the column and the column load distributed by means of a reinforced concrete ‘pile cap’.

![Diagram of pile cap clusters]

**Plans of Typical Reinforced Concrete Pile Caps**

*Figure 6.10*

PILE CAPS are used to tie the heads of a group of piles together, act as a base for the superstructure, and provide an even base to work from.

Adjacent caps are usually linked together by ground beams of reinforced concrete and provide lateral rigidity to the tops of the piles. The reinforcement is cast in-situ and with some precast types, continues into the cap or beam.
6.6 SHAPES OF PILES (DRIVEN TYPE)

CONCRETE - Round, square, hexagonal, octagonal, being either solid, voided or hollow tube type (usually spun).

METAL - Normally hollow tube, which, in many cases, is filled with concrete after driving.

STEEL SHOES - Cast in the foot of concrete piles or fixed to timber piles for ease of driving through hard stratas.

For softer soils it is only necessary to shape the pile to a point.

HELMET - Placed on the top of piles to minimise damage during driving operations.

---

**Typical Prestressed Pile**

*Figure 6.11*

**Cross Sections**

*Prestressed Pile Sections*

*Figure 6.12*
Typical Splice Details to Precast Piles

Figure 6.15

(Reproduced with permission of Humes Concrete.)

6.7 PILE DRIVING METHODS

DROP HAMMER

This traditional method is still used occasionally. It consists of a rigid frame 12 - 30 m high which supports the pile in its correct position and guides a heavy ram or drop hammer. The ram is successively raised by means of a powered winch and dropped on to the head of the pile. The Frankipile method differs only in the
respect that the ram operates at the toe of the pile instead of the head. (See Figure 6.16 for details.)

STEAM AND COMPRESSED AIR HAMMERS

These comprise a piston and cylinder operating directly on the head of the pile. In the single-acting type, the piston is raised by air or steam and allowed to drop.

A further development is the double-acting type in which the piston is not only raised by air or steam, but is also driven downwards by it. The more rapid action helps to keep the pile in constant motion.

DIESEL HAMMERS

These are similar to single-acting steam hammers; they are self-contained and do not need boilers or compressors. As the piston drops, diesoline is injected and fired by the compression just as in a diesel engine. The resultant detonation multiplies the kinetic energy of the falling piston and, at the same time, raises it for the next stroke. See Figure 6.17.

![Typical Pile Driving Frame Drop Hammer](image)

Figure 6.16
Three Hammer Types

Figure 6.17
Typical Pile Driving Frame

Figure 6.18
JACKED PILES.

These piles completely eliminate vibration and driving noise. They are especially valuable for underpinning work because they may be driven directly below the existing footing which is used as a kentledge for the purpose. The piles are assembled from short sections of reinforced concrete which are successively jacked down, one after the other.

The essentials for this method are a power-driven hydraulic pump, jack and kentledge.

![Diagram of a jacked pile](image)

**Figure 6.19**

PILE 'SET'

An effective means of estimating when a pile has been driven to the required depth is by the 'set'. This is measured by the number of blows required to drive the pile the final 300 mm. The principle is identical to that of the penetrometer except that there are several variables which must be calculated; for example, the type of foundation, diameter and length of pile and weight and drop of the hammer.

6.8 PILE TESTING

Usually at least one pile in a job is tested by applying a load to the test pile. This is done by controlled jacking against either a kentledge (Figure 6.20), or a beam anchored to tension piles (Figure 6.21). Settlement, and the rise that occurs when the load is removed, is continually monitored.
200 tonne load set (2½ times the design load being applied to a prestressed concrete pile

Figure 6.20

(Reproduced with permission of Humes Concrete.)
Figure 6.21

(Reproduced with permission of Frankipile Australia Pty. Limited.)
Chapter 7

RETYAINING WALLS

7.1 INTRODUCTION

7.2 PRINCIPLES OF DESIGN

IN GRANULAR SOILS
IN COHESIVE SOILS

7.3 TYPES OF RETAINING WALLS

MASS OR GRAVITY WALLS
CANTILEVER WALLS
CRIB-BLOCK RETAINING WALLS
DIAPHRAGM WALLING

7.4 ALLUVIAL OR GROUND ANCHOR

7.1 INTRODUCTION

Forms of construction or walling which are primarily designed to resist the lateral movement of earth can be classed as retaining walls. The design of retaining walls may vary significantly in regards to size, shape, materials of construction, and load-bearing capacities. However, all retaining walls are designed with the basic function of resisting the lateral pressures exerted by soils and moisture.

The simplest form of retaining wall is related to surface protection of sloping sites to avoid erosion from wind and water. These revetments or breast walls are commonly used in landscaping, and consist of paving slabs, masonry, or precast concrete interlocking units. The more complex types of retaining walls involve the construction of vertical walls at embankments caused by excavations. The basement walls and underground service shafts in large buildings act as retaining walls in addition to their function of loadbearing walls.

7.2 PRINCIPLES OF DESIGN

The design of retaining walls is affected by many critical factors, including:

- the type of soil to be retained
- the size and loading of the wall
- the presence of surface and sub-soil water
- the loadbearing capacity of the foundation materials.

In *granular soils* the lateral pressure from the embankment tends to cause failure by pushing the retaining wall forward, or overturning it. Resistance to the forward movement is provided by friction at the base of the wall, caused by the shear weight of the structure. Passive resistance can be provided by the earth in front of the base of the wall. Resistance to overturning is obtained by constructing the wall thick enough to maintain stability. Refer to Figure 7.1.

![Forces on Retaining Walls](image)

**Forces on Retaining Walls**  
**Figure 7.1**

In *cohesive soils* the lateral pressure has little direct effect on the stability of retaining walls, as failure usually occurs due to circular slip. However, enormous pressure is applied on retaining walls due to the swelling of cohesive soils with increased moisture content.

![Circular Slip Failure Under Retaining Wall](image)

**Circular Slip Failure Under Retaining Wall**  
**Figure 7.2**

Adequate provision of drainage should prevent the percolation of water beneath the wall, and offsets the consequential loss of frictional resistance causing circular slip. An impermeable
surface layer covering the retained soil protects the retaining wall from damage caused by swelling of cohesive soils. In addition, the provision of rubble counterforts and a rubble layer at the back of the stem, ensure adequate drainage to below the assumed slip surface. Refer to Figure 7.3.

![Draining Cohesive Soils Diagram](image)

**Figure 7.3**

With a dam wall the active pressure on the wall is hydrostatic pressure directly proportional to the depth of water. Pressure on a retaining wall is also related to depth, but soil tends to support itself so the lateral pressure is less than hydrostatic pressure unless the soil becomes waterlogged.

The introduction of sheet piling in front of the base can prevent the forward movement of walls in cohesive soils due to circular slip failure.

The "wedge theory" is a method of calculating the dimensions of retaining walls for various types of soils. The assumptions are based on the specific angle of repose, or inclination of an embankment, for particular soils. For example:

**TABLE 7.1**

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Angle of repose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>30° to 35°</td>
</tr>
<tr>
<td>Gravel</td>
<td>30° to 40°</td>
</tr>
<tr>
<td>Soft clay</td>
<td>40° to 50°</td>
</tr>
<tr>
<td>Stiff clay</td>
<td>60° to 70°</td>
</tr>
<tr>
<td>Solid rock</td>
<td>Greater than 70°</td>
</tr>
</tbody>
</table>
If the wedge of soil above the angle of repose, and extending to the back of the stem, were bisected, the plane of rupture would be obtained. A diagram of forces can be prepared with the line of rupture and any lateral force drawn to scale to obtain a resultant force. Study Figure 7.4.

The Wedge Theory of Retaining Wall Design

Figure 7.4

7.3 TYPES OF RETAINING WALLS

Formerly most retaining walls were designed as simple gravity walls, where the mass of masonry or brickwork resisted the lateral force from the retained soils. Today there is a diversity of designs with numerous types of materials which include:

- timber logs and sleepers
- corrugated sheeting like Hardies' "mark 3" profile fibrecement sheets
- masonry
- brickwork
- in-situ concrete
- precast concrete interlocking units, including the "V" blocks and "Crib Walls".
As many of the materials are accompanied with instruction details for their erection, and others are of very simple design, only the following types of retaining walls will be detailed:

- Gravity
- Cantilever
- Crib
- Diaphragm walls

**MASS OR GRAVITY WALLS**

These are the simplest form of retaining walls which achieve their efficiency because of the mass of construction materials and the thickness of the base. Gravity walls are usually limited to 1800 mm in height, with a thickness equal to $\frac{1}{4}$ to $\frac{1}{3}$ rd of the height. Because the materials generally used in gravity wall construction are weak in tension, the outer face is usually set back at an angle from the vertical. This trapezoidal form assists stability by placing the resultant force within the middle third of the thickness of the retaining wall, as illustrated in Figure 7.5.

![Gravit retaining wall diagram](image-url)
A brick gravity wall to 1800 mm in height is illustrated in section, detailing suitable dimensions for well-graded compact sand. Figure 7.6.
CANTILEVER RETAINING WALLS

Considerable economies in materials can be achieved in the design of reinforced concrete cantilever retaining walls. The walls are usually designed on the principles of leverage, with comparatively thin sections reinforced to counter tensile stresses.

Reinforced cantilever retaining walls involve considerable work in setting out the formwork and placing the reinforcement. They are economical in heights exceeding 1200 mm and can exceed 6000 mm with prestressing techniques incorporated in their design.

Two basic designs of cantilever retaining walls can be varied to suit most situations with the addition of ribs, counterforts and alluvial anchors. Refer to Figure 7.7.

1. With the base extended to form a large toe, the walls have greater resistance to overturning, as illustrated in Figures 7.7 (a), (e) and (f). The addition of ribs increases the resistance to circular slip failure and forward movement. The buttress-type counterfort in Figure 7.7 (e) resists the tensile stresses induced from the lateral force to the back of the stem.

2. With the base extended to form a large heel, the mass of retained soil increases the necessary friction between the base and foundation, and resists overturning. Refer to Figures 7.7 (b), (c) and (d). Boundary retaining walls are often designed with large heels as illustrated in Figure 7.7 (b) and (c). These designs with extended heels require extensive excavation and back-filling, but are most efficient for walls exceeding 4500 mm in height.

The counterforts are triangular beams placed between the base and stem at suitable centres. In front of the wall (as in Figure 7.7 (e)), counterforts are in compression and often referred to as buttresses. A most efficient design of reinforced or prestressed concrete cantilever retaining wall is illustrated in Figure 7.7 (d) where the counterfort is placed in tension by the pressure from retained soil.

The placing of reinforcement is most critical in thin walled sections of large cantilever retaining walls. Figure 7.8 illustrates the vertical primary reinforcement and secondary distribution rods in the tensile side of the stem. The steel also resists tensile stresses in the top of the heel and bottom of the toe, caused by the mass of the overburden, and a tendency for over-turning.
Cantilever Retaining Wall Designs

Figure 7.7

Reinforced Cantilever Retaining Wall

Figure 7.8

7.8
CRIB-BLOCK RETAINING WALLS

Crib walls are designed on the principles of mass/gravity retaining walls with precast concrete interlocking units. They form an open grid which gives ideal drainage and provides space for planting of suitable vegetation on the face of the wall. Weepholes and sub-soil drainage are not required as hydrostatic pressure cannot build up behind the openings in the wall.

The manufacturer’s instruction sheets should be studied for erection details, sizes of components, and limitations on height and loadings for different types of foundations. Refer to Figure 7.9.
DIAPHRAGM WALLING

The diaphragm walling techniques involve construction of vertical continuous walls of reinforced concrete which are cast in-situ before any bulk excavation commences. These walls may form part of the load-bearing structure, to depths of 36 m, without any need for sheet piling or under-pinning adjoining structures.

After the trenches have been excavated by the specially developed grab or crane, a cage of reinforcing steel is positioned and concrete poured. To stabilise the soil during these operations, the trench may be filled with bentonite suspension. Concrete placed through a tremie pipe displaces the bentonite which is pumped into storage silos for re-use. Refer to Figure 7.10. The diaphragm walls may remain stable by the cantilever effect of resistance in the ground, or retained by 3 alluvial anchors, as illustrated in Figure 7.10 (a) and (b).

\[ \text{Diaphragm Walls} \]
\[ \text{Figure 7.10} \]

7.4 ALLUVIAL OR GROUND ANCHORS

Alluvial or ground anchors consists of high-tension cables bonded into a zone of pressure grout, and pre-stressed to a desired tension before anchoring. These anchors are suitable for holding back retaining walls, diaphragm walls, and resisting the up-lift forces of wind loading in cyclonic conditions. Figure 7.11 illustrates the forms of ground anchors developed for different types of alluvial soils. Rocks can also be penetrated and specially designed rock anchors imbedded to perform a similar function for restraining structures.
Alluvial or Ground Anchors

Figure 7.11
Chapter 8

BRICKS AND CONCRETE MASONRY

8.1 CLAY BRICKS

DEFINITIONS

CHARACTERISTICS OF A GOOD CLAY BRICK

PHYSICAL PROPERTIES

8.2 CALCIUM SILICATE BRICKS

RAW MATERIALS

MANUFACTURE

PROPERTIES

8.3 CONCRETE MASONRY

MIXING

PRESSING

AUTOCLAVING

LAYING BLOCKS

HANDLING AND STORAGE OF BLOCKS

CLEANING

PREVENTION OF WATER PENETRATION

BONDING OF BLOCK WORK

8.4 COMPARISON OF CHARACTERISTICS OF BRICKS

THERMAL EXPANSION

MOISTURE MOVEMENT

CONSTITUTIONAL CHANGES

POROSITY, ABSORPTION AND FUNCTION

8.1 CLAY BRICKS

This type of brick may be divided into three classifications:

- Facing brick
- Common brick
- Clinker brick
DEFINITIONS

(a) **Facing brick**: Bricks generally intended for use in locations where they will be exposed to view and not intended to be cement rendered or otherwise decoratively treated.

(b) **Common brick**: Bricks generally intended for use where they will not be exposed to view.

(c) **Clinker bricks**: Bricks which are vitrified or semi-vitrified, such as occurs in some proportion in the burning of bricks generally.

CHARACTERISTICS OF A GOOD CLAY BRICK

Bricks should be well burnt and free from large cracks, large voids, warpage, stones, pebbles or particles of lime that would affect their handling, service ability or strength. They should be uniform in shape with sharp arrises.

Shape: Bricks should have rectangular surfaces and may be with or without a frog or perforated with straight holes or channels.

Dimensions: Bricks must conform to the following standard dimensions.

<table>
<thead>
<tr>
<th>TYPE OF BRICK</th>
<th>DIMENSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LENGTH. X THICK. X HT.</td>
</tr>
<tr>
<td>STANDARD - CORED</td>
<td>230 x 110 x 76</td>
</tr>
<tr>
<td>STANDARD - ON EDGE</td>
<td>230 x 76 x 110</td>
</tr>
<tr>
<td>MODULAR</td>
<td>290 x 90 x 90</td>
</tr>
<tr>
<td>MODULATED - STD.</td>
<td>305 x 90 x 76</td>
</tr>
<tr>
<td>INT. BLOCK UNIT</td>
<td>295 x 90 x 162</td>
</tr>
</tbody>
</table>

Variations from the above measurements will usually be accepted provided the following tolerances are not exceeded:

(a) ± 76 mm on the length of 24 stretchers laid square end to end in contact in a straight line or 2 rows of 12 bricks

or

3 rows of 8 bricks

(b) ± 44 mm on the depth of 24 bricks stacked each in contact with the next.

(c) ± 44 mm on the width of 24 bricks laid side by side.
PHYSICAL PROPERTIES

(a) Soundness - Bricks when struck together or by a steel hammer should give out a clear ring.

(b) Structure - Bricks should be a uniform texture throughout.

(c) Efflorescence - Bricks classified as facing or clinker bricks shall show not more than "nil" to slight efflorescence when treated in a manner prescribed in S.A.A. Code and bricks classified as common shall show not more than moderate efflorescence when similarly treated.

(d) Spalling - Bricks when immersed in water for two days must not show any appreciable spalling due to the expansion of lime particles or any other cause.

(e) Strength - Bricks are graded according to their "average crushing strength", which is the average strength of a random sample of twelve bricks, tested in accordance with the S.A.A. 21 and S.A.A. 91, Australian Standards. The compressive strength of clay bricks may vary from 10 MPa to 110 MPa.

8.2 CALCIUM SILICATE BRICKS

Calcium Silicate bricks are made from a mixture of lime, sand and water which react together under high pressure steam. This reaction produces crystals of hydrated calcium silicate which grow between the grains of sand and bind them together.

Calcium Silicate bricks were produced in Sydney, Melbourne and Perth in the early part of this century but production stopped in Sydney and Melbourne prior to the 1st World War and in Perth in 1921-22. Production was reintroduced into Perth in 1955 and is now established throughout Australia.

RAW MATERIALS

Sand

Sand comprises approximately 90 per cent of the brick and as such normally dictates the location of the plant, the plant being located on, or as near as possible to the sand supply. The sand should be clean, sharp, well graded and free of humus and vegetable matter. The grading of the sand has a large influence on the final properties of the brick and sometimes sands need to be blended to improve the grading.
Lime

It is critical that the lime be of the highest quality. Most commercial limes contain impurities such as magnesium carbonate which can make them unsuitable for brick manufacture.

Most manufacturers use Quick Lime and this desirably is soft burnt so that it hydrates more quickly during manufacture. Before using, the lime is ground as finely as practical.

Water

Water supply is not critical provided it does not contain large amounts of soluble salts or organic material.

MANUFACTURE

The whole manufacturing process is highly mechanised and automated; from the time the raw materials enter the plant till they leave on the truck as bricks, they need not be touched by hands.

The sand and quick lime are drawn from the storage silos, weighed batched and mixed together. Just sufficient water is added in the mixing to hydrate the lime. The mixture is stored in a "reactor" for enough time to allow for the complete slacking of the lime, usually between 2 and 24 hours. After hydration the materials are remixed with extra water added to make the mix suitable for pressing. The mix is fed into the presses which shape and press the mix under a load of about 300 tonnes into a compact mass. The higher the pressure used, the more dense and consequently stronger the brick will be. The moulded brick is ejected onto a conveyor, from where it is picked up and stacked onto trolleys. From here the bricks are conveyed into autoclaves.

The curing process is what basically differentiates the Calcium Silicate manufacture from that of clay bricks. Instead of firing in a kiln to fuse the brick together, the brick gains its strength from the chemical action between silica and lime. The reaction takes place in the autoclave under high pressure and high temperature steam. The higher the steam temperature, the quicker the reaction takes place. For practical reasons the usual time is about 6 hours at 200° C. the size of the autoclaves vary but they usually hold between 10 000 and 15 000 bricks. The bricks are placed into and taken from the autoclaves on trolleys which run on steel rails. There is no change in size during the process so that the bricks are always very accurate in size and shape and have sharp arrises. Clay bricks on the other hand shrink considerably during drying and burning and vary considerably in size.
PROPERTIES

**Strength**

Calcium Silicate bricks can be produced over a wide range of compressive strengths to suit the specification.

The strength can range from about 12 to 48 MPa. However, normal production, which suits most requirements, is 20 to 30 MPa. Keeping the strength down to only that which is required means they are easier to cut and chase. The tensile strength, as measured by the transverse strength ranges from 2.5 to 4.0 MPa.

**Thermal Resistance**

Thermal conductivity varies with density moisture content.

Dry bricks have a value of 1.1 w/m²/c⁰

**Thermal Expansion**

Coefficient of linear thermal expansion at normal temperature is 14 x 10⁻⁶ per °C.

**Fire Resistance**

Existing testing has been done in Australia by Calsil Limited of fire resistance ratings. While some special bricks have obtained higher ratings, the wall thicknesses required to give the ratings are:

- 1 hour - 90 mm
- 1½ hour - 110 mm
- 4 hour - 190 mm

**Sound Ratings**

The sound transmission varies with thickness, density and rendering. A Sound Transmission Coefficient (S.T.C.) of 45 requires a wall mass of 180 kg/m² and S.T.C. 50 requires a wall mass of 300 kg/m².

**Light Reflection**

Being white they give excellent light reflection when used as face brick internally.
Size

Calcium Silicate bricks are made in a wide range of sizes varying in wall thickness from 90 mm to 190 mm and in height from 76 mm to 190 mm in lengths of 230 mm and 290 mm.

Efflorescence

Calcium Silicate bricks are free of soluble salts and therefore do not effloresce. Any signs of efflorescence would be due to the mortar.

Plastering

Calcium Silicate bricks can be readily finished by plastering or cement rendering. An advantage they offer is uniform suction.

Mortars

Normal composition mortars such as the 1:2:9 and 1:1:6 cement: lime: sand can be used to lay calcium silicate bricks.

However, in hot, dry weather there may be a need to increase the water retentivity of the mortar.

<table>
<thead>
<tr>
<th>Names</th>
<th>Bricks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMALL SOLID</td>
<td><img src="image1" alt="Brick Image" /></td>
</tr>
<tr>
<td>230mm x 90mm x 76mm</td>
<td></td>
</tr>
<tr>
<td>STANDARD SOLID</td>
<td><img src="image2" alt="Brick Image" /></td>
</tr>
<tr>
<td>230mm x 110mm x 76mm</td>
<td></td>
</tr>
<tr>
<td>STANDARD 3 HOLE</td>
<td><img src="image3" alt="Brick Image" /></td>
</tr>
<tr>
<td>230mm x 110mm x 76mm</td>
<td></td>
</tr>
</tbody>
</table>

Standard Brick Range

![Figure 8.1](image4)
<table>
<thead>
<tr>
<th>Names</th>
<th>Bricks</th>
</tr>
</thead>
</table>
| MODULAR 76 | ![Image](image1.png) 
 290mm x 90mm x 76mm |
| MODULAR 90 | ![Image](image2.png) 
 290mm x 90mm x 90mm |
| MODULAR 119| ![Image](image3.png) 
 290mm x 90mm x 119mm |
| MODULAR 162| ![Image](image4.png) 
 290mm x 90mm x 162mm |
| MODULAR 190| ![Image](image5.png) 
 290mm x 90mm x 190mm |

Modular Brick Range

Figure 8.2
8.3 CONCRETE MASONRY

Many types of bricks and blocks are manufactured in a variety of shapes, sizes and colours.

Briefly stated the procedure consists of:

- Mixing materials
- Pressing or shaping the brick
- Autoclaving or finishing the products.

The whole cycle in the manufacture takes about eight hours.

Because of the availability of raw materials such as sand and metal near the works, these materials are often not stored on site but brought in as needed; they are tipped into a hopper and conveyed up into a storage bin known as the tower.

(a) MIXING

Grey cement is purchased in bulk tankers and pumped up into the storage bin which is divided into several compartments keeping each different material segregated. White cement may be purchased in bags and stored until needed. This is also placed in the storage bin at the top of the tower.

When the type of block to be manufactured is determined, the required materials are weigh batched into a hopper below the storage bin and are dropped into a lower bin from where they are moved by conveyor belt into a large mixing machine. If the bricks are to be coloured, then an amount of coloured ochre is added at this stage.

Mixing is carried out for approximately 6 minutes.

(b) PRESSING

From the mixing machine, the mixed material is conveyed to an automatic pressing machine. The bricks are then compressed and vibrated into a mould and then conveyed into racks, from where they are transported by fork lift truck into an autoclave.

At this stage the bricks are in a soft state and are placed in a series of metal plates on the rack. As each rack full of new bricks is taken into the autoclave, a rack full of bricks which were processed the previous day are placed back near the automatic machine; these bricks are then conveyed to a stacking area and the plates released for use for the newly formed bricks.

(c) AUTOCLAVING

This is carried out over a period of approximately six hours. When the autoclave is filled with bricks, the door is sealed shut and steam is injected gradually over a period of approx.
1½ hours up to a pressure of 1 MPa. The bricks are left to cure for 3 hours before the pressure is released, the autoclave is opened and the bricks are taken out ready for use.

Bricks at this stage have an equivalent strength of 28 days air curing.

Other forms of curing equal to autoclaving:

(i) 28 days air cured.

(ii) 8 hours dry heat - which consists of placing bricks in a heated chamber. Water is allowed to drip into a hot plate producing steam which is circulated throughout the bricks. This is followed by 14 days of air curing. However, this type of curing is done only in country centres. Coloured bricks cured in this manner require a different proportion of colour than when autoclaved as autoclaving bleaches the colour to some extent and for this reason a completely black brick cannot be cured by the autoclave method.

Advantages of Autoclaving

- Higher strength
- Lighter colour
- Cuts shrinkage by half
- Speed. Blocks produced in 1 day
- Fast production - less stocks required - can be made at short notice
- Less damage to arrises of blocks
- Minimises efflorescence.

LAYING BLOCKS

Mortar - Mix 1:1:6 with blocks laid clean edge down.

HANDLING AND STORAGE OF BLOCKS

Ensure that a suitable site is available for off loading. If the ground is muddy or dirty, there should be a solid base onto which the bricks can be stacked.

The delivery driver is to off-load all face bricks onto plastic sheeting and also cover the top of the stacks with plastic. Stack all bricks neatly on site and ensure that handling is kept to a minimum.

Ensure an ample supply of face bricks is on site before any laying is commenced and draw from different stacks to blend any variation in colour.
Cleaning

Special care must be taken to prevent mortar smearing or dropping on the surface of the wall. Embedded mortar smears can never completely be removed after hardening, and will not be covered by most paints or surface treatments. Mortar droppings adhering to a wall should, however, be allowed to dry before they are removed with a brush or a trowel. When dry and hard, most of the mortar remaining can be removed by rubbing with a small piece of concrete block the same colour as the wall. Many cleaning problems can be avoided, particularly with coloured blocks, by using coloured mortar which matches the wall.
NOTE: Acid wash cleaning must not be used on concrete masonry walls except as a last resort.

PREVENTION OF WATER PENETRATION

Silicone Fungistat is especially formulated to impart the maximum water repellency to a large variety of porous surfaces whether they be alkaline or acidic. It has the advantage of being non-alkaline in itself and non-staining even on natural stone containing iron. Silicone Fungistat is intended for the treatment of most types of masonry including limestone, brick, mortar, concrete, natural stone, cast stone, cement fibre, etc. It is not suitable for plaster finishes. When suitably applied to masonry this product penetrates to the surface pore structure and renders it highly water repellent. This presents the passage of liquid water but does not greatly hinder the passage of air or vapour. Thus, treated masonry can still breathe and moisture can dry out through the surface. While this property of breathing is a desirable one it does mean that water under considerable hydrostatic pressure will penetrate the treatment. For this reason this material is not recommended for application to basement walls or other underground masonry. Treatment with this material preserves the structure from the damaging effect of the weather, keeps the masonry cleaner and free from staining and maintains the heat insulating properties.

BONDING OF BLOCKWORK

The principles of bonding are the same as for brickwork but, because of the range of thickness available, the blocks are only bonded longitudinally, no cross bonding being required. Stretcher bond is normal, although this may be varied for facing.

Half-lap bond is normal, but where necessary to permit bonding at returns and intersecting walls this may be reduced to one-quarter of the block length.

When the block thickness is less than half the length of the block, the use of quoin blocks avoids the presence of narrow edge faces on the extreme corner of the wall and the need to cut blocks (see Figure 8.4).
Methods of Bonding Blockwork

Figure 8.4

Except at quoin loadbearing masonry block walls should preferably not be bonded at junctions. At tee-junctions and intersections one wall should butt against the face of the other to form a vertical joint which provides for movement in the walls at these joints and thus controls cracking in the walls (study Figures 8.5 and 8.6).

Figure 8.5

Figure 8.6
Where lateral support must be provided by an intersecting wall, and in the case of piers and buttresses, the walls and piers should be tied together by 6 mm x 32 mm wide metal ties, spaced vertically at intervals of 600 mm (see Figure 8.7 (a)). When hollow blocks are being used, the cores at these points may be filled with mortar or concrete, especially in the case of load-bearing piers. Non-loadbearing walls, for similar reasons, are tied together at intersections by strips of expanding metal or galvanised mesh bedded in alternate courses (see Figure 8.7 (b)).

Apart from piers, the bearing area of a hollow block wall may be increased at points of concentrated load by filling the cores at such points with concrete for the full height of the wall and, if required for reasons of strength and stability, vertical reinforcing bars can be placed in the filling (Figure 8.7 (c)). Reinforced columns thus formed and reinforced piers can be linked with longitudinal reinforcement (Figure 8.7 (d)).

Hollow blocks of dense concrete may be used for loadbearing walls but the courses directly supporting floor and roof structures should be built of solid construction in order to distribute the load over the length of the wall and thus avoid the concentration of stresses. This may be accomplished by the use of solid blocks for such courses, by filling the cores of the hollow blocks in these courses with concrete, the wet concrete being supported by strips of expanded metal laid in the bed joint of the course, or by using lintel or bond beam blocks filled with concrete (see Figures 8.8 and 8.9).
Bond Beam and Large-Span Lintel

Figure 8.8

D.C.M. (Dense Concrete Masonry)
Lintel blocks
Concrete infill
Reinforcement

Figure 8.9
| TABLE 8.1 |
| COMPARISON OF CHARACTERISTICS OF BRICKS |
| CLAY | CONCRETE/MASONRY | SAND/LIME |
| Control joint space (depends on exp/drying/coeff.) | 24 m | 12 m | 6 - 9 m |
| Weight of solid products (Mass/m) | 2000 - 2300 | 2300 | 2000 |
| Permissible size variation | large 90 mm per 20 bricks | low ± 1 mm | low ± 1 mm |
| Compressive strength MPa | 10.0 - 110 MPa | 7.0 - 30.0 MPa | 10.0 - 56.0 MPa |
| Permanent expansion contraction | up to 0.2% exp. | shrinkage | shrinkage |
| Drying shrinkage | 0.00% - 0.015% | 0.02% - 0.08% | 0.01% - 0.035% |
| Thermal Exp. | 0.000 008 - 0.000 010 | ? | 0.000 015 |
| Porosity Absorption/Permeability | 7.5% - 14% | low | 9% - 16% |
| Initial Rate of Absorption (Suction) | moderate to high | low | low |
| Fire resistance of 100 mm thick | 2 hrs | 2 hrs | 2 hrs |
| Chemical Resistancty | very resistant | Susceptible to acids & sulphates | susceptible to acid & salt solutions resistant to sulphates |
| Thermal conductivity 'K' | 1.15 | 1.08 | 1.08 |
| Sound Insulation 10 mm thick | 45 dB | 45 dB | 45 dB |
| Limitations/Remarks | do not dampen | do not dampen |
The function of the final structure can be vitally affected by the properties of the bricks. These are set out in Table 8.1 and those requiring explanation are described below.

**THERMAL EXPANSION**

Clay bricks have a low expansion rate of 0.000 000 6 (increase per 0°C rise in temperature). To cite an example, a 100°C rise in temperature in a wall 10 000 mm long would result in an expansion of 3 mm.

The rates for calcium silicate and concrete products are about double that for clay bricks.

Thermal expansion is not a great problem in normal work but requires special consideration where there may be great temperature changes, such as around fireplaces.

**MOISTURE MOVEMENT**

Masonry products undergo expansion with a rise in moisture content. It is usually much greater and, therefore, more significant than thermal expansion. The rate of such movement is usually given as a difference between the oven-dry and saturated lengths and is referred to as "drying shrinkage".

Again, clay products show a very low movement, with concrete and calcium silicate units a much higher movement. This obviously is not relevant in situations where moisture content remains nearly static, as in internal walls. External walls, however, are subject to wetting and drying as well as humidity changes.

**CONSTITUTIONAL CHANGE**

After manufacture, masonry units show a permanent change of size. This is related to the absorption of moisture by clay bricks and the continued chemical reaction in calcium silicate and concrete units. Unlike the movements associated with a change in temperature or humidity, this movement is permanent and irreversible. Most of the movement occurs within a short time after manufacture, but it continues at a decreasing rate for some time.

Clay bricks also show a marked difference in this property. They are subject to expansion while the others shrink, although shrinkage is considerably reduced by autoclaving. It is important to note here that cracking of brickwork normally only occurs as a result of shrinkage because brickwork is strong in compression but weak in tension.

All bricks (and this applies to concrete and sand lime products) should be stacked for as long as possible after manufacture and before use.
Porosity, Absorption and Suction

Here lies an anomaly. The porosity of a brick shows little correlation with the "suction", or ability of the brick to absorb moisture from the mortar. For example, a calcium silicate brick has less suction yet greater porosity than a normal clay brick.

The suction of bricks has particular application to the ability of the bricks and mortar to bond together. Bricks with a very low rate of absorption will tend to float and will be easily displaced while the work is green, nor will a strong bond develop. On the other hand, a high rate of absorption will allow the brick to dry the mortar too quickly, weakening both the mortar and its bond with the brick.

Fortunately, it has been found that bricklayers are able to judge the correct absorption rate, because a suitable absorption rate ensures ease of laying. To reduce the suction, where necessary, the bricks must be damped before laying. Nothing can be done to increase suction, but some compensation is possible by reducing the "retention rate" of the mortar. (See Notes on the Science of Building 119, "Testing Bricks" and NSB 70, "Mortar for Unit Masonry Construction", Experimental Building Station.)
Chapter 9

CEMENT

9.1 INTRODUCTION

9.2 COMPOSITION OF PORTLAND CEMENTS

9.3 HYDRATION

   WATER CONTENT AND HEAT GENERATION
   SETTING TIMES
   WATER/CEMENT RATIO
   STRENGTH GAIN
   CURING

9.4 COMPONENTS OF CEMENT

9.5 TYPES OF PORTLAND CEMENT

   TYPE A
   TYPE B
   TYPE C
   TYPE D
   WHITE CEMENT
   BLENDED CEMENTS
   MASONRY
   HIGH ALUMINA

9.6 TESTING OF PORTLAND CEMENT

   SETTING TIME
   SOUNDNESS

9.1 INTRODUCTION

The existence of grey and white cement is common knowledge. What is not so well known, however, is that there is a range of cements, all with different characteristics. The common grey cement is correctly called ordinary Portland cement because there are several other special Portland cements, such as white cement.

There are also cements that are not Portland cements; high alumina cement, for example.
9.2 COMPOSITION OF PORTLAND CEMENTS

The main constituents of Portland cements are calcium, silica and alumina with small quantities of iron and other compounds (see Table 9.1). The main raw materials are clay or shale (which contain the silica, alumina and iron oxide) and limestone, coral or chalk (which are calcium carbonates). Small quantities of gypsum are also used to control setting time.

In manufacture, the clay and limestone are ground together and passed through a high temperature kiln to emerge as a clinker. This is mixed with a controlled proportion of gypsum and then ground to a fine powder ready for use.

In the process, four major calcium compounds are formed, each of which imparts specific properties to the cement. By adjusting the quantities or type of raw materials, the proportions of these compounds may be varied to produce Portland cements possessing a range of characteristics.

Production of cements other than ordinary Portland are restricted because of lack of demand and the difficulty of changing from one production run to another. Low heat cement is usually produced for specific jobs such as dam walls and large rafts. White cement is especially sensitive to the slightest adulteration. It is, therefore, imported from specialist companies overseas, with the exception of an off-white cement, now manufactured in Australia.

<table>
<thead>
<tr>
<th>COMPOUND</th>
<th>CHEMICAL FORMULA</th>
<th>ABBREVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tri-calcium silicate</td>
<td>3CaO·SiO₂</td>
<td>C₃S</td>
</tr>
<tr>
<td>Di-calcium silicate</td>
<td>2CaO·SiO₂</td>
<td>C₂S</td>
</tr>
<tr>
<td>Tri-calcium aluminate</td>
<td>3CaO·Al₂O₃</td>
<td>C₃A</td>
</tr>
<tr>
<td>Tetra-calcium Allumino-ferrite</td>
<td>4CaO·1Al₂O₃·Fe₂O₃</td>
<td>C₄AF</td>
</tr>
<tr>
<td>Calcium Sulphate</td>
<td>CaSO₄</td>
<td></td>
</tr>
<tr>
<td>(gypsum)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium Oxide</td>
<td>CaO</td>
<td></td>
</tr>
<tr>
<td>(quicklime)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 9.1

MAJOR COMPOUNDS PRESENT IN PORTLAND CEMENT
9.3 HYDRATION

WATER CONTENT AND HEAT GENERATION

This process is exceedingly complex and the ensuing explanation is necessarily greatly simplified. Basically, it is a chemical reaction in which water combines with the various constituents of cement. The resulting change of state occurs in three stages:

- **initial set**, when the cement paste starts to stiffen
- **final set**, when stiffening is complete
- **hardening** which is the gain in strength - rapid at first - and continuing at a decreasing rate, sometimes for many years.

Water is retained in set cement in three forms:

- as combined water in hydrated crystals;
- as water contained in the gel structure of the set compounds;
- as water present in capillary voids in the set structure.

A crystal is a regular arrangement of molecules forming a relatively stable, rigid, geometrical shape.

A gel might be described as a microscopic sponge containing water in the pores. Gels absorb water in wet conditions and give it up in dry conditions. This is accompanied by expansion and contraction and is referred to as drying shrinkage. It is the reason for moisture movements in concrete and sand-lime products.

In common with most chemical reactions, hydration produces heat (termed heat of hydration). This is undesirable in mass concrete where, because of the difficulty of disposing of the heat, dangerously high temperatures may build up. At other times, the heat generation is valuable in maintaining suitable temperatures in excessively cold weather.

Heat generation is almost directly proportional to the rate of hydration and all cements eventually produce a similar quantity of heat. High early strength is produced by a high early rate of hydration and consequently a high rate of heat generation. To restrict heat generation it is necessary to sacrifice early strength. As an extreme example, high alumina cement gains strength in 24 hours similar to that which ordinary Portland cement gains in 12 months. It also generates about the same amount of heat but mainly in the first 12 hours, instead of 12 months.

SETTING TIMES

Regardless of the type being used, cement must retain its workability for sufficient time to permit it to be placed and compacted. Time must also be allowed before final set to ensure that
bond occurs between batches, even after some delay, after which strength gain should be reasonably rapid.

Australian Standards require that initial set should not occur before 1 hour, and that final set must be within 12 hours.

WATER/CEMENT RATIO

It has been established that hydration involves the combining of cement and water by chemical reaction. It follows, therefore, that the combination occurs in specific proportions.

In practice, it is impossible to mix and place concrete with just sufficient water for hydration. Extra water is needed for workability. The excess water remains in the cement paste as free water, either in the gel or in capillary voids. Its presence, in fact, is partly the cause of the voids since it must occupy space.

Little imagination is needed to see that the more voids there are, the weaker the cement paste will be. Tests have shown that the strength of concrete is inversely related to the water-cement ratio. Excess water reduces strength by roughly the same amount as if an equal weight of cement was left out. Alternatively, to double the water-cement ratio is to halve the compressive strength.

\[
\frac{\text{mass of water in the mix}}{\text{mass of cement in the mix}}
\]

![Graph showing the effect of water/cement ratio on compressive strength.](Figure 9.1)

STRENGTH GAIN

It is normal to design structures on the basis of the 28-day strength of concrete; because of the need to determine the quality of concrete at earlier stages, tests are often carried out at 3 or 7 days. Fortunately the rate of hydration and, therefore, the rate
of strength gain is fairly predictable. Consequently, the known strength of concrete at, say 3 days, will provide a good indication of the strength at 28 days.

While cement products have the potential to become over 50% stronger than the 28 day strength, it is seldom likely that they will. This is because it is not feasible to maintain the curing conditions (mainly dampness) beyond the first month.

As a rough guide, cement products gain about 50% of 28 day strength in 3 days and over 70% in 7 days. Thus 30 MPa concrete may be expected to attain strengths of about 15 MPa at 3 days and 21 MPa at 7 days.

![Typical Strength-Age Relationship For N.P.C. Concrete](image)

**Figure 9.2**

![Age-Strength Relationships For Different Cement Types](image)

**Figure 9.3**
CURING

There are two requirements needed for hydration: water and heat. Water, because it takes part in the process, and heat, because hydration completely ceases at about 0°C. Note that this can be taken to extremes because excessive heat can have an adverse effect.

More than enough water for hydration is present in the mixing water. This, however, may be quickly lost, especially in hot or windy conditions unless suitable precautions are taken. (See also "Curing of Concrete").

![Typical Effect of Curing on Compressive Strength](image)

**Figure 9.4**

COMPONENTS OF CEMENT

Of the compounds in cement (Table 9.1) the two calcium silicates are the most important because they constitute over 70% of the bulk. The others may be considered as control agents to adjust the setting times and early strength characteristics.

CaS (tri-calcium silicate) hydrates at a moderately fast rate and contributes to the initial and final sets. It is responsible for most of the early strength. High early strength cements, therefore, contain comparatively high proportions of this compound. (Figure 9.3.)

CaS (di-calcium silicate) has no definite initial or final set because of its very slow hydration. It contributes little strength in the first 7 days, but continues to hydrate for a year or more provided it is kept wet. Because of its slow heat generation it is the predominant component in low heat cements. (Figure 9.3.)

CaA (tri-calcium aluminate) having a very rapid hydration rate, contributes to the setting and early hardening of cements. It is susceptible to sulphate attack, and, therefore, must be strictly limited in sulphate-resisting cement.
C₄AF (tetra-calcium alumino-ferrite) affects the setting and early strength because of its rapid hydration.

Pozzolan is the name given to certain silica containing materials which may be mixed with Portland cement or lime. On their own, they have no cementitious properties but they react with cement or lime during hydration. The resultant cement has strength and heat properties similar to low heat cement, with better workability, less drying shrinkage and increased durability. Blast furnace slag has been used as a pozzolan.

9.5 TYPES OF PORTLAND CEMENTS

Type A: Ordinary Portland Cement

This is the cement formulated to suit most applications in the construction industry. Other cements are rarely, if ever, used.

Type B: High Early Strength Cement

Known in Britain as 'Rapid Hardening Cement', it is almost 50% stronger than type A at 3 days. The rate decreases and, in fact, its ultimate strength is less than that of type A. It has not been produced in Western Australia.

Type C: Low Heat Cement

Produced only on specific orders for mass concrete. It has a slow rate of hydration with correspondingly slow strength gain and low heat generation. Although 15% weaker at 28 days than type A, its ultimate strength is higher.

Type D: Sulphate Resisting Cement

Because sulphate attack is not a real problem in Western Australia, this cement has not been used locally. Where danger exists, it is usual to use high alumina cement because of its resistance characteristics and its availability.

White Cement

Manufactured from china clay and lime, white cements comply with requirements for type A cements. None is manufactured in Australia, although an off-white product is made in South Australia.

Blended Cements

Portland cements mixed with up to 60% of blast furnace slag or other pozzolons assume different properties. They display low-heat properties, better workability, increased chemical resistance and reduced drying shrinkage.
Blended cements generally have a slower rate of strength gain and less heat of hydration when compared to normal cements. However, with continuous curing, they may achieve higher long term strengths.

**Masonry Cement**

Under no circumstances must this cement be used for concrete. It is for use in masonry mortar only and is not acceptable for calculated brickwork because of its chemical plasticizer content. Most masonry cements contain Portland cement and limestone and, possibly, blast furnace slab and gypsum.

**High Alumina**

This is not a Portland cement and is made from bauxite (aluminium ore) and limestone. It has several outstanding properties:

- Its 24-hour strength exceed the 28-day strength of Portland cement. Where required, slabs and beams may be used under full load after one day.

- A high resistance to chemical attack by sulphates and dilute acids makes it valuable for use in concrete for boiler stacks, dairies, breweries, sewers, etc.

- When cured, it has a high tolerance to heat. Mixed with special aggregates it is used for furnace work where it can withstand temperatures up to 1600°C.

- Heat of hydration is extremely high because of the rapidity of hydration. At the same time, it is extremely susceptible to loss of strength if its temperature rises above 30°C at any time after mixing and before it has been dried out after curing.

- The thickness of concrete must be strictly limited to allow for dissipation of heat. This varies from 200 - 400 mm, depending on the richness of the mix. Curing by spraying or flooding must commence about 6 hours after casting and continue for over 24 hours. It is not suitable for use in hot moist conditions.

- A flash set is likely to occur when mixed with Portland cement. This property has application for quick setting repair work.

- It is susceptible to attack by alkalis. Aggregates containing lime, such as blast furnace slag and integral waterproofing agent, must not be used.
9.6 TESTING OF PORTLAND CEMENT

SETTING TIME

The setting time of the cement must be sufficient to allow the concrete to be mixed, deposited and worked into position. Finely ground cement clinker without any admixture sets too rapidly for normal use, so a small proportion of gypsum, which has a retarding action on the setting process, is added during grinding.

To comply with the requirements of the Australian Standards 1315-1973, Portland Cements are required to have an initial setting time of not less than 60 minutes. The hard setting time of all Portland cements is not more than 12 hours. These times do not represent any sudden change in the hydration process. They are related to a particular test on neat cement pastes and the specification requirements ensure that concrete made with these cements will behave normally. A Vicat apparatus is used for measuring the setting time. This apparatus is also used for determining the amount of water required for the setting time test. For the purpose of arriving at the 'standard' consistency of cement paste a plunger 10 mm in diameter is fitted to the needle holder of the Vicat apparatus. Trial pastes of cement and water are mixed and placed in the mould. The plunger is then gently brought into contact with the surface of the paste and quickly released. The quantity of water required to produce a paste of 'standard' consistency is that required for a paste which will permit the settlement of the plunger to a point 5 to 7 mm from the bottom of the mould 30 seconds after the needle has been released.

The time of the initial set is found by filling the mould with a paste of standard consistency and using a needle, 1 mm square, in place of the plunger. The needle is lowered to the surface of the cement paste in the mould and quickly released, when it may pierce the block completely. The operation is repeated until the needle will only reach a point about 1 mm from the bottom of the mould, 30 seconds after the needle has been released. The period between the time when the water is added to the cement and the time when the needle penetrates this distance is the initial setting time.

The needle used in finding the hard setting time is also 1 mm square. It is fitted at the end with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm in diameter beyond which the needle projects 0.5 mm. The time adjudged to be the hard setting time is that at which the needle makes an impression on the cement paste block but the circular cutting edge does not. In all cases, the rod and appropriate attachments together weigh 300 g ± 1 g.
The Vicat Apparatus Used For Determining
The Setting Time of Cement

Figure 9.5

SOUNDNESS

If any excess of lime is used in the manufacture of cement it may not all combine with the other minerals and some may remain free in the finished cement. When the cement is used in concrete this free lime slakes slowly and the resulting expansion may cause the concrete to disintegrate.

The soundness test is designed to discover the presence of any such particles of free lime and consists in accelerating their slaking by the application of heat, quickly making apparent a defect which might not have been discovered until some time after the cement had been used.

The soundness test is made by the Le Chatelier method and the apparatus consists of a small split cylinder of metal 0.5 mm thick forming a mould 30 mm in internal diameter and 30 mm high. On either side of the split are attached two indicators with pointed ends. The distance from the centre of the cylinder to the ends of the indicators is 165 mm. The mould is placed on a glass plate and filled with cement paste of standard consistence, care being taken to keep the edges of the mould gently together during this operation. The mould when filled is covered with a glass plate and immediately submerged in water at a temperature of 23°C ± 2°C and
left there for 24 hours. After this period has elapsed the distance separating the ends of the two pointers is measured. The mould is submerged again and the water brought to boiling point in 25 to 30 minutes. It is kept boiling for six hours. The mould is then removed and left to cool, when the distance between the points is again measured. The difference between the two measurements represents the expansion of the sample.

![Apparatus For Le Chatelier Test](Figure 9.6)
Chapter 10

CONCRETE

10.1 PROPERTIES OF CONCRETE

10.2 PROPERTIES IN HARDENED STATE

STRENGTH
COMPRESSION STRENGTH
WATER-CEMENT RATIO
DENSITY (COMPACTION)
AGE OF CONCRETE
TYPE OF CEMENT
CURING CONDITIONS
TENSILE STRENGTH
DURABILITY

10.3 PROPERTIES IN PLASTIC STATE

WORKABILITY
COHESIVENESS

10.4 COMPACTION OF CONCRETE

GENERAL
HAND COMPACTION
VIBRATION

10.5 TYPES OF VIBRATORS

IMMERSION VIBRATORS
FORM VIBRATORS
SURFACE VIBRATORS

10.6 LIGHTWEIGHT CONCRETE

USE OF LIGHTWEIGHT
TYPES OF LIGHTWEIGHT AGGREGATES
AERATED CONCRETE
NO-FINES CONCRETE

10.1 PROPERTIES OF CONCRETE

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Concrete is a mixture of cement, water, coarse and fine aggregates, which is plastic when first made, then hardens to a strong, homogeneous mass possessing great durability. In its plastic state, concrete may be moulded into practically any shape required. When hard it is capable of carrying high loads, particularly in compression, and of resisting fire, weather and other deteriorating influences.

The properties of concrete depend on the properties of the components used in the mixture and on the way it is handled, compacted, finished and cured. Care is necessary during all these operations to ensure the best results.

10.2 PROPERTIES IN HARDENED STATE

**STRENGTH**

The strength of concrete determines the loads it can carry and indirectly affects its durability. Concrete is strong in compression; that is, it can resist high crushing loads, but is comparatively weak in tension, i.e. it cracks fairly readily if stretched or put in flexure. In practice concrete is reinforced with steel when it is to be subjected to tensile stresses.

Concrete has some tensile strength, however, and it is an important property of the material when it is used in pavement, floor slabs on ground or similar applications. In such cases the tensile strength of the concrete is sufficient to support the bending loads applied.

**COMPRESSIVE STRENGTH**

Compressive strength is a measure of the ability of concrete to resist crushing. It is determined by crushing test specimens to destruction and measuring the loads required. (See Figure 10.1.)

Compressive strength is the most widely used measure of concrete quality because it is readily determined and because most of the other properties of concrete improve with increases in compressive strength.

Compressive strength of concrete is affected by the following factors:

(a) Water-Cement ratio

(b) Density (compaction)

(c) Age of concrete

(d) Type of concrete

(e) Curing conditions
(a) WATER/CEMENT RATIO

This is the ratio of the amount of water and the amount of cement present in the concrete. The water/cement ratio is expressed as the weight of water divided by the weight of cement, e.g. if 1 m³ of concrete contains 150 kg of water and 300 kg of cement then the water/cement ratio is 0.5.

The water/cement ratio may be expressed in terms of litres of water per bag of cement. Conversion from one term to the other is a simple matter, since one litre of water weighs one kilogram.

The strength of concrete depends almost entirely on the water/cement ratio and is inversely proportional to it, i.e. as the water/cement ratio of concrete is increased the strength is decreased. See Figure 10.2.

Effect of Water/Cement Ratio on Compressive Strength

Figure 10.2
(b) **DENSITY OF CONCRETE**

Density of concrete is its weight per unit volume. The density of concrete depends largely on the density of its major components - sand and coarse aggregate. The density of concrete will be reduced by insufficient compaction. Voids in the concrete created by excess mixing water or improper compaction reduce the density and the strength of concrete (see Figure 10.3.)

![Graph of Loss in Potential Concrete Strength](image)

**Figure 10.3**

(c) **AGE OF CONCRETE**

One of the factors affecting concrete strength is its age particularly during its early life. Concrete in most cases will continue to gain strength for a number of years, rapidly at first and more slowly as it becomes older. (See Figure 10.4.) Therefore, in determining the strength of concrete, the age at which the test is made must be noted. In most cases concrete is tested at 28 days which is a compromise between obtaining a strength indication as early as possible and accurately determining the long term concrete strength.

![Graph of Concrete Age and Strength](image)

**Figure 10.4**

10.4
(d) **TYPE OF CEMENT**

The type of cement also influences the strength of concrete at a particular age since different types of cement gain strength at differing rates. Concretes made with the same water/cement ratio and cured under the same conditions tend to gain the same order of strength. (See Figure 10.5.)

![Concrete Age and Strength](image)

*Concrete Age and Strength*

*Figure 10.5*

(e) **CURING CONDITIONS**

To gain its ultimate potential strength concrete must be kept continuously moist, i.e. water must be available at all times to chemically react with (hydrate) the cement.

The importance of curing on strength may be judged from the fact that a concrete curing in air for 28 days may gain only two-thirds of the strength of the same concrete moist cured for the same period. (See Figure 10.6.)

![Effect of Curing](image)

*Effect of Curing*

*Figure 10.6*
Hydration of cement is a chemical reaction and, like most chemical reactions, the rate at which it proceeds depends upon the temperature. Thus the temperature at which concrete is cured affects the rate at which it gains strength.

From Figure 10.7 it may be seen that concrete gains strength more slowly at low temperatures than at high temperatures. It is essential that concrete test specimens be cured at the standard temperature to ensure that results can be compared.

![Graph showing effect of curing temperature on compressive strength](image)

**Effect of Curing Temperature**

*Figure 10.7*

**Note:** With steam curing rate of strength gain and long term strength is dependent on method of steam curing used.

**TENSILE STRENGTH**

Tensile strength is a measure of the ability of concrete to hold together. Although the tensile strength of concrete is small in comparison with its compressive strength, 3-5 MPa compared with, 20-50 MPa, it is of importance to certain types of concrete, notably unreinforced concrete pavements, floor slabs and the like. Tensile strength is affected by much the same factors which affect compressive strength, and in more or less the same way. An additional factor is the nature of the aggregate used, angular aggregates tending to give higher tensile strengths than rounded water-worn aggregates such as river gravel.

**DURABILITY**

Concrete is a durable material, i.e. it will resist the ravages of time and weather to a remarkable extent. The durability of concrete is dependent on the water/cement ratio, cement content and degree of compaction and curing. Durability improves with lower water/cement ratios, higher densities and with extended moist curing. In general any measure designed to reduce the voids and pores in concrete will increase its durability.
10.3 PROPERTIES IN PLASTIC STATE

Two properties of plastic concrete are of fundamental importance -

Workability

Cohesiveness

WORKABILITY

The workability of concrete is a measure of the ease with which it may be placed and compacted. Workability is affected by the following factors -

(a) Water Content. For a given amount of sand and stone the higher the water content the more workable the concrete. However increases in water content without corresponding increases in cement content will increase the water/cement ratio. The water/cement ratio of concrete is fixed by considerations other than workability, e.g. strength and durability, and should not be increased beyond the maximum figure dictated by these considerations.

(b) Cement Content. The cement paste in concrete acts as a lubricant and at a fixed water/cement ratio the higher the cement content (and hence the higher the water content) the more workable will be the concrete. Adjustments to the workability of concrete should be made by adding paste of the required water/cement ratio, NOT by adding water alone.

(c) Grading. The grading of the aggregates also affects workability. In general, well graded aggregates, i.e. those having a range of particle sizes, tend to produce the more workable concrete.

(d) Particle Shape and Size. The particle shape and maximum size of aggregates also affects workability. In general smooth, rounded particles tend to produce more workable concrete than rough, angular particles. Further, for a given cement content and water-cement ratio, workability increases as the maximum size of aggregate increases, assuming that equipment is available to handle the larger sizes of aggregate.

COHESIVENESS

The cohesiveness of concrete is a measure of its ability to resist segregation and bleeding (i.e. migration of water to the surface) during placing and compaction. Factors affecting cohesiveness in concrete are:

(a) Consistency. The wetter the mix, i.e. the more water contained in concrete, the more likelihood there is of segregation and bleeding occurring. Very wet mixes slump readily and segregation of the cement paste from the coarse and fine particles occurs readily.
On the other hand, very dry mixes are friable and again segregation may occur, particularly of the larger particles. Greater care must be exercised, therefore, in handling very wet or very dry mixes, than is necessary for mixes which are plastic and cohesive.

(b) Aggregate Grading. Cohesiveness is also affected by the quantity of fines present. Thus mixes which are deficient in cement or the finer sand particles tend to segregate more readily during handling. On the other hand, the presence of an excessive amount of fines tends to make the concrete sticky, and whilst it is then very cohesive, it becomes difficult to work and place.

10.4 COMPACTION OF CONCRETE

GENERAL

The object of compacting concrete is to ensure that maximum density is obtained and that complete contact between the concrete and the surface of reinforcing steel and formwork is achieved.

Thorough compaction is most important as it leads to:

1. Maximum strength
2. Sound, watertight concrete
3. Sharp detail at corners
4. Good surface appearance
5. Good bond with steel reinforcement, and
6. Sound protective cover to steel reinforcement.

HAND COMPACTION

Ordinary hand methods of compaction consist of rodding, tamping and spading with suitable tools.

VIBRATION

Although hand compaction may produce satisfactory results for some purposes, the use of vibration allows the use of drier mixes, resulting in higher strength and reduced shrinkage for given mix proportions.

10.5 TYPES OF VIBRATORS

- Immersion Vibrator
- Form Vibrator
- Surface Vibrator
(a) Immersion Vibrators

This type of vibrator may be mechanically, electrically or pneumatically driven. Pneumatic vibrators have a safe and flexible drive, but since compressed air motors are relatively inefficient and expensive to maintain they may not be economic unless the compressor is otherwise being used on the job. Petrol engines are small and very mobile, thus enabling vibrators to be readily moved about a job. Electric motors operate at constant speed and are conveniently portable, but require a reliable electricity supply.

Immersion vibrators (sometimes referred to as internal or poker vibrator) are probably the most efficient type of vibrator as they vibrate the concrete directly. They are available with heads ranging from 25 mm to 150 mm diameter, the 25 mm diameter head being suitable for small heavily reinforced sections while the 60 - 70 mm head is the most common general purpose type.

Vibrations are caused by an eccentric shaft which rotates within the vibrator head. Vibrators should be checked regularly either with special instruments or by comparing their effectiveness in concrete alongside a vibrator which is known to be satisfactory.

![Internal Vibrator is Slowly Withdrawn as Mortar Begins to Collect at the Surface](image)

*Figure 10.8*

The vibration of concrete should be done systematically. The concrete should be placed in shallow layers and the vibrator allowed to penetrate each layer fully. The vibrator head should be inserted vertically at points 500 mm apart and then slowly withdrawn to close up the hole left by the vibrator. Vibration at any point should not be prolonged beyond the point at which mortar commences to collect on the surface, usually 5 to 15 seconds. As a general rule, the vibrator should not come nearer than 100 mm to the forms in order to obtain a uniform appearance. If it touches the forms a sand streak can result and the form could be damaged. In shallow sections some consolidation can be obtained by using the vibrator in a sloping or horizontal position.

10.9
INCORRECT
Concrete placed in heaps and the vibrator used to flow concrete to desired level causes segregation and risks pockets of weak mortar honeycombing, excessive blow holes

CORRECT
Concrete should be placed in uniform shallow layers and compacted

INCORRECT
Vibrator inserted haphazardly and to insufficient depth to penetrate previous layer results in unsatisfactory variable compaction and poor structural quality. Too short a period of vibration and rapid withdrawal leaves air voids within the concrete

INCORRECT
Excessive (prolonged) localised vibration causes segregation and bleeding, particularly with high slump concrete resulting in pockets of weak mortar

CORRECT
Vibrator held vertically is inserted at closely spaced intervals to depths sufficient to penetrate previously placed layer of concrete, until air bubbles disappear, then withdrawn slowly

USE OF INTERNAL VIBRATORS

INCORRECT
Concrete placed at top of slope tends to pull apart under compaction and mortar flows down slope

CORRECT
Commence placing at bottom of slope

Placing and Compacting Concrete

Figure 10.9

10.10
(b) Form Vibrators

Form vibrators, or external vibrators, are rigidly attached to the outside of forms by means of clamps, and impart oscillations or shaking motion to the forms. This form of vibrator is suitable for small members or narrow and heavily reinforced sections into which it is difficult to insert immersion vibrators. They are often used in conjunction with poker vibrators for a high degree of compaction and good dense surface finish.

Form vibrators are more power-consuming than immersion vibrators, as energy is absorbed by the formwork.

The formwork must be very rigid to withstand the oscillations and corners must be especially tight to prevent loss of cement mortar. The use of form vibrators is usually limited to steel forms.

Concrete should be placed continuously in shallow layers (say 500 mm deep) while the forms are kept vibrating. In this way air holes are removed as the concrete builds up. To ensure the concrete makes proper contact with the side forms towards the top of a lift, it is advisable to use immersion vibrators for the top 500 mm if space allows.

These electrically driven form vibrators are required for a heavily reinforced, thin precast unit - NOTE: the massive steel form required due to high reuse and the effect of the external vibrators.

![Figure 10.10](image)

Vibrating Tables

Vibrating tables are a type of form vibrator where the whole mould is vibrated uniformly while clamped to the table. This form of compaction is widely used for the manufacture of small precast concrete products.
(c) Surface Vibrators

This form of vibrator is used for floors, road slabs and other thin sections with large surface areas. Surface vibrators may consist of a flat pan or tray with handles at either end and a vibrating unit mounted in the middle, or a screed board with one or more vibrating units fixed to it. On large road or airfield jobs, a mechanically drawn compaction machine may be used which spreads, compacts, and finishes say an 8 m width of concrete pavement in a run. Surface vibrators are not generally effective beyond depths of 175 mm, depending on the type used. To avoid excessive surface mortar and laitance their use is usually limited to concretes with a slump of less than 60 mm.

A steel surface vibrator (two pneumatic motors) is supplemented with two pneumatic immersion vibrators to place a low slump concrete.

Figure 10.11

10.6 LIGHT WEIGHT CONCRETE

USE OF LIGHT AGGREGATE

Lightweight concretes are commonly made by using a light weight aggregate instead of the normal metal. Many of these aggregates are being produced in various countries and new ones come on to
the market from time to time, although not all of them are available in this country. The advantages of these aggregates for building lie not only in the reduced weight but in the better thermal insulating properties that they give to the concrete. On the other hand, their light weight is a disadvantage in respect of insulation against sound.

TYPES OF LIGHTWEIGHT AGGREGATES

The main lightweight aggregates in use are clinker, foamed slag, expanded clay and exfoliated vermiculite.

Clinker

For the purpose of definition as a concrete aggregate, the term "clinker" is applied only to well burnt furnace residues which have been fused into lumps. Certain clinker aggregates have been found to cause serious expansion of the concrete in which they are used owing to the presence of a proportion of unburnt or partially burnt coal of certain kinds. One of the major difficulties in the use of clinker as an aggregate is the wide variation in this content of combustible matter. It may be reduced by screening the clinker through a mesh of about 5 mm before it is crushed and discarding the fine material, since this usually contains the greater proportion of the combustible matter.

Certain clinkers have been found to contain particles of material that expand slowly when wetted, and if these particles are near the surface of the concrete they may cause popping of the applied plaster coating. Should this be suspected the clinker should be wetted and allowed to stand in a moist state for a few weeks. Occasionally small pieces of iron occur in the clinker and may cause staining of the concrete surface. If staining is likely to be objectionable, the iron bearing particles should be removed magnetically from the clinker.

A clear distinction must be made between clinker and breeze. The latter, which is simply a finely divided coke, is not recommended for use as a concrete aggregate. Blocks made with clinker aggregate are still commonly known as "Breeze Blocks" but this description is wrong and likely to lead to confusion.

Foamed Slag

Foamed or expanded blast furnace slag has become one of the principal lightweight aggregates. It is produced by allowing limited amounts of water to come into contact with the molten slag. The conversion of the water into steam expands the slag so that it forms a porous material resembling pumice. The foamed slag is prepared for use as an aggregate by crushing and screening to the sizes required for the particular use to which it is to be put. The weight of the material ranges from 324 kg - 900 kg per m³.
Expanded Clay, Shale and Slate

When certain clays, shales or slates are heated to the point of fusion, they expand or bloat owing to the generation of gases within the mass of the material. The porous cellular structure is retained on cooling, giving a lightweight material.

Expanded Vermiculite

Vermiculite is a material resembling mica and when heated to temperatures between 650°C and 1 000°C, depending upon the material it expands by exfoliation of the thin plates of the vermiculite to give particles resembling small concertinas. The product is very bulky since it weighs only some 72 kg - 195 kg per m³.

Pumice

Pumice is a volcanic rock and as quarried usually contains other matter. It is important that pumice for use as a concrete aggregate be washed to remove dust and clay. The weight of the pumice varies from 486 - 900 kg per m³.

Expanded Perlite

Perlite is a glassy volcanic rock, which, when heated rapidly to the point of fusion, will expand to form a light cellular material having a weight of 81 - 243 kg per m³.

AERATED CONCRETE

Concrete in the form which builders are most familiar is a heavy strong material. These properties are essential for many purposes, but for others a much lighter concrete has advantages, even if its strength is lower. Lightweight concrete can be produced either by using aggregates such as clinker, foamed slag or pumice, that are much lighter than the usual stone or metal, or by forming air or gas bubbles in the plastic cement mix so as to give the concrete a sponge-like structure. The latter type, with which we are concerned here, is now usually called an aerated concrete, although the descriptions "cellular", "gas", "foamed", and "pore concrete" are often used.

Types of Aerated Concrete

In making aerated concrete, various methods have been used for producing the aeration of the concrete mix. They may be conveniently classified as follows:

1. Processes in which gas is produced by a chemical reaction within the mix before it sets.

2. Processes in which a foam-producing substance is added to the mix to introduce and stabilise air-bubbles.
3. Processes involving the use of excess water, which on drying out leaves air-filled pores.

Portland cement is normally used as the cementing agent but lime is an alternative if combined with a high pressure, steam maturing process in a matter similar to that used in the curing of sandlime bricks.

Aerated concretes may be made with or without aggregates. Coarse aggregate is not used in true aerated concretes. The lightest material (weighing about 324 kg per m³) is obtained when cement is used without any sand or other aggregate. This type of product is used for insulating cold stores, pipelines, etc. For denser concretes, mixtures of cement and sand up to 1:4 are used, but for products of moderate density (648 - 1053 kg per m³) part of the sand must be very fine and may have to be specially ground.

NO-FINES CONCRETE

This description is commonly applied to concretes which contain only a single size coarse aggregate (either a dense aggregate or a lightweight aggregate) with sufficient cement to joint the particles while leaving voids between them. The density is about two thirds to three quarters that of dense concretes made with the same aggregates.
Chapter 11

CONCRETE REINFORCEMENT

11.1 INTRODUCTION

11.2 BASIC PRINCIPLES OF REINFORCED CONCRETE
   CHARACTERISTICS OF CONCRETE
   CHARACTERISTICS OF STEEL

11.3 TYPES OF STRESSES FOUND IN A STRUCTURE

11.4 PROPERTIES OF STEEL

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11.6 TYPES OF REINFORCING STEEL
   AUSTRALIAN STANDARDS
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11.7 ACCEPTING DELIVERY
   CLEANING REINFORCEMENT
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11.8 HANDLING REINFORCEMENT
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11.9 SPLICES

11.10 FIXING REINFORCEMENT
   SUPPORTING

11.11 POSITIONING OF MAIN TENSILE REINFORCEMENT
   FIXED AND SUPPORTED BEAMS
   SUPPORTED ENDS
   FIXED ENDS
   ONE END FIXED ONLY
   CONTINUOUS BEAMS
   CONTINUOUS TEE-BEAMS
   CANTILEVER
   COLUMNS
   RETAINING WALLS

11.2 GLOSSARY
11.1 INTRODUCTION

There are many structural requirements for which plain concrete does not give the most satisfactory solution. Reinforced concrete is able to meet many more loading conditions than can plain concrete. It can also be used to limit deflections or to reduce the size of cracks.

While the designing and detailing of reinforcement is the job of the design engineer, it is important that those who supervise the fixing of reinforcement on the job site have an appreciation of the basic principles of reinforced concrete. This will help them to understand why it is necessary that reinforcement be correctly handled and correctly fixed in the position indicated on the drawings.

11.2 BASIC PRINCIPLES OF REINFORCED CONCRETE

Reinforced concrete is a building material which is designed to combine concrete and steel into the one structural entity, in such a manner as to use to the best advantage the characteristics of each of these materials.

**CHARACTERISTICS OF CONCRETE:**

- Plastic mouldable when fresh
- High compressive strength when hard
- Low tensile strength
- High resistance to fire
- Inexpensive.

**CHARACTERISTICS OF STEEL:**

- Can be made into rods suitable for embedding in concrete
- High compressive strength
- High tensile strength
- Low resistance to fire
- Expensive.

The aim of the reinforced concrete designer is to combine steel reinforcement with concrete in such a manner that just enough of
the expensive steel is used to resist tension forces and excess shear forces, while the comparatively inexpensive concrete is used to resist compressive forces.

Steel and concrete combine together successfully because:

(a) Upon hardening, concrete bonds firmly to steel reinforcement and the two act as though they are one when a load is applied.

This means that any tendency for the concrete to stretch and crack in a region of tensile stress, can be directly counteracted by steel rods embedded in that area.

(b) When subjected to changes in temperature, concrete and steel expand or contract by similar amounts. If this were not so, they would separate because of differential expansion and no longer act as one material. If this occurred, the lack of bond between concrete and steel would prevent tensile stresses in the concrete being transferred to the steel reinforcement and the concrete would crack and collapse.

(c) Concrete, having a high resistance to damage by fire, protects the steel reinforcement embedded in it, preventing it from losing its strength at high temperatures.

11.3 TYPES OF STRESSES FOUND IN A STRUCTURE

The following are the principal types of stress which develop in structural members:

(a) Compression

\[ \text{Load} \rightarrow \text{Concrete} \rightarrow \text{Load} \]

Compressive stresses tend to cause concrete to crush.

(b) Tension

\[ \text{Load} \rightarrow \text{Concrete} \rightarrow \text{Load} \]

Tensile stresses tend to cause concrete to stretch.

(c) Shear

\[ \text{Load} \]

\[ \text{Concrete} \]

\[ \text{Load} \]

Shear stresses tend to cause sliding between adjacent sections of concrete.
11.4 PROPERTIES OF STEEL

Steel has a very great resistance to tensile and other forces against which concrete has but little resistance. A mild steel bar with a cross-sectional area of 645 mm$^2$ will resist a pull of up to 490 MPa, while some special steels will resist a stretching (or tensile) force of over 700 MPa.

Tests have shown that when a pull is applied to concrete it will break, even if the pull is only 4 MPa. When a much larger pull is applied to a steel bar, however, it continues to lengthen before it breaks. A stress in a bar of about 270 MPa will increase its length very slightly and, when the stress is released, the bar will return to its original length. This point is known as the "Elastic Limit". If the pull is increased up to about 300 MPa and then released, the length of the bar will be permanently increased; it no longer acts as an elastic material. On still further increasing the pull, a point is reached at which the increase in the length of the bar becomes very much greater without any increase in the applied stress. This is called the "yield point", and occurs when the stress is about 300 MPa or about two-thirds of the stress at which the bar will break.

If the load on a beam stresses the reinforcement within the elastic limit the beam will sag, but will return to its original shape when the load is removed. A heavier loading - but not so heavy as to stress the steel to its yield point - will also cause the beam to sag but, when the load is removed, the beam will be permanently deflected at the middle. If, however, the load is great enough to stress the steel to its yield point the beam will continue to sag due to the increased lengthening of the bars, cracks will appear on the underside and extend towards the top, and the beam will fail because the area of the concrete in the upper part (where it is in compression) is so reduced that it is unable to resist the compressive stresses and is crushed. The stress at which the bar will break is, therefore, of less importance than the stress which will cause it to increase in length, because the yield point of the steel corresponds to the failure of the beam.

To allow an adequate factor of safety, ordinary mild steel reinforcement bars are designed to have a stress in the steel of 105 MPa to 120 MPa (i.e. about half the stress at the elastic limit) when carrying their full load.

11.5 BOND AND ANCHORAGE

It has been explained that the effectiveness of reinforced concrete depends upon adequate bond developing between the concrete and steel reinforcement, so that stresses can be transferred from the concrete to the steel. Good bond can be achieved by thoroughly compacting concrete around clean reinforcing bars. Higher strength concretes generally have better bond to steel, and deformations in the shape of the steel rods improve bond. Deformed bars can develop approximately twice the bond strength of plain bars, consequently the majority of reinforcing steel is deformed bar.
With the exception of the 10 mm diameter bar the majority of reinforcing steel is *deformed bar*.

The hard-drawn wire used in fabric is very smooth but bond with this type of reinforcement is seldom critical due to the small lengths between cross wires - usually a maximum of 200 mm.

It is usual to extend reinforcing bars beyond the region of tensile stress in a structural member, to ensure that the bar has sufficient contact with the concrete below the region of stress, so as to develop satisfactory bond strength. Where it is difficult to extend the length of a bar, a bend or hook is used to develop bond with the concrete.

11.6 TYPES OF REINFORCING STEEL

*AUSTRALIAN STANDARDS*

Reinforcement should comply with the applicable Australian Standard Specification.

AS 1302 Steel Reinforcing Bars for Concrete.

AS 1303 Hard-Drawn Steel Reinforcing Wire for Concrete.

AS 1304 Hard-Drawn Steel Wire Reinforcing Fabric for Concrete.

Sizes of plain wire mesh and deformed bars together with the tensile properties of the wire and bars are shown in the following tables. These Tables are taken or adapted from the above Australian Standards.

Sizes of Plain Wire

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>Nominal Area (mm²)</th>
<th>Mass (kg/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>12.6</td>
<td>0.099</td>
</tr>
<tr>
<td>5</td>
<td>19.6</td>
<td>0.154</td>
</tr>
<tr>
<td>6.3</td>
<td>31.2</td>
<td>0.245</td>
</tr>
<tr>
<td>7.1</td>
<td>39.6</td>
<td>0.311</td>
</tr>
<tr>
<td>8</td>
<td>50.3</td>
<td>0.395</td>
</tr>
<tr>
<td>9</td>
<td>63.6</td>
<td>0.499</td>
</tr>
<tr>
<td>10</td>
<td>78.5</td>
<td>0.616</td>
</tr>
<tr>
<td>11.2</td>
<td>98.5</td>
<td>0.773</td>
</tr>
<tr>
<td>12.5</td>
<td>122.7</td>
<td>0.963</td>
</tr>
</tbody>
</table>

Note - The calculation of mass in Tables 1, 3 and 4 is on the basis of the density of steel being 7850 kg/m³.

Table 11.1

11.5
BAR TYPES

Plain round bar

Transverse ribs Longitudinal ribs

Deformed bar

Transverse ribs Longitudinal ribs

Twisted deformed bar

Reinforcement Bars

Figure 11.1

MESH

Mesh reinforcement, supplied in rolls or mats, is used mostly in reinforced concrete roads and floor slabs, and saves the assembling and wiring together of bars on the site. In such cases it is common first to lay the concrete which is to be under the reinforcement, followed by the top layer of concrete; if this is done the top layer must follow immediately so that the two layers will combine as one and the bottom concrete will not set before the top layer is placed. Care must be taken to ensure that the reinforcement is in its proper position, lifting it if necessary before the top layer is placed.

Rectangular Mesh

Square Mesh

Trench Mesh

Girder Wrap

Mesh Shapes

Figure 11.2

11.6
Laps

A rule which has long been used and one which experience has shown gives satisfactory results, is that Welded Wire Fabric should be over-lapped not less than one mesh spacing.

When more than one sheet is required it will usually be necessary to have a splice between adjacent sheets to provide continuity by transferring the tensile stresses between the corresponding wires of the spliced sheets. The transfer of the tensile stresses between these corresponding wires depends primarily on the anchorage provided by the transverse wires.

Splices must not only be able to transfer the tensile stresses but also must be so detailed as to control the width of cracks in the region of the splice. Study Figure 11.4 below.

Figure 11.3

Figure 11.4
11.7 ACCEPTING DELIVERY

Before accepting a supply of reinforcing steel on a job, it should be checked for the following:

(a) Correct type, size and quality

(b) Damage

(c) Rusting.

CLEANING REINFORCEMENT

AS 1480 requires that, at the time of placing concrete, reinforcement must be free from mud, oil, grease and other non-metallic coatings and loose rust which would reduce the bond between the concrete and reinforcement.

It is this loss of bond that should always be kept in mind when examining reinforcement for cleanliness.

Light surface rusting and pitting improve surface bond but loose mill scale and flaky rust reduce it and must be removed even though it may require wire brushing or sandblasting.

Heavy corrosion reduces the effective size of the reinforcement and badly corroded bars should be used only where directed by the site engineer.

STACKING REINFORCEMENT

The following principles should be remembered when stacking reinforcing steel on a job site:

(a) Reinforcement should be protected from rain, mud, oil, paint, etc.

(b) It should be stacked conveniently - according to size, and lengths.

(c) When bent each bundle should be clearly tagged with its bending schedule number.

11.8 HANDLING REINFORCEMENT

CUTTING

For small quantities, a rule or tape may be used for measuring the lengths required; however, in work of any magnitude, it is best to have a bench marked in metres and millimetres and with a stop at one end against which one end of the bar can be placed. A convenient size for the bench is about 7 m long and 1 m wide by 1 m high. Hand shears may be used for cutting bars up to 10 mm in
diameter. Bars between 10 mm and 24 mm in diameter may be cut with a hand machine. For diameters greater than 24 mm, power-operated machines are necessary.

**BENDING**

When bars are bent, hairpin shapes or hooks are formed at the end; it is important that the radius of the bend should not be too small. A good rule is to use a mandrel four times the diameter of the bar; that is, a 10 mm bar would be bent around a mandrel 40 mm in diameter. This is shown in Figure 11.5 where the diameter of the mandrel is four times the diameter of the bar. The hook is composed of a semi-circular part and a straight piece known as the tail. The length of the hook, that is, from the point opposite the middle of the mandrel where the bend starts to the end of the hook - should be twelve times the diameter of the bar. The length of the tail is four times the diameter.

In the case of bars that are bent at right angles to pass around other bars, the mandrel should be of the same diameter as the main bar so that there will be no gap between the two bars as would happen if the bent bar did not fit snugly against the main bar. Figure 11.6 shows what is meant.

![Hook](image)

*Hook*

![Right-angled Bend](image)

*Right-angled Bend*

**Figure 11.5**

**Figure 11.6**

**Bending Requirements**

(a) Bars should be bent cold wherever practicable, with a slow and regular movement so as not to cause a fracture.

(b) Bars which depend for their strength on cold working should never be heated.

(c) If unusual circumstances make it necessary to bend steel by heating, a cherry red heat (not exceeding 850°C.) should be used.

(d) Bars bent hot should not be cooled by quenching.

(e) Bars must be bent accurately to the dimensions shown on the bending schedule.

(f) Rebending - If steel has been bent and subsequently bent in the reverse direction or straightened, it should not be bent again near the point of the previous bend.
**FIRST PREFERENCE BAR BENDING SHAPES.**

Notes:
1. All dimensions are to intersection of straight portions of the outside of all types of bends.
2. "L" is the sum of the individual out-to-out dimensions "A", "B", etc.

<table>
<thead>
<tr>
<th>NAME</th>
<th>CODE</th>
<th>DIAGRAM</th>
<th>Essential Dimensions</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRAIGHT</td>
<td>Straight</td>
<td>A</td>
<td>A</td>
<td>&quot;A&quot; is also the length &quot;L&quot;.</td>
</tr>
<tr>
<td>L-shape</td>
<td>L</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>One 90° bend</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double L-shape, Two 90° bends</td>
<td>LL</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hooked bar, One 180° bend</td>
<td>H</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double hooked, Two 180° bends</td>
<td>HH</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabric, Only if flat sheet</td>
<td>F</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>V-shape, Bend less than 90°</td>
<td>V</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-shape, 180° bend only</td>
<td>U</td>
<td>B</td>
<td>D = bend diam.</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tie for beams or columns</td>
<td>T</td>
<td>A</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>Stirrup for beams (hooks in)</td>
<td>SH</td>
<td>A</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stirrup for beams (hooks in)</td>
<td>SC</td>
<td>A</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cranked column bar for lap splice</td>
<td>CC</td>
<td>A</td>
<td>C</td>
<td>A</td>
</tr>
</tbody>
</table>

---

**SECOND PREFERENCE BAR BENDING SHAPES.**

Notes:
1. All dimensions are to intersection of straight portions except where shown.
2. First preference shapes with hooks & cogs are to be included here.

<table>
<thead>
<tr>
<th>NAME</th>
<th>CODE</th>
<th>DIAGRAM</th>
<th>NAME</th>
<th>CODE</th>
<th>DIAGRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-angled Crank Shape</td>
<td>RC</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Right-angled Truss Shape</td>
<td>RT</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>135° Hooked Tie</td>
<td>HT</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>V-plus L-shape</td>
<td>VL</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Diamond Shaped Tie for Columns</td>
<td>DT</td>
<td>A</td>
<td>B</td>
<td>D</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Double V-shape</td>
<td>VV</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Cross-over Tie</td>
<td>XT</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Joist Bar or bent-up bar</td>
<td>J</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Circular Tie for Columns</td>
<td>CT</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Link for Columns</td>
<td>LH</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Double J-shape or truss bar</td>
<td>JJ</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Spiral or Helix</td>
<td>SP</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
</tr>
<tr>
<td>Acute Angle Bend more than 90°</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
<td></td>
</tr>
<tr>
<td>Radised Bar</td>
<td>R</td>
<td>A</td>
<td>B</td>
<td>&quot;A&quot; = length of main wire (8000 mm max).</td>
<td></td>
</tr>
</tbody>
</table>

---

All shapes are to be drawn and dimensioned in full.

---

**Bar Bending Shapes**

Figure 11.7
### Reinforcement Schedule

![Image of Reinforcement Schedule Table](image)

**Figure 11.8**
11.9 SPLICES

The main reinforcing bars are not always continuous in length, and therefore have to be spliced together. Methods of making connections are by lapping and tying, end bearing, by welding or by means of an approved mechanical bar splice.

![Tension Splice](image)

*Figure 11.9*

![Compression Splice (Offset)](image)

*Figure 11.10*

![End Bearing Splices](image)

*Figure 11.11*
11.10 FIXING REINFORCEMENT

Whether the reinforcement is assembled before it is placed in the shutters or assembled bar by bar in position, the bars should be tied together where they cross one another. Soft black iron wire about 1.5 mm in diameter is generally used for this purpose in short lengths according to the diameters of the bars to be tied. It is only necessary to bend the tying wire to the shape of a letter U, pass it over the crossing, and tighten it with pliers or other tool. The ends must be turned inwards away from the shuttering, otherwise the ends of the wire may touch the shuttering and thus be exposed on the face of the concrete with the result that rust stains will appear on the concrete if the latter is subject to the effects of weather. If steel reinforcement is subject to damp conditions it will rust and increase in size, and probably spall off the concrete covering it. For this reason, it must have a cover of concrete sufficient to prevent it being affected by weather conditions.

In most cases 25 mm of dense concrete cover is sufficient but, in exposed positions or in marine work, the cover should not be less than 50 mm.

SUPPORTING

It is important that the reinforcement should be supported in position so that it will not be moved when the concrete is placed. In the case of beams and slabs it can be kept at the required distance from the bottom of the shuttering or from the ground by supporting it on small blocks of concrete or purpose made steel or plastic chairs.

![Reinforcement supports](image)

Figure 11.12

Reinforcement for beams and footings may be hung by wires fixed to pieces of wood or reinforcement bars resting across the top of the shuttering or excavation.
A means of keeping wall and column reinforcement in position is shown in Figure 11.14.

**Figure 11.14**

Plastic spacers used to position reinforcement in walls and columns.

11.11 POSITIONING OF MAIN TENSILE REINFORCEMENT

**FIXED AND SUPPORTED BEAMS**

The design of beams is affected by the conditions at the ends which may be supported, restrained, or fixed according to circumstances, and this condition is of considerable importance because
not only is the capacity of the beam influenced, but also the stresses in the beam are affected. Beams and slabs are divided into different types, as follows:

- support only at both ends
- fixed at both ends, and
- supported at one end and fixed at the other.

These types are distinct from the cantilever or bracket, which is obviously fixed at one end only with no support or assistance at the other end. Beams and slabs which are continuous over several spans will be equal to those having fixed ends, because the ends of each span will be held in position by the adjacent bay and they are not, therefore, free to move as in the case of an end which is simply supported.

**SUPPORTED ENDS**

Dealing with the most simple type first, the condition when the ends are supported only as shown in Figure 11.15 where a beam is shown carrying a centrally concentrated load. The tendency for the load to cause bending or deflection is shown in an exaggerated manner, and it will be seen that the ends of the beam are free to move so that the whole beam becomes part of a circle with the whole of the top part in compression and the whole of the lower part in tension. This condition will apply to beams and slabs only where the ends are supported; the condition of loading whether concentrated or distributed, will only make a difference in the value of the stress not the nature.

![Simple Supported Beam](image)

**Figure 11.15**

**FIXED ENDS**

If the ends of the beam are held firmly in position, then the beam is unable to bend in a simple curve under the action of the load, and the tendency is to take the shape shown in an exaggerated manner in Figure 11.16. In this diagram both ends are fixed and a
portion of the beam at each end acts as a cantilever with the top surface tending to stretch and the bottom surface tending to contract, while the central portion acts as a beam between the two cantilever portions. The shape of the beam is, therefore, a combination of three curves, and the two end curves radiate from a centre below the beam while the middle portion radiates from a centre above the beam; it follows that the tendency to compress the top surface, which occurs with a supported beam, does not apply to the end portions of a fixed beam. The fixing of the ends therefore results in tension and compression on the top surface, (tension at the ends and compression in the centre portion), and the reverse stresses on the bottom surface (compression at the ends and tension in the centre).

![diagram](image)

**Fixed End Beam**

*Figure 11.16*

In the diagrams the portion under compression is shown by a thick line, and the portion under tension by a thin line.

The stress, therefore, changes in character at some point in the length of the beam, and this point is called "the point of contraflexure". The position of this point will depend on the type of load which will cause a slight variation, but for all practical purposes it can be taken as one-fourth of the clear span from each end. This is shown in Figure 11.17 as $\frac{1}{4}L$ when $L$ equals the span, and the point of contraflexure is indicated by B. This change of stress is of the greatest importance, because it is necessary for the reinforcement to be placed in the tension area of the beam and, therefore, in the beam shown, the rods must be placed near the upper surface between the points A and B, and near the lower surface between the two points marked B. In order to arrange this, the rods are cranked at the point of contraflexure as shown.
The fixing of the ends reduces the maximum stresses in the beam because it has the effect of theoretically reducing the span, and therefore this method is adopted in practice whenever possible. The effect of fixing the ends, as compared with the condition of supported ends only, can be easily tested by experimenting with a small beam made with rubber, or even a piece of wood say about 50 mm square, laid across two supports some distance apart. By leaving the ends free in the first case and putting a weight on the piece of wood sufficient to cause bending, the shape can be noted, and if the weight is then removed and the ends firmly secured by nailing down and the weight again applied it will be found that the piece of wood is much more rigid and, when bending does occur, the shape is quite different from that obtained when the ends were free.

![Diagram of Contraflexure of a Fixed Beam]

*Figure 11.17*

**ONE END FIXED ONLY**

It is not always possible to fix both ends of a beam in practice, but it may be possible to fix one end while the other is supported only, and in this case the conditions will be as shown in Figure 11.17. The action of the load in this case tends to bend the beam to the shape again (shown exaggerated) the portion A-B is under tension on the top surface and the portion B-C is under compression, on the upper surface, because the part near the fixed end acts as a cantilever and the remainder acts as a supported beam. The shape consists of two curves instead of three as in the case of both ends fixed, and the point of contraflexure at the position at which the curve changes is situated at 0.2731 or, for practical purposes, say, one-quarter of the span from the fixed end. The reinforcement in this type of beam should be placed near the upper surface between the points A and B, and near the lower surface between the points B and C, with a crank at the point of contraflexure.
CONTINUOUS BEAMS

In reinforced concrete floors, beams which are continuous over several spans are often used. The intermediate supports consist of reinforced concrete columns and, in this case, the length of the beam between any two columns can be considered as restrained or fixed at the ends and calculations made accordingly. In the case of the end span, this will generally be taken as supported at one end when it is resting on a wall and the other end will be considered as fixed. The tendency of a beam which is continuous over several spans is shown in Figure 11.19. Where the bending is indicated, the thick lines give the portion under compression and the thin lines the part under tension. It will be seen that the stress is alternately compression and tension in both top and bottom surfaces because of the cantilever action on each side of the column support.

The importance of this aspect of the design of reinforced concrete is considerable, because the calculations are based on certain conditions, and allowance is made for the increase in strength due to the fixed ends which must be given in the executed work. The reinforcement must be cranked exactly as shown on the drawings; the continuity of the rods must be given by strict adherence to the details supplied by the designer; and any special rods provided in the upper surface to take the tension over the supports must be accurately placed. Again, it will be necessary to take particular care to ensure the ends of the beams are properly fixed when provision is made for this condition; otherwise, the bending tendency will be greater than that considered in the calculations.

In some schemes, when concrete beams are used in conjunction with brickwork, a beam is designed as continuous running across one or more brick piers and, when this is the case, it is essential that the brick piers be built right up to the finished level before the formwork is fixed and the beam executed - otherwise, the removal of the formwork and the props preparatory to the building up of the piers will result in a tendency for the beam to deflect or sag in one large curve and cause tension stress in the whole of the under surface, whereas the design has been made to provide for compression at the points where the piers occur. In addition, the
span of the beam taken in the calculations will be the distance between two piers when they are erected complete, and the omission of support at the pier positions while the concrete is green means that the beam is called upon to carry itself and any load across a much larger span than provided for in the design.

CONTINUOUS TEE-BEAMS

In the case of tee-beams, it is not advantageous to fix the ends; it is necessary to keep the whole length of the upper surface of the beam in compression to allow the slab forming the top flange to take the stress. If the ends of the tee-beam are fixed or restrained and compression has to be provided for in the lower surface of the beam, it is necessary to increase either the concrete or the steel; in some cases, both must be added to. The increase of the steel will not be economical because of the low limit of stress that can be allowed on the steel in compression, and it is better to increase the concrete if this is practicable.

![Continuous Tee-beam]

**Haunched Column**

*Figure 11.19*

This increase is sometimes provided for by making the beam deeper by a splayed portion near the ends as shown in Figure 11.19. The increase in the depth increases the resistance of the beam and compensates for the loss of the assistance of the flange, and it is the best way of providing the necessary concrete unless the splayed portion required is excessively large and interferes with the headroom below the beam. The regulations provide that, where the end of a beam is haunched for the purpose of increasing the resistance moment, such a haunch must not be calculated at a greater angle than 30 degrees from the horizontal. This restricting angle is shown in Figure 11.19 and, if the necessary resistance cannot be obtained by working to this increase in depth, the balance must be made up by the addition of steel in the compression area if the ends of the tee-beam are fixed. These splayed portions are provided for the purpose of giving the strength required to support the calculated load and must, therefore, be executed with the same care as the remainder of the work. When placing the concrete for the column, the work should be stopped at the level of the bottom of the splay in order to allow the full depth of the beam to be concreted in one operation.
CANTILEVER

When a beam is supported at one end only, as in the case of the cantilever, and load is applied, the tensional and compressional areas are reversed and the top edge becomes the tensional edge. Therefore, this is the place for the steel to be placed in order that it can do its job of reinforcing. It will also be seen that as the bending flexure changes so will the stress areas, and this occurs over any intermediate support. Steel is not wasted; it is bent up as shown in Figure 11.20.

If a beam is overloaded it will fail, and during failure, cracks will develop - at first, on the underside of the beam nearest to the support. Failure at this point means that the beam has sheared. Nearer the support it is more likely to fail owing to the shear. Therefore, the reinforcement which is placed in the position of shear will be closer together near the support and further apart towards the centre of the beam. Shear reinforcement takes the form of a stirrup. Shear force is zero at the centre of a symmetrically loaded beam.

Figure 11.20 shows longitudinal and cross sections through the beam and the bent shape of individual bars.

Position of Reinforcement in a Simply Supported Beam and Cantilever

Figure 11.20

COLUMNS

Columns under load can bend in any direction, depending upon the load distribution on framing beams. Reinforcement is therefore placed near the outer faces of all sides. In Figure 11.21 if the load is moved to another beam, the stresses in the column will change to conform with the new mode of bending.
RETAINING WALLS

The earth pressure behind a retaining wall and the soil pressure under the footing, tend to cause the wall to bend in the manner shown in the diagram. Reinforcement is placed in the region of tensile stress. (See Figure 11.23.)

Stresses in Retaining Walls

Figure 11.23
11.12 GLOSSARY

**ANCHORAGE**
The embedment in concrete of portion of a reinforcement bar, either straight or with hooks, designed to prevent pulling out or slipping of the bar when subjected to stress.

**BENDS**
Various angles.

**CHAIRS**
Metal or concrete supports of various forms to give the reinforcement with the necessary cover.

**COLUMN**
An upright compression member the length of which exceeds three times its least lateral dimension.

**COLUMN CAPITAL** *(Flat slab construction)*
An enlargement of the upper end of a reinforced concrete column designed and built to act as a unit with the column and flat slab.

**CONSTRUCTION JOINT**
A junctioning surface where concrete has been placed against concrete no longer plastic.

**CRANKS**
Two angles keeping the axis of end sections of rods parallel.

**DEFORMED BARS**
Reinforcement bars with closely spaced shoulders, lugs or projections formed integrally with the bar during rolling so as to engage firmly with the surrounding concrete.

**DROPPED PANEL**
The structural portion of a flat slab which is thickened throughout an area surrounding the column capital.

**EMBRACING HOOK**
A hook around a bar including a bend of at least 180° and with the free end of the hooked bar projecting at least 8 diameters of the hooked bar beyond the centre of the embraced or cross bar. The length of the embraced or cross bar shall not be less than eight times its own diameter which shall not be less than that of any bar hooked around it.

**FLAT SLAB**
A reinforced concrete slab so designed as to transfer its load to the supporting members without the intervention of beams and girders.

**HOOKS**
At ends to anchor rods.

**WIRE TIES**
Soft wire used for tying reinforcing members together.

**NEGATIVE REINFORCEMENTS**
Reinforcement so placed as to take tensile stress due to negative bending moment.
**PLAIN CONCRETE**  
Concrete without metal reinforcement.

**PLAIN HOOK**  
A hook which is not bent around a bar. All plain hooks shall be semicircular and of an internal radius of not less than 2\(\frac{1}{4}\) times the diameter of the bar of which the hook is made.

**POSITIVE REINFORCEMENT**  
Reinforcement so placed as to take tensile stress of positive bending moment.

**RODS OR ROUND BARS**  
Generally in tension but occasionally in compression.

**SPIRAL REINFORCEMENT**  
In accordance with general usage, reinforcement wound in the form of a helix or spiral.

**LIGATURES OR STIRRUPS**  
Secondary, transverse, shear reinforcement members which also locate the main longitudinal steel, which is tied to them.
Chapter 12

FORMWORK

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DESIGN
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12.1 INTRODUCTION

The plasticity of fresh concrete allows it to be moulded into any desired structural or architectural shape. The moulds or forms are equivalent to a photographic negative of the concrete construction, any inaccuracy or blemish in the formwork being reproduced identically in the structure. It is therefore essential that forms be designed and constructed accurately, so that the desired size, shape, position and finish of the cast concrete structure are obtained.

Forms themselves are temporary structures in that they are required to carry, in addition to their self load, loads and pressures from freshly placed concrete as well as construction loads such as materials, equipment and workmen. Formwork must be designed and constructed to carry all these loads without fear of collapse or excessive deflection.

The cost of formwork can be one third to two thirds the total cost of a concrete structure. Its cost is therefore significant, and the efficiency with which formwork is built can play an important part in the overall speed and economy of a job.

12.2 BASIC REQUIREMENTS OF GOOD FORMWORK

These can be summarised as:

- Quality
- Safety
- Economy
QUALITY

Quality in formwork requires that the forms be:

(i) **Accurate** - the size, shape, position and alignment of structural elements will depend upon the accuracy with which the forms are built. The designer should specify the allowable tolerances in form dimensions but not make these tolerances finer than necessary, as this will add unnecessarily to formwork cost. Formwork tolerances must always be less than the tolerances for the finished concrete.

(ii) **Rigid** - Forms must be sufficiently rigid to prevent movement, bulging or sagging during the placing of concrete. Formwork must therefore be adequately propped, braced and tied. Special consideration may be given to such items as corner detail and the effect of any uplift pressure.

(iii) **Right Jointed** - Joints which are insufficiently tight will leak mortar. The surface of the concrete will thus be disfigured by fins of mortar and honeycombing, and colour lines will result adjacent to the leaking joint.

(iv) **Well Finished** - The formwork in contact with the concrete should be so arranged and jointed as to produce a concrete surface of good appearance. Wires, nails, screws, etc. must not disfigure the concrete surface. In some cases the provision of special form lining may be necessary to achieve the desired surface finish.

SAFETY

Safety in formwork requires that the forms be:

(i) **Strong** - To ensure the safety of the structure and the protection of workmen. It is essential that formwork be designed to carry the full load and side pressures from freshly placed concrete, together with construction traffic and any builder’s equipment. On large jobs the design of formwork is the responsibility of an engineer, but on routine jobs it may be the responsibility of the foreman carpenter.

(ii) **Sound** - The materials used to construct the forms must be not only of the correct size and quantity, but they must be of good quality and be sufficiently durable for the job.

ECONOMY

Economy in formwork requires that the forms be:

(i) **Simple** - For formwork construction to be economical it must be designed to be simply erected and dismantled. Forms
should be self-aligning; falsework and shuttering should be
easily assembled and dismantled in the desired sequence.

(ii) *Easily Handled* - The sizes of form panels or units
should be such that they are not too heavy to handle.
Formwork should also be designed for ease of stripping to
avoid damage to the concrete.

(iii) *Standardised* - Formwork should be standardised where-
ever possible.

(iv) *Re-usable* - Formwork which is intended for re-use
should be designed for easy removal.

12.3 LOADS ON FORMWORK

The load to be carried by formwork is the weight of the wet con-
crete, the weight of the forms themselves and a live load; that
is, impact, wheeling barrows over the forms, and other construc-
tion loads. The weight of the forms may be neglected, as it is
small compared with the other loads. To simplify calculations, the
weight of concrete may be taken as 2300 kg/m³.

To live load for construction is generally assumed to be 360 kg/m²
of floor, but this may have to be increased for incidental loads
arising from the transportation of the concrete or reinforcement.

In the case of walls and columns, horizontal pressure - because of
the depth of the wet concrete - will act on the forms. This
pressure depends on the rate of filling and the rate at which the
concrete sets and hardens. As a general rule, this pressure is
16 kg/m² per 10 mm depth rising to 23 kg with vibration; therefore
joints between the boards must be tight; wedges must be nailed,
and formwork must be adequately braced to prevent any movement
during vibration.

Allowance should be made for any settlement or deflection of form-
work which is likely to arise during construction. The deflection
of the finished concrete member, because of loading and creep of
the concrete, may be offset by laying the formwork to a camber.
The decision as to the amount of camber requires experience and is
invariably a matter for the engineer.

12.4 SUPERVISION

Formwork accidents generally cause casualties as well as damage
and expense. Proper supervision of workmanship with particular
regard for safety, is an essential part of the site supervisor's
work.
The field supervisor's work falls into four categories:

**CONTROL**

He must ensure that formwork is constructed in accordance with the specifications and working drawings and he must check that all dimensions are within the allowable tolerances.

**PLANNING**

He might also play a part in planning the work to achieve an efficient cyclic programme of construction, concreting, striking and finally re-shoring or propping the exposed soffits.

**SAFETY**

He must play a leading role in ensuring adequate safety precautions to protect workmen. There will be many occasions where he should seek the counsel of the site engineer. Some of the deficiencies which can lead to form failures are:

(a) Premature removal of forms or props.

(b) Inadequate bracing and poor splicing of multiple-storey timber props. Splices should have long cleats at the joint on all four sides and be well nailed.

(c) Failure to control rate of placing concrete in deep forms without regard to the effect of temperature changes.

(d) Failure to regulate properly the placing of concrete on horizontal forms and prevent unbalanced loadings.

(e) Failure to check adequacy of footings for false-work to prevent settlement in unstable ground.

(f) Failure to inspect formwork during concreting to detect any abnormal deflections or signs of imminent failure.

(g) Failure to provide adequately for lateral pressure on formwork.

(h) Props not plumb.

(i) Locking devices on metal props not locked or inoperative.

(j) Overturning by wind.

(k) Damage in excavation by reason of embankment failure.

(l) Failure to check that the drawings are being interpreted correctly.
WORKMANSHIP

It is necessary that he concern himself with the quality of workmanship in the form construction. Apart from general dimensional accuracy and safety matters which have already been mentioned, some of the points on workmanship which warrant attention are:

(a) Joints or splices in sheathing, plywood panels and bracing should be staggered.

(b) There should be the proper number and location of tie rods or clamps.

(c) Tie rods or clamps should be properly tightened.

(d) The connections of props and stays to joists, stringers and walings must be adequate to resist any uplifts or twisting at joints.

(e) Form coatings should be applied before placing of reinforcement and should not be used in such quantities as to run onto bars.

(f) Bulkheads for control and construction joints should preferably be made by splitting along the lines of reinforcement which pass through the bulkhead so that each portion may be positioned and removed separately.

(g) Bevelled inserts to form keyways at contraction joints should be left undisturbed when forms are stripped, and removed only after the concrete has cured sufficiently.

(h) Wood inserts for architectural treatment should be partially split by sawing to permit swelling without applying pressure to the concrete.

(i) The loading of new slabs should be avoided in the first few days after concreting.

(j) Formwork must not be treated roughly or overloaded if re-use is desired.

12.5 MATERIALS FOR FORMWORK

TIMBER

Oregon and Australian building hardboards are normally used for the supporting members of the formwork. All timber species must conform with the relative stress grade rating according to the spacing of members and the loads to be supported.

Rough sawn 19 mm to 50 mm thick boards may be used for sheeting floors, column, beams and walls when the concrete finish is only secondary.
Dressed tongue-and-groove flooring boards may be specified where surface finish of the concrete is important. However, the boards will leave the imprint of the intersections as a seam on the concrete surface.

The following sizes may be used as a general guide:

<table>
<thead>
<tr>
<th>USE</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor sheeting</td>
<td>25 mm or 32 mm thick</td>
</tr>
<tr>
<td>Wall sheeting and sides of beams and column</td>
<td>25 mm to 50 mm thick</td>
</tr>
<tr>
<td>Beam soffits</td>
<td>38 mm to 50 mm thick</td>
</tr>
<tr>
<td>Joists</td>
<td>100 x 50 to 250 x 75, generally 150 x 50</td>
</tr>
<tr>
<td>Bearers</td>
<td>100 x 75 to 150 x 75</td>
</tr>
<tr>
<td>Props</td>
<td>100 x 50 to 100 x 100</td>
</tr>
<tr>
<td>Walers</td>
<td>100 x 75 to 150 x 75</td>
</tr>
</tbody>
</table>

**STEEL**

Many proprietary systems of steel formwork are available, generally consisting of panels made up to steel sheet on light steel angle framing, in sizes that can be easily handled. This type of formwork can be re-used many times. Special panels are supplied for circular work.

Composite panels, consisting of metal-faced plywood stiffened with small steel angles, can be used for wall and floor panels. The metal facing protects the plywood and lengthens the life of the panels.

Special telescopic units, which are easily removed provide a simple type of joist for suspended slab formwork. There are also various proprietary fittings, such as beam and column clamps, and adjustable props designed to facilitate erection.

**HARDBOARD**

Specially produced 4 to 6 mm "Concrete Formboard" in 3660 x 1220 sheets is obtainable. This extra-hard, oil-tempered hardboard is less liable to swelling and softness on exposure to the weather and should give an average of ten uses compared with four or five for standard board.

Hardboard panels are generally nailed to rough timber formwork with short thin nails, at 150 to 225 mm spacing. The width of
backing boards should not be greater than 150 mm for good class work; 100 x 25 mm dressed timber is most suitable as it is less likely to warp.

A durable method of fixing, which prevents deformation because of moisture content, consists of bonding the hardboard to the timber with waterproof glue. Tempered hardboard is somewhat sensitive to water and undergoes slight variation in length on absorbing water. This can be prevented by storing the panels under damp conditions before fabrication. When stacked on site, the sheets should be placed with their rough sides against each other; these sides should first be wetted.

PLYWOOD

Plywood panels are prepared and used in the same way as hardboard. They are expensive but, on the other hand, can be used a large number of times and are more durable than hardboard. Phenolic resin-bonded plywood should be used because it is completely waterproof and does not 'laminate' as does ordinary plywood.

Plywood can be obtained in thicknesses ranging from 3 mm to 19 mm; sheet sizes vary from 2.4 m to 3.0 m in length and from 0.9 m to 1.5 m in width. 6 mm or 10 mm plywood requires a solid backing (as for hardboard) nailed at 100 to 150 mm intervals along the four edges and with at least one nail every square of 300 mm throughout the surface. The edges of sheets should be tacked to the same backing board to ensure the production of a smooth joint.

Thicker plywood (10 mm and 16 mm) may be nailed to a skeleton backing before fixing to the studding and 19 mm thick plywood may be nailed direct to studs at a maximum recommended spacing of 450 mm.

PLASTIC-FACED PLYWOOD

The plastic face is made an integral part of the plywood during the process of manufacture. The plywood is obtainable in sheets 2.4 m by 1.2 m and from 10 to 32 mm in thickness. Larger sheets can be manufactured. These boards are durable and produce very neat concrete faces, relatively free from blemishes.

SPECIAL EFFECTS

Wet concrete will adapt to any shape into which it is poured and the limitations of shape lie mainly in the difficulty and cost of forming the mould. Asbestos pipes have been successfully used as permanent shuttering; columns and sculptural forms have also been cast into the fabric of the structure. The field for experiment on these lines is wide and relatively unexplored; however, the following notes illustrate the versatility of plastic materials as
formwork aids. Many of the buildings at the University of Western Australia have the rough wood-graining of the formwork as a special effect.

**POLYSTYRENE SHEET**

The use of polystyrene sheet as a lining to shuttering for formwork and moulds for precast units has aroused wide spread interest. It is possible to achieve many types of finished surface by vacuum-forming the sheet prior to site usage, thereby offering freedom of design to the architect and contractors in the field. The vacuum-forming process permits the production of many identically shaped sheets from the same master. Repetitive designs may be cast by the successive use of the same mould; twenty or more mouldings may be taken from the same sheet without loss of the face; the number of castings is dependent upon the gauge of sheeting used and the type of aggregates in the mix.

A parting agent is not required, as the slight flexibility of the sheet facilitates the removal of the shuttering from the hardened concrete.

The sheets are secured to wooden shuttering using an adhesive recommended by the manufacturers of the polystyrene sheet. Small gaps between panels may be filled with a cellulose filler and the excess smoothed down with a suitable polish.

Concrete is cast into polystyrene-lined shuttering in the same way as with wooden shuttering, with the exception that reinforcing rods and horizontal members should not be supported on blocks of hardened concrete resting on the shuttering. This may produce areas exhibiting the porous surface of the precast concrete blocks and will be visible when the shuttering is removed. Instead, it is advisable to pour a layer of concrete on to the shuttering first, position the reinforcing rods over this layer, and then cover with the remainder of the concrete.

*Reinforced Plastics* are used for making lightweight moulds of large size and complex shape. Release of the concrete is excellent; the surface finish is very good; and the moulds are said to last several times as long as those of wood.

*Polythene Film* can be used in precast concrete work for lining wooden moulds, for casting posts, steps and coal bunkers and other sections of simple configuration where they are instrumental in imparting a good surface to the completed moulding and a harder concrete. The film facilitates removal from the mould and protects the shuttering from any harmful effects of the concrete. The life of the mould is increased, and cheaper woods may be employed for making them.

*Glass fibre reinforced polyester resin* moulds are used for intricate cast shapes. The advantages are similar to those of polythene but the labour in lining moulds is eliminated. Being light in weight, moulds of this nature may be stored easily for
use on future occasions; and they possess satisfactory dimensional stability. Many precast concrete manufacturers are using moulds made in glass reinforced polyester resin.

Expanded Polystyrene Cores. Expanded polystyrene cores can be pre-shaped to produce any interior shape in large prestressed hollow concrete members without the use of interior shuttering which requires removal after casting. Large structural members up to 20 m in length have been produced.

12.6 FORMWORK DETAILS

COLUMNS

In a reinforced concrete framed building the correct setting out, general alignment, and plumbing of the columns probably more than any other factor, controls the accuracy of the dimensions of the building.

Each lift of column steel is usually spliced at the floor level, and, because the concrete floor offers a free area for accurate setting out, the steel fixer and setter-out are busy at this stage of construction. As each floor is poured and hardens sufficiently, the setter-out strings his main lines through - if possible - the centre lines but, otherwise, down the sides of the columns and from these, as a base, sets out the correct dimensions of the column by scribing the surface of the green concrete.

The steel fixer, having made up the "cage" of the column - if the size of the column will allow - hoists this over the splice bars and, after centering it correctly, drops his three or four lower stirrups and completes the wiring up of the complete column. Alternatively, if the column is of large size, the new steel is erected, bit by bit, stirruped and wired in-situ.

A frame of timber is then fixed to the floor into which the column boxing will fit, see Figure 12.1. This can be fixed to the green concrete with nails. A common method is to cast a concrete "nib" or profile the exact size, and in the correct position of the column, and about 75 mm high. The column box fits snugly over this and is then clamped tight, leaving the floor clear around the column base. See Figure 12.2.
Column Reinforcing in Position

Figure 12.1

(Courtesy of the Australian Government Publishing Service.)

Internal Concrete Profile for Use in Erecting Column Centering

Figure 12.2

12.11
Two methods of arranging formply panels for a square column are shown in the illustration.

- Method one enables the four panels to be cut to the same width.
  - Width of column plus one thickness of formply.
- Method two requires two different panel widths.

The stud arrangement and fillet positions for both sheeting methods are shown in the illustration.

Figure 12.3
(Courtesy of the Australian Government Publishing Service.)
Column Cramps

Figure 12.4
For circular column shutters (whether lined with plywood or other similar material to give a finished surface, or left with the laggings exposed to form a key for plaster) the type of shuttering shown in Figure 12.5 is common.

Construction of Circular Column

Figure 12.5

Other methods used in construction are steel custom-made two-piece forms. These forms consist of two halves which are bolted or clamped together. See Figure 12.6.

Steel Two-piece Forms

Figure 12.6

(Courtesy of The Australian Government Publishing Service.)
Cardboard, glass fibre and plastic cylinder tubes may be used to achieve a smooth off-form finish that will receive paint finishes and decorative surface treatments with a minimum of preparation. The main disadvantage is that the tubes can only be used once.

**STRIPPING**

Two methods of stripping pressed cardboard forms are:

- Making two vertical cuts on opposite sides of the column and then levering the forms off.
  
  - The two halves can be wired back against the column to protect the concrete surface from damage.

- Making one vertical cut approximately 300 mm long with a linoleum knife and then peeling back the casing in a spiral direction using a broad bladed tool.

![Stripping Column Forms](image)

*Figure 12.7

(Courtesy of The Australian Government Publishing Service.)*

**WALLS**

Some reinforced concrete walls are no more than 100 mm thick and require very special care during their construction.

The reinforcement must be very carefully and accurately placed and fixed. It must be securely held in position if the correct "cover" is to be maintained. As they are usually external walls, the surface must be a reasonable finish and the concrete must be waterproof.
The formwork for thin reinforced concrete walls can be made up of timber panels, the surfaces being of flooring, plywood or hardboard depending on the finish required. Steel formwork, of which there are many proprietary brands, is often more economical on large jobs. Sometimes, on very large jobs, steel formwork is designed to suit the peculiarities of the site.

With a thin wall it is often an advantage to erect one side of the formwork to full height, fix the reinforcement also to the full height and then erect the formwork for the other side either in lifts or to the full height. If the concrete is to be compacted by hand the second side of the shuttering should be added in successive lifts of between 1.2 m to 1.5 m. If it is to be compacted by vibration and the thickness is sufficient it could be erected to the full height before any concrete is placed.

It is usual to cast on top of the existing concrete a small ridge, nib or kicker about 50 mm high and the exact width of the wall. This acts as a spacer and allows both sides of the formwork to be fixed accurately in their correct position for the first lift.

![Timber Wall Formwork]

Figure 12.8

(Courtesy of the Australian Government Publishing Service.)
The intermediate spacers depend upon the method of compaction. When the wall is cast in 1.2 m to 1.5 m lifts and compacted by hand, timber spacers can be used, and, as concreting proceeds, these can be lifted and used above. On the other hand, when the full height of the wall is to be cased in one operation and compacted by vibration, it would be difficult to remove spacers low down and it is preferable to use spacers which can be left in position.

The formwork should be fixed with wire ties or bolts to resist the outward thrust of the concrete. These pass through the wall and, acting together with the spacers, hold the formwork in the correct position. Bolts are extracted while the concrete is still green, the holes being made good afterwards. If wire ties are used the wires must be cut off at least 18 mm in from the face of the concrete, and the holes carefully filled. If this is not done, rust spots form on the face of the concrete, causing unsightly marks.

A variety of proprietary brands of ties on the market will secure the formwork without the use of wire. Alternatively, several clamp systems of formwork are available, which dispense with the need for ties and are suitable for the construction of thin walls.
Wall Panel

Figure 12.10

(Courtesy Acrow Australia Limited)

Adjustable Prop

Figure 12.11

(Courtesy Acrow Australia Limited)

The patented, self-cleaning nut that saves time and money. It automatically cleans dirt and concrete from the thread as it is rotated.
CONVENTIONAL SHE-BOLT SYSTEM

BAR TIE SYSTEM

CONE/TIE SYSTEM

Wall Form Ties

Figure 12.12 (a)

(Courtesy of Rapid Metal Developments (Australia) Pty. Ltd.)

FORMWORK SNAP TIES

Figure 12.12 (b)

(Courtesy of Cyclone Scaffolding Pty. Ltd.)
BEAMS

In beam and girder construction, the slab panels, beam and girder sides and bottoms are prepared to the correct dimensions in advance ready for erection. The formwork for the columns may be cast first and stripped, or erected with the beams and floor shuttering. Whichever method is used, the columns should only be filled to just below the lowest beam bottom at the first pour. A most important item in column and beam work is the corner fillet. When stripping of formwork is carried out the sharp corners in concrete are easily damaged, so a small triangular fillet is nailed at the corners.

Where a column and beam intersect the column formwork is stiffened by the use of 75 x 50 ledgers or cleats, which also support the beam soffit and sides at the point of intersection. Beams are constructed so that sides may be removed before the soffit to aid curing. The beam soffit is supported on 125 x 100 bearers on timber or adjustable steel props.

The general arrangement of formwork for encasing steel framework in buildings is similar to that employed in reinforced concrete construction - except that bearers, instead of being supported by vertical members from below, are suspended from above with metal hangers or bolts.

A rod is shaped to enable a concrete casing to be provided in-situ around the steel beam by supporting the formwork in the required position. Concrete spacers are used below the beam to give the necessary cover of concrete to the steel. The beam bottom is pulled tight against the spacer by the bolts in the hangers.

When ordering hanging bolts, the width and depth of beam should be given - also, thickness of spacer block, thickness of formwork and thickness of bearer. The gap between a hanger socket and inside of formwork should not be greater than 12 mm.

Figure 12.13 shows a hangar used on a large beam cased on all sides. Concrete spacers are used below the beam to give the necessary cover of concrete to the steel. The beam bottom is pulled tight against the spacer by the bolts in the hangers.

Figure 12.13

12.20
FLOORs

Floor formwork is made up of boards or "decking", on which the concrete is placed, supported by joists, bearers and props. The materials suitable for decking have already been discussed; they are timber boards or flooring, steel panels, hardboard and plywood.

If boards are to be used, they should run the length of the floor panels so that they do not require cutting into short lengths, and so that the joists span across the shortest dimension. The usual size of a joist is 150 x 50, but may range from 100 x 50 to 250 x 75. The actual thickness and type of decking and the size of the joists used will depend upon the loads the forms must carry, the spacing and the span of the joists and the maximum deflection of the shuttering which may have been specified.

The joists are supported on ledgers fixed to beam sides or on timber bearers. To minimise the size of joists, intermediate bearers are sometimes used, carried on props bearing on the floor below. The size of joist and prop should be such that bearers and props do not have to be closely spaced causing excessive obstruction of working space.

Combined Beam and Floor Formwork

Figure 12.14
Recommended Method for Installation of Horizontal Forms

Figure 12.15

(Courtesy of the Australian Government Publishing Service.)

Steel telescopic beams are designed to span between supports, thus leaving the floor beneath clear for other trades. Extremely light (about 10 kg per metre) they can be easily adjusted to various widths with the capacity to meet average slab loads.

The steel beams can be supported by hanging ties and suspended formwork; by propping - using timber beams on "U" shaped head props and by resting on brick or concrete walls.

Expanding Beam

Figure 12.16

(Courtesy of Rapid Metal Developments (Australia) Pty. Ltd.)
**HANGING**

The use of hanger ties, such as snap tie hangers or coil tie hangers, enable the whole of the floor and beam formwork to be suspended off the R.S.J in structural framed buildings.

**SITTING**

Expanding beams may be rested on brick or concrete walls. This is of value in multi-storied buildings such as home units or flats.

**PROPPED**

In flat slab, or plate slab buildings, the use of U-heads and timber joists enable formwork to be built with the minimum of labour.

Figure 12.17

(Courtesy of Cyclone Scaffolding Pty. Ltd.)
Opinions vary as to the best procedure for the construction of staircases in relation to the principal job programme. Sometimes the main structure of a building is carried up first, and stair construction follows two or three floors behind, or is sometimes delayed until the whole of the floors are completed.

The most logical procedure, however, seems to be to construct each complete flight of stairs from floor to floor concurrently with the floor construction. By so doing, not only is the construction period kept to a minimum but, also, the stairs become - as soon as possible - the main traffic arteries for the job personnel.

As it is the custom to finish off staircases with terrazzo, granolithic, cork or similar tread and riser facings, slight wear and tear is not objectionable on the average job after casting. In any case, protection can quite easily and cheaply be arranged by covering the treads and arrises of the step with rough-sawn timber.
The strings are built up against a wall or at an open well with the profile strings cut to suit square or undercut treads.

The framing for the average staircase is usually made up from 100 x 75 timber with the same scantling for toms and head-trees if one of the proprietary types of props is not available. It is advantageous to keep the head-trees and props at right-angles to the slope of the joints, although vertical shoring is quite sound provided the joists are birdsmouthed at the bearers or secure wedge packings are employed.

One point in all staircase work worth particular attention where nosings of the moulded or bullnosed type are under construction, is the soaking - immediately before placing - of the riser boards. If this is observed the riser board tends to dry with the concrete and does not disturb the green concrete by swelling.

Formwork for Stairs

Figure 12.19

Circular staircases or flights with winding portions follow very much the same principles of construction as described for the straight flights.

If these stairs span between circular walls the profile of the soffit and the treads is set-out on, and cut in, the wall centering. In cases where the stairs cantilever inwards from an outer wall, or outwards from an internal or core column, the profile is formed in the centring for the wall or column on the side of support. At the other extremity the only accurate procedure is to build up a false internal or external profile drum, as the case may be, on which to build up the stair profile and support the end of the riser boards.
The following information on formwork has been provided by courtesy of the Cement and Concrete Association of Australia.

12.7 PREPARATION OF FORMS FOR CONCRETING

CLEANING

All dirt, mortar, wood chips, sawdust, etc. must be removed from inside the forms before concreting can commence. If the bottom of the form cannot be reached, then clean-out holes should be provided at suitable points to permit the removal of foreign matter. A jet of air or water can often be used effectively to remove debris. All clean-out holes must be carefully closed after cleaning out the forms.

RELEASE AGENTS (FORM OILS)

Most form materials require the application of a release agent to the surfaces which will make contact with concrete. The following are the requirements for release agents:

(a) To act as a parting compound to facilitate the easy release of forms without concrete sticking to their surfaces.

(b) To act as a sealer to prevent the forms absorbing water from the concrete.

(c) Not to stain or disfigure the concrete surface.

(d) Not to leave a surface deposit which will prevent adhesion of a subsequently applied render, paint or other material.

(e) Not to reduce the effective life of the forms.

There are some materials such as plastic liners which require no release agent and others which only require wetting to facilitate stripping. Most form material, however, will benefit from an application of a suitable release agent.

TYPES OF RELEASE AGENTS

Release agents (also known as form oils or mould oils) are generally one of six types:

(a) Neat oil.

(b) Mould cream (water emulsified into oil vehicle).

(c) Water soluble emulsion (oil emulsified into water vehicle).

(d) Neat oil with additives (surfacing or wetting agents).
(e) Chemically reactive agents.

(f) Barrier paints and coatings.

Commercial form oils for wood forms should be capable of penetrating the wood to some extent while leaving the surface only slightly greasy to the touch.

Hardwood may contain sufficient tannin to cause retarded set. When this condition is recognised, it can be remedied by treating with a cement wash before applying the form oil coating.

Apart from the commercial form oils, diesel oil or linseed oil cut with kerosene may be satisfactory for plywood forms. Plywood may also be coated with shellac, lacquer, resin-base proucts, or plastic compounds which almost totally exclude water from the plywood, thus preventing the grain from rising. Such coatings require only very light oiling.

**METAL FORMS**

Form oils that are satisfactory on wood may not always be suitable for steel forms. Paraffin base form oils, and petroleum base oils blending with a synthetic oil, silicones or graphite, have been successfully used.

**APPLICATION OF COATINGS**

Surface coating should be applied to smooth, clean surfaces by methods such as roller, brush, spray, wiping, etc. depending on the type of coating. Coverage must be complete and uniform for good stripping and appearance. There should be no excess coating to stain the concrete. Very thin form oils should not be used in hot weather on vertical impermeable forms such as steel as they tend to run causing adhesion at the top and excessive oil on the lower sections.

Whenever possible forms should be coated before erection. When this is not possible, the application of coating should precede steel placement to keep the steel free of the coating material. The concrete surface at construction joints must also be kept free of form oils.

12.8 ADJUSTMENT OF FORMWORK

**BEFORE CONCRETING**

(a) Devices should be installed on supported forms and elsewhere as required, to facilitate detection and measurement of formwork movements during concreting.

(b) Wedges used for final alignment before concreting should be secured in position after the final check.
(c) Positive means of adjustments (wedges or jacks) should be provided to permit realignment or readjustment of falsework if excessive settlement or displacement occurs.

In most circumstances it will be virtually impossible to realign forms containing concrete.

DURING AND AFTER CONCRETING

The level, camber and plumbness of formwork should be checked constantly and appropriate adjustments made promptly. During concreting it is especially important to have at least one carpenter watching the forms constantly; tightening wedges, adjusting braces and looking for weak spots. He can take prompt action if an emergency arises.

If, during concreting, a weakness develops and the falsework shows excessive settlement or distortion before the weakness can be corrected, the work should be stopped, the affected construction removed if permanently damaged, and the falsework strengthened.

REMOVAL OF FORMS AND SUPPORTS

Stripping requires considerable care on the part of workmen to avoid damage to the green concrete. Concrete can easily be marred by scratching and chipping even though it may have developed sufficient strength to support itself.

Care must be taken to protect the concrete and to extend the useful life of the forms by careful handling. Not only must the forms hold together, but they must remain dimensionally accurate and stay in good condition to make accurate alignment and clean joints possible. Form panels and other falsework components should not be dropped.

12.9 STRIPPING TIMES

Although the construction office is generally responsible for the design, construction and safety of the formwork, the time of removal of the forms and supports is generally specified by the engineer in the contract documents. Alternatively, this is made subject to his approval, because of the danger to the structure if the forms are stripped before the concrete has developed adequate strength.

On the other hand, the earliest possible form removal is desirable:

- where the re-use of forms is planned
- to permit specified curing to begin
- to permit any surface repair while the concrete is still "green".

12.28
Vertical forms can generally be stripped before beam and slab soffit forms.

Strength tests using job cured specimens are the most reliable means of determining when forms can be removed with safety. Forms can usually be stripped when the concrete has gained about two-thirds of its 28-day strength (around 7 days). More precisely, the concrete should have gained sufficient strength to give a factor of safety of about two on the stresses to be sustained.

Where stripping times have not been specified, Table 12.1 may be used as a guide when using normal cement and correct curing techniques. When using high early strength cement, these times may be reduced, and when using low heat cement or lean concrete these times should be increased.

**TABLE 12.1**

<table>
<thead>
<tr>
<th>Member Type</th>
<th>Member</th>
<th>*Effective Span (m.)</th>
<th>Minimum Stripping Time (days) for Average Air Temperature During Period Prior to Stripping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical, unloaded</td>
<td>Wall, column, beam side</td>
<td>0</td>
<td>2  3  5  7</td>
</tr>
<tr>
<td>Vertical, Loadbearing</td>
<td>Wall, column or loadbearing structure</td>
<td>0</td>
<td>5  6  7  9</td>
</tr>
<tr>
<td>Horizontal</td>
<td>Slab</td>
<td>under 3</td>
<td>7  10  14  21  28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3-6</td>
<td>10  14  21  28  28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>over 6</td>
<td>14  21  28  28  28</td>
</tr>
<tr>
<td>Horizontal</td>
<td>Beam</td>
<td>under 3</td>
<td>10  14  21  28  28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3-6</td>
<td>14  21  28  28  28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>over 6</td>
<td>21  28  28  28  28</td>
</tr>
</tbody>
</table>

*Effective span is the maximum distance between supports (either temporary or permanent).*

12.10 **SHORING AND RESHORING FOR MULTI-STORY STRUCTURES**

Multi-storey work presents special conditions particularly in relation to removal of forms and shores. (Unframed vertical shores are also known as props or toms). Early stripping is desirable to allow re-use of formwork and also to permit associated building trades to follow concrete work as closely as possible. However, the shoring which supports "green" concrete is necessarily supported by lower floors and shoring must be provided for a sufficient number of floors to develop the necessary capacity to support the imposed loads without inducing excessive stresses or deflections.
There are two systems of shoring and two systems of reshoring. The systems are described briefly in order of preference although it is best to avoid any methods which require reshoring.

(a) **Undisturbed Shores** - This is the preferred system. It permits stripping of forms at an earlier age than other systems. It eliminates the problems of placing reshores and ensuring uniform tightness of these reshores. It also provides better assurance that shores are placed in the same pattern on each floor.

(b) **Secondary Reshoring** - These are secondary shores placed before any formwork is disturbed.

(c) **Partial Reshoring** - The soffit is stripped bay by bay (say 2 m x 3 m) and reshores placed in the stripped bay before further stripping is undertaken.

(d) **Total Reshoring** - The complete soffit is stripped and subsequently replaced by shores. This method is the least desirable of the four.

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This programme of 'reshoring' would require two storeys of forms and three storeys of props
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**Figure 12.20**

12.11 OFF-FORM FINISHES

Off-the-form concrete finishes are those obtained when the formwork is removed and there is no further surface treatment. The finish obtained depends mainly on the nature of the formwork. Concrete with a well-designed mix, and which has been properly placed will provide a true reversed impression of the formwork, including any defects in the formwork.

Finishes for off-the-form concrete can be considered in three distinct categories:

- smooth finish
- textured finish
- profiled finish
SMOOTH FINISH

A smooth finish can be obtained by the use of any suitable smooth-surfaced material such as water-resistant plywood, steel, or plastic sheet.

Generally these materials have little or no porosity. They therefore tend to prevent the escape of air bubbles in the concrete and can lead to voids or pits in the concrete surface which may or may not be significant, depending on the finish required.

Water-resistant plywood is most generally used, with joints taped to prevent seepage of the cement. See Figure 12.21.

![Image](image.png)

*Grout loss at a joint caused by incorrect sealing between formwork panels.*

**Figure 12.21**

*(Courtesy of the Cement and Concrete Association of Australia.)*
Rigidity is a prime consideration in the design of formwork; forms have to withstand considerable pressures from the poured concrete and from the effects of vibrating machines.

When plastic sheet is used, it is too thin to be rigid, and it needs to be solidly backed to give it support. Plastics have a relatively poor resistance to abrasion, and care must be exercised in their use to avoid damage to the surface during the placement of steel reinforcement and concrete. Plastic sheeting can be obtained in long lengths and thus provides a smooth and even finish.

Plastic-faced plywood has the advantage of speedy erection, but attention must be given to the taping of joints.

Steel forms give a satisfactory uniform finish. Where steel slip forms are used, the forms have a tendency to spread, and care must be taken to keep a continuous check on the width of the form after the lifting operation.

Absorptive Linings

Hardboard can be classed as an absorbent lining; its pores rapidly become clogged, giving a concrete surface that is progressively lighter in colour. The repeated use of absorptive linings is therefore not recommended for the purpose. Highly absorbent linings of soft can or wood-fibre, are similar to hardboard in this respect and require constant replacement.

Absorbent form linings provide a dense, even, and highly textured surface that is virtually free from blow holes. Such a surface is more resistant to weathering and abrasion, and less likely to craze, than is a normal concrete surface.

It is important that cement of the same age and from the same manufacturer be used to achieve consistency of colour. Cement tends to set more slowly with age, hence, a change in tone should be expected in the concrete where new and old cement are used in association.

Bolt Holes

It is generally more economical and practical to use bolts and spacers to maintain uniform width of formwork than to provide the bracing necessary to stop any tendency of the formwork to spread. After stripping the formwork, the holes will clearly be visible, and they must be either filled up solid or be partially filled, leaving a predetermined pattern on the surface.

Patches tend to be darker in colour than the surrounding concrete. Therefore, instead of using the same mix for patching, some 15 to 30 per cent of the cement may be replaced by white cement. Patches should be covered and be kept moist for several days to prevent unduly rapid drying out.

12.32
The sand used for the original concrete will usually be too sharp for patching and will lead to a different surface finish. A finer sand, or even stone or marble dust should be used. A trial patch in an inconspicuous place is advisable.

**Textured Finish**

As explained earlier, the concrete faithfully follows the face of the formwork. This characteristic can be used to advantage to produce patterned or textured surfaces by continuous-form procedures as well as with the other types.

**Board-marked Finish**

To obtain good board-marked finishes, considerable care and experience are needed both in the design of the formwork and in the selection of the boards. Contrary to what might be assumed, a good board-marked finish is generally more expensive than a smooth finish, though considerably less costly than a facing material such as brick or stone.

![Board-marked Finish](image)

*Figure 12.22*

*(Courtesy of the Cement and Concrete Association of Australia.)*
Boards will leave an impression of the grain on the concrete. The species of timber will materially affect the finished surface used, and so will the method by which it is sawn. Well-weathered boards have a pronounced growth ring and raised grain, and they will produce a bold figured finish. Care must be taken to mix boards with more pronounced grain with those of less pronounced grain, to avoid grouping. If boards are thicknessed or tongued-and-grooved, or are machined in both of these ways, joint marks will be less pronounced.

Careful selection of the boards is conducive to a uniform colour of the concrete finish. Boards should be selected from timber of the same species and moisture content, otherwise considerable variations in the colour of the finish will occur. Irrespective of the moisture content of the timber, the timber should be well saturated before the concrete is poured, and be kept wet until the formwork is removed. This wetting will prevent the boards from shrinking or cupping, and results in a more even colour of the concrete finish.

Other Textured Finishes

Textured finishes can be obtained by the use of plastic or rubber linings to formwork. Ribbed or crepe rubber is expensive but, with reasonable care, it can be used up to thirty times before replacement becomes necessary. Mineral oil should never be used on rubber as a release agent, as it will attack the rubber. An organic oil such as castor oil is more suitable.

![A Panel Cast Against a Thermoplastic Liner](image)

*Figure 12.23*

*(Courtesy of the Cement and Concrete Association of Australia.)*
PROFILED SURFACES

Profiled surfaces, whether raised or sunken, can be formed with almost any material. By nature they are generally dominant in character and, for this reason, they are often used on decorative panels. A common way to form a sunken pattern is to attach shaped pieces of timber to the formwork.

![Exposed Aggregate Cast Against Profiled Sheet](image)

Figure 12.24

(Courtesy of the Cement and Concrete Association of Australia.)

For large areas of wall, a simple overall pattern is more acceptable - such as recesses formed at the joints of formwork panels by fixing cover battens over the joints in the formwork. For more intricate treatments, patterned form liners made from plastic or sheet metal can be used.

It is extremely important to check that the minimum cover specified to the reinforcement is maintained, and is not encroached upon by any indentation made in the face of the concrete.

Moulded form liners, such as fibreglass and sheet metal with recesses that vary in depth, should be packed against the formwork to avoid deflection when the concrete is placed, and be of sufficient strength to resist undue deformation. It is important also to check that the size of the aggregate is such that it can be compacted into the smallest recess in the moulded lining. This is particularly important in sculptural panels and high-relief work, to ensure an accurate reproduction.

Expanded polystyrene sheets are an excellent medium for the production of decorative panels. They can be cut with a knife or routing machine, and the surface can be moulded or incised with an electric soldering iron which quickly melts the polystyrene. Polystyrene readily adheres to the face of concrete. The removal operation can be deferred to allow the polystyrene to protect the concrete during subsequent building operations.
Good use of surface texture here relieves what might otherwise be a very bland facade. Panels are full height with every third joint masked by a downpipe. The surface finish to the top and bottom parts of the panels is exposed aggregate, while the centre band was created by recessing and cast against a formliner. The surface is unpainted, the colour variation is due to shadow pattern.

Figure 12.25

12.12 CONTINUOUS MOVING FORMS

SLIP FORMWORK

The formwork system uses a 1.06 m high steel panel, held rigidly with a steel framework, and having strategically placed yoke units. Mounted in these yoke units are patented hydraulic climbing jacks, which climb a black mild steel jack rod passing through the jacks. This jack rod is usually cast in the wall, and if desired, forms part of the wall reinforcement. Alternatively, in some suitable projects, the jack rods may be recovered and re-used.

Initially, the wall reinforcement is placed to the height of the yoke units, with vertical bars extending to a convenient level. Openings can be formed in the walls by the use of temporary frames or blockouts which are ideally secured to the reinforcement to prevent movement during construction. Inserts, such as steel plates, would more likely require tack welding to the reinforcement to ensure correct positioning.

12.36
Concrete is normally placed in the forms slowly in layers of 150 mm to 200 mm. Compaction is effected by suitably sized immersion vibrators applied to each layer. The setting rate of the concrete would always need to be controlled to match the expected jacking speed, taking into account such variables as mix design, ambient temperature and prevailing on site conditions.

The jack units are connected to a centrally placed electro-hydraulic pump, which, when activated, will cause the jacks to lift the form approximately 24 mm per lifting cycle. The rate of climb under normal conditions would be approximately 300 mm per hour, or one lifting cycle every four to five minutes. This normally desired rate should only be exceeded when job organisation and staffing permit concrete, reinforcement and blockouts to be efficiently placed in position in accordance with the specified required spacing as the form rises.

The freshly exposed concrete can be sponged or treated if required. If secondary treatment is proposed, very little attention will be necessary. It is also possible to include a shaped surface, by using ribbed or curved form panels. Slipforming can be handled in two ways:

(a) Continuous-pouring concrete 24 hours a day, or

(b) Discontinuous pouring, which means completing a predetermined height of wall on any particular working day.

When used on a continuous basis, slipforming can produce monolithic vertical concrete walls at an average rate of 6 m to 8 m each twenty-four hours. Discontinuous slipforming is more suitable to commercial or residential structures. Here the usual practice is to pour a storey height in one day, parking the form for one or two days to extend the vertical reinforcement, placing floor connection blockouts and other inserts as necessary, before recommencing concrete operations. This method has been used to form walls ranging in height from 5 m to 300 m.

DESIGN

When the decision is made to slipform a structure there are several aspects of design which usually require special consideration. These are - stability of the structure, stability of individual walls or columns, methods of slab and beam connections and reinforcement detailing. However, on projects where particular construction methods or systems are to be adopted the resulting programme may influence or even govern the structural design.

(a) Stability of the structure.

In buildings where the core or load bearing walls are to be completed ahead of the remaining structure as quickly as possible, savings can be obtained resulting from early installation of mechanical plant and lift equipment. Here,
overall free standing stability of the core or walls is an important consideration in order that these advantages inherent in the system can be achieved. The vertical elements of the structure should be designed such that the free standing height is not limited by structural instability. In the case of service cores, it is usually possible to increase stability by casting internal slabs close behind the slipform or by installing temporary bracing.

Sometimes it is found more economical in terms of quantity and utilisation of labour to maintain the slipform only 2 to 3 floors ahead of the remaining structure. In these cases the ability of the walls to free stand is not as critical.

(b) *Stability of individual walls or columns.*

Ideally, the design of individual walls and columns in the structure should be such that no temporary bracing is required to ensure their stability prior to the casting of slabs or beams. In specific cases, however, where open space layouts are used or columns are slipformed, temporary bracing may be a necessity.

(c) *Methods of connection between beams or slabs and slipformed walls.*

The design of connections should be as simple as the structural requirements allow. Simple connections are always the most practical. In general, almost all conventional connections can be adapted to suit the slipform system, but where early consideration can be given to floor framing layouts, slab spans and restraint conditions, a more practical and economical result can be expected.

Connections between the structural components of the floor system and the slipformed wall can be broadly placed into two categories.

(i) Simply supported, and

(ii) Connections where full or partial restraint is required.

Connection types vary widely between projects, but some commonly used details are shown.

(d) *Reinforcement.*

To suit slipforming the following aspects of detailing should be kept in mind:

Horizontal reinforcement should be in manageable lengths and should be free of hooks and bends where possible. Corner laps should be in the form of a separate corner bar.
Vertical reinforcement should be detailed in storey heights for non-continuous pouring and splices should be staggered where continuous slipforming is employed.

The use of fabric reinforcement should be avoided because of practical limitations.

**LEGEND**

A. Water Frames  
B. Trusses  
C. Adjustable Yoke Units  
D. Steel Panel Forms  
E. Hydraulic Climbing Jacks  
F. Steel Jack Rod  
G. Electro Hydraulic Pump Unit  
H. Hydraulic Pipelines  
J. Cantilever Scaffold Brackets  
K. Hanging Scaffold Brackets  
L. Hanging Scaffold Slings  
M. Handrail Post  
N. Water Level Tank  
P. Water Level Distributor

1. Working Platform  
2. Steel Reinforcing  
3. Timber Joists  
4. Plywood Deck  
5. Vertical Reinforcing Guide  
6. 10 mm Clear Plastic Water Level Line

12.39
Method of Connection between Beams and Slabs

Figure 12.26
Allendale Square, Perth, Western Australia. 137 metres high overall. As shown 120 metres free standing above the last structural slab.

Free Standing Structure

Figure 12.27
Stability to Structure by the Main Frame Following

Figure 12.28

12.42
JACKING AND VERTICAL LEVELLING

The movement of the formwork is effected by standard 3 tonne hydraulic climbing jacks, mounted in the yoke units. The positioning of these yoke and jack units needs careful consideration to ensure the correct degree of control over the formwork during construction.

Jacks with varying capacities are available, and can be used when the applied loads are in excess of the standard unit. Jacks are inter-connected by a combination of pipe lines to a centrally placed electro-hydraulic pump unit. The pump units also have varying capacities, which relate to the number of jacks being employed on the project. Where the high pressure pipelines are exposed, protective sheathing is used to prevent damage to the wire braided hose.

Each jack has individual stroke adjustment, which enables accurate control of the formwork during jacking operations. The technician is guided in this control by a water level system, which consists of a main tank and distributors connected by 10 mm I.D. clear plastic tube. Indication points are strategically located around the project. For the vertical control of a project, the technician employs standard techniques including manipulation of the jacking units, together with "verticality control rollers". These take the form of a rolling brace connected to the formwork, and running on the hardened concrete wall. By employing these correct procedures, the experienced technician is able to control the verticality of the structure within specified tolerances.

Verticity can be surveyed by instrument, or if desired, simply prepared plumb bobs. These may be hung on standard brackets and winches which can be supplied, if required, with other slipform items. 26 S.W.G. Piano wire is used to support a weight of approximately 10 - 15 kilograms. The number of plumb bobs is determined by the size and nature of the project involved. Four to six would be a typical requirement.

In summary, the advantages of continuously moving forms are:

- jointless construction
- scaffolding is unnecessary
- high salvage value
- speed of construction, although much preparation is necessary
- central mixing plant possible.

Against these points are:

- considerable preparation time required
- great accuracy is required
- cost of night shifts as continuity must be obtained.

12.43
Chapter 13

FLOOR STRUCTURES

13.1 FUNCTIONAL REQUIREMENTS
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   SOUND INSULATION
   THERMAL INSULATION
   DAMP RESISTANCE

13.2 UPPER FLOOR CONSTRUCTION
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   DOUBLE FLOORS

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   FIXINGS

13.4 SOUND INSULATION AND FIRE PROTECTION FOR
    TIMBER JOIST FLOORS

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   COLUMN/BEAM/SLAB SYSTEMS

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  DEFINITION
  CONSTRUCTION

13.1 FUNCTIONAL REQUIREMENTS

The main function of a floor is to provide support for the occupants, furniture and equipment of a building. To perform this function and, in addition, others which will vary according to the situation of the floor in the building and the nature of the building itself, the floor must satisfy a number of requirements in its design and construction. These may be defined as the provision of adequate:

- Strength and stability
- Fire resistance
- Sound insulation
- Thermal insulation
- Damp resistance.

STRENGTH AND STABILITY

Problems of strength and stability are usually minor ones at ground and basement levels because of the full support available at all points. Where very heavy floor loads or the upward pressure of subsoil water is involved however, the floor will need to be reinforced.

A suspended upper floor is required to be strong and stiff enough to bear its own self-weight and the dead weight of any floor and ceiling finishes, together with the superimposed live loads which it is required to carry, without deflecting to such an extent as to cause damage to ceiling finishes, particularly if these are of plaster. In framed buildings the floors are sometimes designed to act as horizontal 'struts' capable of transferring wind pressure to stiff vertical members in the structure and so provide lateral rigidity to the frame. They also serve to provide lateral restraint to loadbearing walls especially when these are calculated and lateral restraint becomes an important design factor.
FIRE RESISTANCE

Fire resistance is important in respect of upper floors which are often required to act as highly resistant fire barriers between the different levels of a building.

SOUND INSULATION

Except when sources of excessive sound vibration, such as an underground railway, are in close proximity to a building, sound insulation need not normally be considered in ground or basement floors. Contact with the mass of the earth damps out to a great extent sound vibrations originating at any one part of the floor. It is, however, an important consideration in the design of upper floors.

The degree of insulation required will vary with the type of building and the noise sources likely to create a nuisance and the form of sound insulating construction adopted will vary with the type of floor used, particularly whether it is of timber or concrete construction.

THERMAL INSULATION

Thermal insulation is normally not required in upper floors unless in relation to certain forms of floor to ceiling heating but some regard must be paid to it in ground and basement floors. This is especially so in the case of suspended and ventilated timber floors where the heat losses can be considerable.

DAMP RESISTANCE

The problem of damp penetration into the building generally arises only in connection with ground and basement floors. In the case of basements the problem becomes acute when the floor is below subsoil water level and its solution involves the use of waterproofing methods resistant to water under pressure.

13.2 UPPER FLOOR CONSTRUCTION

The choice of floor type for small-scale buildings will usually be governed by considerations of loading and span, cost, sound insulation, and speed of erection. For large-scale and multi-storey buildings, other factors, such as the nature of the building structure, accommodation of services and fire protection, will also need consideration.

TIMBER FLOORS

In multi-storey and heavily-loaded buildings, floors are main structural elements closely related to the general structure of the building and they must be considered at the design stage in relation to the building.
The timber floor has the advantages of being lightweight and of being a dry form of construction. It is simple to construct and, this together with the savings gained in the supporting structure because of its lightweight make it economical, particularly where the imposed loads are small.

In itself, it is a combustible form of construction and has a low fire resistance which depends on the thickness of the boarding, size of joists and, especially on the nature and thickness of the lining. There is scope, however, for the use of the timber floor in many types of building higher than two storeys, where the means of escape is good and the building is divided by fire stop walls into sections of limited area or cubical content.

**SINGLE FLOORS**

Single floors are generally used in the first and other floors in dwellings, and are suitable for spans up to about 5 metres. Where possible, the joists should span the shortest distance of the room, and advantage should be taken of any partition or wall, to shorten the span and, therefore, economise in the size of joist. Figure 13.1 shows a plan, cross and longitudinal section, of a single floor trimmed for the fireplace and around the chimney breasts. The wallplate is carried on an offset in the brickwork, and the floor is stiffened by two rows of herring-bone strutting.

Where the joists vary in depth, they should be notched down on to the wall plate, so as to bring their top edges level for the floor boards; any unevenness is made good in the plaster ceiling. The joists should be fixed with their round edges upwards. The trimming joist and trimmer should be made 3 mm thicker for every joist to be carried, but, generally, they are made 25 mm thicker than the bridging joist. No timber or woodwork should be placed within 50 mm of the face of the brickwork of a chimney or flue, unless the face of the brickwork is rendered.

Tusk tenon joints are used to connect the trimmer to the trimming joist, however this joint is rapidly disappearing in favour of pressed metal connectors.

Strutting, as previously mentioned, is used to give additional stiffness to the floor, by distributing the weight and preventing the joists from buckling, or bending sideways. It is fixed at right angles to the joist, and at distances of 1200 to 1800 mm apart. The two kinds of strutting generally adopted are solid strutting and herring-bone strutting. Figure 13.2 illustrates solid strutting, which consists of 25 to 38 mm boarding, cut tightly between the joists and nailed to them; these struts tend to become loose, if any shrinkage in the joist takes place.
Joists for Wood Flooring

Figure 13.1
Solid Strutting

Figure 13.2

Herring-bone strutting is shown in Figure 13.3 and is the better method; if any shrinkage in the joists occurs, this strutting has a tendency to become tighter because the ends are fixed to the edges of the joists.

Herring-bone Strutting

Figure 13.3
Bearing for Joists

Joists are often built in the wall and bear directly on the brickwork. In this method the weight is not evenly distributed along the wall, and the ends of the joists are liable to dry rot. Another method is to bed a wall plate in the wall and the ends of the joists are nailed to it. In both cases, space should be left for the air to circulate freely around the ends of the joist.

A better method is to rest the wall plates on an offset or on corbelling. In both cases, the joist is spiked to the plates and, in the case of fire, there would be no danger of the wall overturning if the floor gave way.

DOUBLE FLOORS

Double floors consist of binders and bridging joists with or without ceiling joists, and are used for spans of 5 m and upwards. In this type of floor, the binders are placed (where possible) across the shortest span of the room, at distances of about 2.400 centres so far as any openings in the wall will allow. These binders support the bridging joist and ceiling joist (if any) and should rest on concrete or stone templates or corbels. The availability of rolled steel joists in long lengths has displaced wooden binders in modern construction practice.

When universal beams are used as a binder, wood plates are supported by the lower flanges and are bolted together by a bolt passing through the web of the binder. The bridging joists are notched to fit over the top flange and are spiked to the plates. The lower part of the binder would be cased with wood or plaster.

Figure 13.4 shows a section through a universal beam binder with bridging joists and the necessary cradling for supporting the casing, when cased with wood or plaster.
When ceiling joists are used, the passage of sound is reduced to a minimum but the depth of the floor is considerably increased. Figure 13.5 shows a universal beam with the ceiling joist notched out to fit over the flanges; the bridging joist rests on the top flange. A suitable method of jointing the latter joists is shown.

Notched Ceiling Joist

Figure 13.5

An alternative method is shown in Figure 13.6. In this case the U.B. has timber plates bolted to the web, to support the bridging joist. The ceiling joists are notched and carried by the lower flanges of the binder as shown in the drawing. This method reduces the overall thickness of the floor-ceiling dimension. Special care must be allowed for timber shrinkage in the floor joist.

Notched Joist

Figure 13.6
### TABLE 13.1

**STRENGTHS OF AUSTRALIAN TIMBERS**

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<tr>
<th>Timber</th>
<th>Strength Group</th>
<th>Timber</th>
<th>Strength Group</th>
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<td>Alder, rose</td>
<td>D</td>
<td>Hardwood, Johnstone River</td>
<td>B</td>
</tr>
<tr>
<td>Ash, alpine</td>
<td>C</td>
<td>Ironbarks (various)</td>
<td>A</td>
</tr>
<tr>
<td>Ash, hickory</td>
<td>B</td>
<td>Ironwood, Cocktown</td>
<td>A</td>
</tr>
<tr>
<td>Ash, mountain</td>
<td>C</td>
<td>Jarrah</td>
<td>C</td>
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<tr>
<td>Ash, silver</td>
<td>C</td>
<td>Karri</td>
<td>B</td>
</tr>
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<td>Ash, silvertop</td>
<td>B</td>
<td>Mahogany, red</td>
<td>B</td>
</tr>
<tr>
<td>Ash, white</td>
<td>C</td>
<td>Mahogany, southern</td>
<td>B</td>
</tr>
<tr>
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<td>C</td>
<td>Mahogany, spur</td>
<td>B</td>
</tr>
<tr>
<td>Beech, myrtle</td>
<td>C</td>
<td>Mahogany, white</td>
<td>B</td>
</tr>
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<td>Blackbutt</td>
<td>B</td>
<td>Maple, scented</td>
<td>C</td>
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<tr>
<td>Blackbutt, W.A.</td>
<td>B</td>
<td>Marri</td>
<td>C</td>
</tr>
<tr>
<td>Bloodwood, brown</td>
<td>A</td>
<td>Messmate, Gympie</td>
<td>B</td>
</tr>
<tr>
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<td>B</td>
<td>Oak, northern silky</td>
<td>D</td>
</tr>
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<td>B</td>
<td>Penda, brown</td>
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<td>C</td>
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<td>D</td>
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<td>B</td>
</tr>
<tr>
<td>Gum, river red (bending only) (other uses)</td>
<td>D</td>
<td>Stringybark, messmate</td>
<td>C</td>
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<tr>
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<td>B</td>
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<td>B</td>
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<tr>
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<td>Gum, scribbly</td>
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<tr>
<td>Gum, shining</td>
<td>C</td>
<td>Tailwood</td>
<td>A</td>
</tr>
<tr>
<td>Gum, southern blue</td>
<td>B</td>
<td>Tea-tree, broad-leaved</td>
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<tr>
<td>Gum, spotted</td>
<td>A &amp; B</td>
<td>Tuart</td>
<td>B</td>
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<tr>
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<td>C</td>
<td>Walnut, yellow</td>
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<tr>
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<td>Yeratchuk</td>
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When the above data is utilized with information obtained from Table 13.3 (which gives the standard live loads for the various types of buildings), the cross-sectional sizes of joists for various spans and spacings can be calculated from Tables 13.2.
### TABLE 13.2

**CROSS-SECTIONAL SIZES OF FLOOR JOISTS**

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<tr>
<th>Joist Spacing mm</th>
<th>Span metre</th>
<th>A &amp; B Standard Grade</th>
<th>A &amp; B Common Grade</th>
<th>C Standard Grade</th>
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### 13.3 STRUCTURAL PINE DECKING

Bunning's double tongued and grooved structural pine decking is produced from kiln-dried pine and is used as second storey floors and first storey ceilings supported by exposed jarrah glulam beams.

Recommended spans for domestic floor loads are:

#### DECKING:

- **130 x 35 mm**: Span 1.6 m when continuous over 2 or more equal spans. Span 1.3 m when single span between 2 supports.
- **130 x 45 mm**: Span 1.9 m when continuous over 2 or more equal spans. Span 1.6 m when single span between 2 supports.
FIXINGS

Structural decking is nailed to beams or wall plates and may be stitch nailed together as illustrated in Figure 13.8.

\[ \text{Structural Decking} \]

\[ \text{Figure 13.7} \]

50mm Stitch nails at 600mm centres—45mm Decking.
45mm Stitch nails at 600mm centres—35mm Decking.

75mm Holding down nails—45mm
65mm Holding down nails—35mm

45°

Stitch nailing

\[ \text{Recommended Fixing Details} \]

\[ \text{Figure 13.8} \]

13.4 SOUND INSULATION AND FIRE PROTECTION FOR TIMBER JOIST FLOORS

Noise is one of the problems in urban living, and the reduction of noise by insulation is becoming a more common requirement in buildings. More attention has been paid to this because developments in building techniques have concentrated on lighter construction methods and the use of thin resonant sheeting.

Figures 13.9 (a) and (b) show a platform floor and a heavy pugged floating floor, which, in most circumstances, would give good insulation against airborne and impact noise.
(a) Platform Floor

Figure 13.9

(b) Pugged Floating Floor

Figure 13.9
Fire resistance is important in respect of upper floors, which often require to act as fire resistant barriers between the different levels of a building.

**Figure 13.10**

(a) Fire Protection to Joist by Two Layers of 13 mm Gypsum Super Fyrchek

(Courtesy of CSR Building Materials)
13.5 CONCRETE FLOORS

Suspended concrete floors are used in buildings for a variety of reasons - structural, economic, functional utility, durability and fire resistance being among the more important considerations.

Methods adopted in constructing concrete floors can be either:

floors cast in-situ, or

precast floors.

13.6 CAST IN-SITU FLOORS

(Courtesy of the Cement and Concrete Association of Australia.)

There are a number of structural systems for supporting floors. The supporting elements acting together with the floor not only carry the vertical loads but may also provide the structural stability to resist any horizontal loading. This stability may
have to be provided separately if the required resistance is not available within the floor system, e.g. by independent shear walls in flat plate or column/beam/one-way-slab systems. It is the supporting elements which impose most restrictions on the functional uses of a building.

The principal structural systems are:

**BEARING-WALL/SLAB SYSTEMS**

In these systems the slab is supported by load-bearing walls. They are commonly used in residential buildings where many walls are in any case needed to permanently subdivide the space.

(a) One-way slab

![Figure 13.11 (a)](image)

If the slab rests on two parallel supports only, then the slab will span between the supports and is known as a one-way slab.

(b) Two-way slab

![Figure 13.11 (b)](image)

If the slab is supported on four sides, then the load will be carried in two directions and the slab is called a two-way slab. Two-way action is only significant if the spans are roughly equal. Codes set an upper limit of 2:1 to the ratio of longer side to shorter side. Above this limit two-way action is assumed not to occur.
COLUMN/SLAB SYSTEMS

These systems dispense with beams altogether, the slab being supported directly by the columns. There are two variations:

(a) Flat plate

Figure 13.12 (a)

Here the columns frame directly into the slab. Flat plate floors minimise both floor thickness and interference to below-slab services.

(b) Flat slab

Figure 13.12 (b)

If the supporting columns have capitals or if the slab is thickened around the column by drop panels, the system is called a flat slab. Flat slabs are used where it is desired to increase the span or load capacity of the corresponding flat plate.
COLUMN/BEAM/SLAB SYSTEMS

Bearing-wall/slub construction imposes severe restrictions on the use of the floor space below. Greater flexibility can be achieved by using columns and beams to support the slabs.

There are a number of variations on column/beam/slub systems:

(a) Column/beam/two-way slab

![Figure 13.13 (a)]

Slabs spanning between beams are classified as one or two-way just as are slabs spanning between bearing walls. Column spacing is largely controlled by the ability of the slab to span between the beams. The overall depth of the floor is governed by the beam depth.

(b) Column/beam/one-way slab

![Figure 13.3 (b)]

Deleting the beams in one direction results in closer column spacing and thicker slabs but simplifies the distribution of below-slab services parallel to the beams. To reduce the dead load void forms, e.g. tubes, may be cast into the slab. Alternatively the slab may be transformed into a series of joists spanning between the beams.
(c) Column/main-beam/secondary-beam/slab

**Figure 13.14 (a)**

If large column spacings are required or heavy loadings are to be carried the slab spans may be broken down by the introduction of secondary beams supported by the main beam/column system. The greater freedom from supports is only achieved, however, at the expense of deeper beams which may restrict service runs and increase floor to floor heights.

**Figure 13.14 (b)**

Waffle slabs can be used to increase slab span and/or load capacity in all situations where two-way slab action occurs.

In general, for all systems, the use of prestressed concrete rather than reinforced leads to shallower members, increases span or load capacity. Water-tightness and crack control can also be improved by the use of prestressed concrete.

13.7 FLAT SLAB

In flat slabs the floor is contained between two plain surfaces. Because of this advantage and, despite their relatively heavy weight, they are increasingly used for spans up to 9 metres or more. Flat slabs may be supported by beams along two opposite edges or on three or four edges, or, they can be carried on columns.

In all forms of slab construction, the main reinforcement runs parallel to the direction in which the slab is spanning. Transverse reinforcement parallel with the supports gives the slab transverse strength so that it can distribute the effects of any
concentrated loadings. In simply supported spans, the reinforce-
forcement will be on the underside of the span. In continuous
spans, it is a common practice to put equal amounts of reinforce-
ment at the top and bottom of the slab.

Where the slab is supported on columns, it is often necessary to
thicken the slab adjacent to the column by the formation of a drop
panel or column capital.

![Diagram of Column Capitals and Drop Panels Supporting a Slab](image)

*Column Capitals and Drop Panels Supporting a Slab*

*Figure 13.15*

Additional reinforcement may be needed in a diagonal direction
between columns to provide against the higher stresses expected at
the column heads.

The concreting of flat slabs must be done in one pouring. No hori-
izontal construction joints should be allowed where the whole slab
cannot conveniently be done at one time; it should be divided into
panels each of which can be completed in one pour.

Flat slab construction is much used in industrial buildings,
flats, office blocks etc. The advantages of the flat slab system
over ordinary beam and girder construction are mainly due to the
absence of the beams, and may be summarised as follows:

- saving of at least 300 mm in the height required from
  floor to floor;
- easier construction through simple shuttering;
- better light, because windows can run from floor to ceiling;
- better ventilation because of the absence of air pockets
  caused by beams;
- easier layouts of service pipes;
- increased fire resistance through general streamlining.

The disadvantage of flat slab construction lies in its weight.
This is minimised by the use of beam and slab or T-beam construc-
tion. The concrete which comes below the neutral axis in ordinary
slabs is cracked or in tension. In T-beam construction, this
concrete is largely omitted and the reinforcement is clustered in
beams or ribs which are generally situated between 1.5 and 5 m
apart. The over-all depth will be greater, however, the reduced
weight allows its use for larger spans than ordinary slabs. The
rib and the slab act together in the form of a T and it is most important that supports should be situated under the rib and, preferably, along the slab as well. Transverse strength can be obtained by putting ribs or diaphragms at right angles to the main ribs.

The T-beam lends itself to a combination of precast and in-situ construction which is particularly valuable in saving of site work and shuttering. The rib is precast in either reinforced or prestressed concrete and placed in position. Conventional shuttering can be suspended from the beams or precast prestressed planks used as a permanent shutter for the slab which is then poured in-situ. Because the rib and slab must act compositely, reinforcement is usually cast into the rib so that it will project into the slab.

There are many proprietary types of hollow-block floor. In these, the hollow bricks are generally supported on the ribs and form the shuttering for the rib, which, in this case will be cast in-situ. Hollow-block floors can provide good sound and heat insulation, and they have the further advantage that the soffit of the floor is a plane surface.

T-beam construction is particularly suited to simple spans. It cannot be as effectively used for continuous spans.

Flat slab floors of either reinforced concrete or prestressed concrete can be entirely precast. It is not easy to provide much transverse strength in these floors and it is usual to connect the individual units by a screed or in-filling of in-situ concrete.

Many types of proprietary flooring systems based on the above principles are available.

13.8 PRECAST CONCRETE FLOORS

A precast concrete floor has the advantage of enabling a space to be "roofed" very quickly, thus permitting other work to proceed - both above and below it - with minimum delay. The cost saving which can result from the reduction in overall construction time could be a bonus, since precast flooring can cost less than other types. Distance from the precasting plant and the number of different elements will influence the cost of a precast floor. Variations in length, thickness, position of holes and openings will adversely affect cost and should be avoided in the interests of overall economy.

Proprietary precast flooring is available in conventionally reinforced and in prestressed types.

On-site precasting of floors is an alternative for larger scale developments, particularly on those sites remote from established precasting facilities. The slabs can be stack- cast, one on top of the other in convenient locations. The slabs needed first are cast last to ensure that each slab need be handled only once, moving it from its place on top of the stack to its position in the building.
TYPES OF UNITS

Prestressed Hollow Planks

Figure 13.16

Ribbed Units

Figure 13.17

(Courtesy of Cement and Concrete Association of Australia.)

ERECTING

Depending on the manufacturer's requirements, units may be seated on a fresh mortar bed. This is done to ensure that the units bear uniformly over their full seating and are not supported only at discrete points, which can chip or crack either the wall or unit.

End-bearing requirements vary between products, and also with the load and the composition of the element on which the panels are bearing. Required bearings will usually fall within the range of 50 - 75 mm.

EDGE JOINTINGS

Edges of precast planks are profiled in such a way as to give a joint which will distribute any concentrated loads over several planks, giving the floor a capacity above that of the individual planks, and resisting abrupt differential displacement. Until any necessary jointing has cured, temporary propping of a precast floor may be necessary in order to reduce deflection; see Figure 13.18. (The above may not be necessary where topping is to be used and the appearance of the soffit is not important. In this situation a difference of up to 12 mm may be tolerated.)
Details on Edge Jointing and Panel Propping

Jointing of Precast Units

Figure 13.18
(Courtesy of the Concrete Institute of Australia.)

Methods of Edge Jointing

HOLLOW FLOOR SLAB

Figure 13.19
(Courtesy of Humes Concrete.)
Toppings to precast units fall into one of two categories, structural or non-structural.

Structural toppings are those which are laid over precast units for strength requirements. Concrete for structural toppings should be as specified by the unit manufacturer.

Non-structural toppings are those which are laid only to give a level floor surface or for the bedding of ceramic tiles, etc.

Ceiling finishes

Soffits of precast floors can be treated in the same way as in-situ floors. Whatever finish is applied, it will usually be advisable to express the joints, since the likely differential movement, though small, can cause unsightly cracking if concealment is attempted.

Sprayed coatings such as 'Vermiculite' are ideal for masking irregularities of construction joints between units.

Rendering of the soffit of precast units is best avoided since satisfactory adhesion to their smooth surface is difficult to achieve.

The surface of most precast units will be satisfactory for painting. A 'high-build' latex-based joint spray applied to give a textured surface is recommended.
SERVICES

Accommodation of services in precast concrete floors causes no problems provided they are given early consideration. Small service pipes can be run in the cores of many proprietary precast floor units, or in the topping where one is being used. Holes can be cut in the top and/or bottom flanges to connect to fittings. Care must be taken to avoid cutting prestressing tendons or main reinforcement.

Small service pipes, conduits and cables can be run in the cores of hollow precast units and brought out through the flanges via holes made on site.

Services in Precast Units

Figure 13.21

13.9 PROFILED METAL FLOORS

Metal floors are designed to replace shuttering, shoring and reinforcement in concrete slab construction. Side laps are formed over a complete rib so that there is equal strength at all points and they are so designed that level surfaces are maintained. There are special sections to form ducting for electrical services and to provide hangers for suspended ceilings.

Concrete keys into the troughs between the ribs and additional reinforcement can be incorporated where necessary.
13.10 OPEN METAL FLOORS

Open metal flooring - some examples of which are shown in the following Figures - is used mainly in industrial buildings, particularly for service and operating platforms for machines, where the passage of light and air is required.

This type of flooring is made up in steel or aluminium alloy in panels of varying widths and lengths, as required. It can be formed of parallel flats, spaced apart and braced either by similar flats or bars intersecting at right angles at intervals
along the length of the panel. The junctions of all members are welded or rivetted and depths range from 18 mm to 85 mm. Clear spans are up to 2.4 m or 2.7 m.

Open flooring pressed from 16 gauge mild steel sheet is also available, produced in sections or planks 175 mm wide and in 1.350 m and 1.80 m lengths. The depth is standard at 30 mm, so that variations in loading must be allowed for by variations in the support spacing.

In aluminium alloy, this type of floor is also produced as a 150 ribbed extrusion in depths from 18 mm to 75 mm, with rectangular or square holes punched in the top plate. Clear spans are much the same as for the other types of floors. For all types, the supporting structure is formed from various rolled steel sections to which the floor panels are fixed by means of clips and bolts. An insulated clip and stainless steel or cadmium plated bolt are used with the aluminium extrusion to isolate the two metals and avoid possible electrolytic action.

![Diagram](image)

Open Metal Floors

Figure 13.24
13.11 PRECAST CONCRETE PLANK AND FILLER BLOCK

The units consist of prestressed webs or planks spaced at 255, 270 and 275 mm centres made in exact lengths to span between structural supports, with hollow filler blocks filling the spaces between the webs. Double cavity filler blocks, involving spaces up to 390 mm, are made particularly for lighter loads and shorter spans. The units are made in standard depths of 125, 150 and 175 mm and 200 mm - the size of unit varying according to span and loading.

Construction is in four stages by placing:

(a) prestressed concrete ribs;
(b) 225 long lightweight filler blocks;
(c) sand and cement grout between splay of filler blocks and webs;
(d) top layer of in-situ structural concrete screed which varies in thickness according to span, loading, and type of unit used.

The screed can be laid as a finished floor or a bed for all types of floor finishes. The soffit of the units can be plastered or left as laid and provision can be made for suspended ceilings if required.

![Precast Concrete Plank and Filler Blocks](image)

Figure 13.25

13.12 HOLLOW PRECAST FLOOR AND ROOF UNITS

Units are precast by using a patented, mechanically-operated, collapsible core and rigid metal side formers. A high degree of dimensional accuracy is thus ensured. The reinforcement is positioned by jig and a minimum of concrete is used for in-situ filling of the grouting channel. Standard units are 300 mm wide and 125 mm, 150 mm, 175 mm, 200 mm and 225 mm deep. The exact lengths to span between structural supports are cast and such notches,
holes fixing for ceiling and floor finishes as may be necessary are incorporated. Special units for extra heavy duties, trimming of openings, etc. can also be made. Multi-core precast hollow slabs are cast in nominal widths from 600 mm to 1925 mm and combine with labour, and weight-saving advantages of standard-width units.

Hollow Precast Floor and Roof Units

Figure 13.26

13.13 HOLLOW BLOCK FLOORS

Hollow block reinforced concrete floors cast in-situ consist of rectangular hollow blocks laid in parallel rows on special open metal formwork or centring to form a homogeneous series of T-beams when the reinforcement is placed in the ribs between the rows and the infilling and topping concrete is poured and thoroughly tamped. Depth of hollow blocks and topping, and diameter of reinforcement, are designed to suit individual spans, loading and end conditions. Arrangements are made for the electrical specialist to incorporate his conduits in the topping before the concrete is poured.

Hollow Block Floor

Figure 13.27
13.14 MEZZANINE FLOORS

DEFINITIONS

(From the Uniform Building By-Laws 1974)

'Mezzanine' means the space within a room which is situated between:

(a) An intermediate floor constructed within the room but not extending across the full area of the room; and

(b) The floor level, ceiling, or roof, as the case may be next above the intermediate floor.

CONSTRUCTIONS

This type of floor may be constructed of timber, unprotected steel, or both.

The floor is generally constructed on the beam, joist and flooring principle. See Figure 13.28. The Uniform Building By-laws will show height and size of floor area allowances.
Section Details

Figure 13.28
Chapter 14

WALLS

14.1 INTRODUCTION AND ESSENTIAL CHARACTERISTICS

14.2 TYPES OF WALLS
   MONOLITHIC CONSTRUCTION
   FRAMED CONSTRUCTION

14.3 FACINGS, CLADDINGS AND INFILL PANELS

14.4 TYPES OF FACING MATERIALS AND FIXINGS

14.5 FAILURE OF SLABS
   TYPES OF FAILURE
   CAUSES OF FAILURE
   CAST STONE
   CORROSION

14.6 TYPES OF CLADDING MATERIALS AND FIXINGS
   CONCRETE
   FIBRE CEMENT SHEETING
   METAL
   CURTAIN WALLING
   PANEL SUPPORT AND FIXING
   LATERAL RESTRAINT

14.7 INFILL PANELS AND PANEL WALLS

14.1 INTRODUCTION

The basic function of a wall is to enclose a space or partition a room. However, in most situations walls are also required to provide load-bearing support and lateral rigidity for structures. To meet the requirements of walling systems the following list of essential characteristics should be studied:

- strength and stability
- durability
- weather resistance
- fire resistance
• thermal insulation
• sound insulation

External load-bearing walls may be considered under all of the above requirements, whereas internal non load-bearing partitions may be selected for appearance, modular planning and prefabrication, and demountable designs.

14.2 TYPES OF WALLS

The internal and external walls of large buildings may be categorised as follows:

(a) Load-bearing - where a vertical loading is applied in addition to the weight of the wall.

(b) Non load-bearing - where no vertical load is to be applied, and the wall merely supports its own weight and defines spaces in a structure.

The Uniform Building By-laws specify the dimensions and types of construction for various types of walls, including the degrees of required fire resistance ratings. These requirements can be specifically applied to particular walls at the discretion of the local authority building surveyor.

In general, walls can also be classified according to the type of structure and materials of construction, as follows:

• Monolithic walls
  - masonry
  - brickwork
  - calculated brick bearing walls
  - in-situ concrete walling

• Framed Construction
  - Column, beam and floor construction incorporating metal, brick or concrete framing and external cladding or in-fill panels.

MONOLITHIC WALLS

These may be erected with many materials, in either normal or reinforced forms of construction. Calculated brick bearing walls can support considerable loadings on slender walls of architecturally designed and engineer calculated construction. High tensile prestressing tendons resist the tensile stresses caused by eccentric loading and lateral wind pressure.

The cavity wall provides better weather protection and thermal insulation than solid walls of similar total thickness. Loads may be carried by either leaf, although in most situations the internal leaf supports vertical loadings, and the external leaf
withstands pressures from wind and rain. To compensate for thermal movements, the length of wall should be divided into panels with joints spaced according to the requirements of the regulations for the different situations and types of materials.

Brickwork provides an attractive facade to a building, with a wide range of textures and colours. However, the use of monolithic walls has led to the introduction of thin facings of selected materials which require fixing to an uninterrupted background.

THE FRAMED METHOD OF CONSTRUCTION

This enables walls to be constructed with large elements or claddings which significantly reduce the structural loads. The structural frame may comprise in-situ or precast concrete components, steel staunchions or brick columns.

The external facade of framed buildings may consist of lightweight claddings or infill panels attached to the structural frame. Claddings enclose the structure by spanning between supports on the face of the building, without any continuous background support. They include dense units of precast concrete to lightweight profiled sheeting and glazed curtain walling.

Infill panels incorporate lightweight enclosures with large elements of panelling attached between the members of a structural frame.

14.3 FACINGS, CLADDINGS AND INFILL PANELS

Facings comprise a range of selected materials with attractive appearance which may be attached to the structural wall, or bonded to a finished surface. According to their method of construction and dimensions of the units, veneers or tiles have been classified as facings.

Facings are materials attached to the structural wall during construction, and included in the thickness of the wall. Facings are to be not less than 100 mm thick and to have an ultimate compressive strength equal to the walling to which they are attached.

Veneers are architectural natural or synthetic materials of not less than 19 mm thickness, that are applied over walls but do not form part of the structural member.

Tiles are units of facing materials which do not exceed the dimensions of 300 mm in length and width by 25 mm in thickness. They have a keyed backing for anchoring to the wall with cement mortar, to an ultimate shearing stress of 345 Kpa.
14.4 TYPES OF FACING MATERIALS

Include natural stone, brick, terracotta, concrete and exposed aggregate concrete with selected re-constructed stone.

14.5 FAILURE OF SLABS

TYPES OF FAILURE

Stone veneers may fail or develop defects that become manifest in a number of different ways, although in many instances the basic cause may be the same. The types of failure that are commonly observed, singly or in combination, are:

(a) fractures across slabs without marked displacement or failure of fixing;

(b) displacement or falling away of one or a number of slabs;

(c) spalling and fractures at horizontal or vertical joints; and

(d) bowing or cupping of slabs, frequently without any other evidence of trouble.

CAUSES OF FAILURE

Failure of stone slabs is nearly always the result of excessive stresses having been placed on the stone or its fixing. The principal causes of these stresses are:

(a) deformation of the building structure resulting from characteristics inherent in the construction;

(b) differential movement between the veneer and other closely associated elements; or

(c) distortion of the slabs for reasons other than those mentioned above.

CAST STONE

Because of the wide variations in the quality of natural stone, it may be advantageous to use cast or artificial stone. Fixing of cast stone is similar to natural; however, because it is possible to reinforce cast stone, it may be possible to use it in much thinner dimensions.

Concrete facing slabs are cast similar to cast stone and like cast stone, may also have non-ferrous fixings cast into them.

Patterned moulds may be used in precasting to give various surface textures, or the surface may be of exposed aggregate produced in the conventional ways.
Terracotta slabs may be produced in sizes up to 600 x 450 mm with thicknesses up to 30 mm. They are dovetailed on the back to give good key and can be fixed with cramps in a similar way to stone facings.

Glazed tiles can be successfully used as facings. They are usually adhered directly to the background by mortar and allowances are made for thermal expansion.

Metal such as stainless steel, copper, bronze, aluminium and in some cases lead, may be suitable for facings to structural backgrounds.

When metals are used they are usually profiled to give added stiffness enabling fewer fixing points.

Plastics. Only certain types of plastics are suitable for facings. Laminated plastics are best suited because of their mechanical strength and insulating value.

Concrete Facings

Figure 14.1

Terracotta and Faience Facings

Figure 14.2

14.5
Typical Fixing Methods

Figure 14.3

(Courtesy of the Commonwealth Experimental Building Station.)
Metal Anchorages - Natural stone facings are fixed to the 'background' structure using metal fixings designed primarily to hold the slabs back to the wall and keep the faces in correct alignment. All metal anchorages should be of non-ferrous metal such as copper and bronze, since galvanizing and bitumen painting of iron or steel give only temporary protection. Those for sedimentary stones are usually in strip form and reasonably substantial when supporting the weight of a thick slab. The ends are accommodated in mortices or grooves cut in the edges of the slabs. The thinner igneous and metamorphic slabs are
invariably secured with wire cramps and dowels. The ends of all forms of anchors and corbels must be fixed firmly to the background; this is usually done by bedding in mortar in mortices cut in, or, in the case of concrete, cast in the background material.

**CORROSION**

Metals used for fixings need to be strong, and extremely durable, and in particular have a high resistance to the corrosive action of mortar and concrete. Corrodible metals, such as unprotected steel, should never be used.

**Metals Used for Fixing**

<table>
<thead>
<tr>
<th>Copper</th>
<th>Stainless Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphor Bronze</td>
<td>Manganese Bronze</td>
</tr>
<tr>
<td>Aluminium Bronze</td>
<td>Silicon Bronze</td>
</tr>
<tr>
<td>Gun Metal</td>
<td>Galvanised Steel</td>
</tr>
</tbody>
</table>

Most materials commonly used for fixing are proof against normal corrosion, but the less familiar stress corrosion and electrolytic corrosion can be important considerations.

**Electrolytic or Galvanic Corrosion**

Precautions should be taken to avoid contact between dissimilar metals in situations that may become damp, so as to avoid the possibility of electrolytic corrosion.

**Stress Corrosion**

Stress corrosion takes place in certain alloys subjected continually to a tensile stress, either internal or applied, and in certain types of corrosive environment. It takes the form of cracks that spread throughout the metal.

14.6 TYPES OF CLADDING MATERIALS AND FIXINGS

**CONCRETE**

As well as being used for facings and permanent formwork, precast concrete panels can also act as a cladding over a structural frame.

The weight of the panel can be reduced by casting a thin panel with ribs around the edges and at intermediate locations. Reinforcement is necessary, particularly at the ribs. Where reinforcement is used in thin panels it should be galvanized to reduce the possibility of corrosion stains on the face of the panel.
Precasting requires the strict observance of tolerances because only minimal adjustments can be made with packing and slotted seatings.

Concrete panels can be designed to run vertically or horizontally. Vertical panels run from floor-to-floor and horizontal panels are usually employed as spandral panels.

Precast concrete panels are hoisted with attachments bolted to inserts cast in the member. These inserts can be designed to provide fixing points for bolting to the frame structure. See Figures 14.7 and 14.8. Large precast concrete panels obtain greater support and stability with extended nibs which can seat on the beam or slab. See Figure 14.5.

FIBRE CEMENT SHEETING

For industrial and similar buildings of less importance fibre cement has wide application as a cladding material. Modern applications include the use of thin sandwich panels filled with a suitable thermal insulation material. Consideration must be given to the method of flashing and sealing the joints between all precast wall claddings. However the degree of watertightness needs to be suitable to the type of work in hand.

METAL

Generally aluminium and sheet steel are used for facings. The metal claddings are usually profiled to provide the strength required to span between fixings. The provision of thermal insulation is a consideration that must be taken when using steel as a cladding material. The insulation is invariably sandwiched between two veneers of metal making the panel about 25 to 30 mm thick.

CURTAIN WALLING

The term curtain walling means a system of cladding which consists of a frame or grid fixed to the face of a building, and an infilling of panels to perform the functions of window and wall.

There are various proprietary curtain walling systems, but basically they consist of vertical members fixed to and spanning the distance between the floor slabs. Horizontal members such as heads, sills and transomes, are fitted between the vertical members.
PANEL BEARING SUPPORT AND FIXING DETAILS

**Figure 14.5**
(Courtesy of the Concrete Institute of Australia.)

**Figure 14.6**
(Courtesy of the Concrete Institute of Australia.)
LATERAL RESTRAINT DETAILS

Figure 14.7

Figure 14.8
Typical Curtain Wall System

Figure 14.9
14.7 INFILL PANELS AND PANEL WALLS

A common method of enclosing the face of a framed structure is with the use of panels fixed between the framework of columns and beams. The denser masonry panels are referred to as 'panel walls' while lighter panels of metal, timber and plastic materials are termed 'infill panels'.

Limitations are placed on the size of panel walls in relation to their thickness, so that they are able to support wind loads and transfer these to the framework:

(a) to 23 m\(^2\) area = thickness of not less than 180 mm
(b) over 28 m\(^2\) area = thickness of not less than 280 mm
(c) maximum unsupported area between the structural framing shall not exceed 46.5 m\(^2\).

Types of Panel Walls

Figure 14.10
Chapter 15

STRUCTURAL STEEL

15.1 INTRODUCTION

15.2 SHAPES AND SECTIONS

15.3 HOLLOW RECTANGULAR AND SQUARE SECTIONS
   TYPICAL CONNECTIONS

15.4 STEEL TUBES
   TYPICAL CONNECTIONS

15.5 COLD-ROLLED STEEL SECTIONS

15.6 TERMINOLOGY

15.7 COMPONENT CONNECTIONS
   COLUMN TO CONCRETE FOOTING
   COLUMN TO COLUMN CONNECTION
   BEAM TO COLUMN CONNECTION
   BEAM TO BEAM CONNECTION
   BRACING

15.8 CONNECTIONS
   BOLTING
   WELDING

15.9 FEATURES OF CONNECTIONS MADE BY BOLTING

15.1 INTRODUCTION

Steel-framed buildings are designed on the principle that beams are supported at their bearings by columns. Connections are made by bolts, or welding, and some fire protection is afforded by encasing the steel in concrete or other suitable materials.

The conventional steel frame is constructed with hot-rolled 'I' sections, beams and columns in the form of a skeleton designed to support the whole of the live and dead loads of floors, external cladding and wind pressure.

The steel members used are universal beams, columns, angle and channels.
Skeleton Structural Steel Frame

Figure 15.1

(Figures 15.1, 15.10, 15.12 and 15.14 are reproduced with permission from "The Construction of Building", Volume 4, by R. Barry.)

15.2 SHAPES AND SECTIONS

The Australian Standard 1204 "Structural Steels - Ordinary Weldable Grades" lists the regular 'normal strength' steel that is widely available from distributors and stockists.

It is produced in a range of shapes and sections, including universal sections, tapered flange beams, channels, equal and unequal angles.

The entire range is detailed in AS1131 "Dimensions of Hot-rolled Structural Steel Sections" which includes large and heavy members mostly used only in fully engineered structures.

Tables 15.1 to 15.5 show the designation, mass/metre and dimensions for some of the lighter and more easily obtained sections.
Notice that the designation is derived from the depth "D" and the weight per metre of the beam. The initials U.B. describe the type of beam.

**TABLE 15.1**

**SPECIFICATIONS OF UNIVERSAL BEAM STEEL**

<table>
<thead>
<tr>
<th>Designation</th>
<th>mass/ metre</th>
<th>depth D</th>
<th>FLANGE width</th>
<th>thickness</th>
<th>Web thickness</th>
<th>radius r</th>
<th>Depth between fillets</th>
</tr>
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<tbody>
<tr>
<td>410 UB 54</td>
<td>53.6</td>
<td>403</td>
<td>178</td>
<td>10.9</td>
<td>7.6</td>
<td>10.2</td>
<td>361</td>
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<tr>
<td>360 UB 45</td>
<td>44.6</td>
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<td>171</td>
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<td>6.9</td>
<td>10.2</td>
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<tr>
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<td>304</td>
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<td>6.1</td>
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TABLE 15.2
TAPER FLANGE BEAM SPECIFICATIONS

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<th>Mass per metre</th>
<th>Depth of section</th>
<th>FLANGE width</th>
<th>FLANGE thickness</th>
<th>Web thickness</th>
<th>RADI</th>
<th>Root</th>
<th>Toe</th>
<th>depth between fillets</th>
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<tr>
<td></td>
<td>kg</td>
<td>D</td>
<td>B</td>
<td>T</td>
<td>t</td>
<td>r₁</td>
<td>r₂</td>
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</table>
### CHANNELS

#### TABLE 15.3
SPECIFICATIONS FOR CHANNELS

<table>
<thead>
<tr>
<th>Nominal Size D x B mm</th>
<th>Mass per metre kg</th>
<th>Thickness web t</th>
<th>Thickness flange T</th>
<th>Radii Root ( R_1 )</th>
<th>Radii Toe ( R_2 )</th>
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</table>
### TABLE 15.4
EQUAL-ANGLES SECTION SPECIFICATIONS

<table>
<thead>
<tr>
<th>Nominal size A x B mm</th>
<th>Thickness t</th>
<th>Actual</th>
<th>Radii Root r₁</th>
<th>Toe r₂</th>
<th>Mass per metre kg</th>
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<td>to 10</td>
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<td>10.7</td>
<td>4.8</td>
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<tr>
<td>to 8</td>
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<td>4.8</td>
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<td>18.9</td>
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<td>to 6.5</td>
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<td>7.6</td>
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</table>
### TABLE 15.5
UNEQUAL-ANGLES SECTION SPECIFICATIONS

<table>
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<tr>
<th>Nominal size A x B mm</th>
<th>thickness t Nominal to Actual</th>
<th>Radii Root R₁</th>
<th>Toe R₂</th>
<th>Mass per metre kg</th>
</tr>
</thead>
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<tr>
<td>152 x 102</td>
<td>12 to 10</td>
<td>12.6</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>16 to 8</td>
<td>15.8</td>
<td>10.4</td>
<td>4.8</td>
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<td></td>
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</table>
15.3 HOLLOW RECTANGULAR AND SQUARE SECTIONS

A range of hot-finished, welded and hot-finished seamless hollow rectangular and square sections is produced. These sections are ideal for use as columns as the material is uniformly disposed around the axis and the rectangular section facilities beam connections.

![Rectangular Steel Section Diagram]

**Hollow Square and Rectangular Steel Sections**

*Figure 15.2*

Square sections have identical properties in both X and Y directions making them best suited to columns. Rectangular sections have differing properties in the X and Y directions making them better suited to beam applications.
Typical Connections for Rectangular and Square Sections

Figure 15.3

15.4 STEEL TUBES

A range of seamless and welded seam steel tubes is manufactured for use as columns, struts and ties. The use of these tubes as columns is limited by the difficulty of making beam connections to a round section column. They are used for single storey lengths where beams are connected to plates welded to the top of the tube. They are extensively used in steel trusses.
Steel Tube

Figure 15.4

Circular steel tube is symmetrical in any plane and therefore handles combinations of bending, tension, compression or torsion in any direction.

Directions of Loading

Figure 15.5
Shop Welded Mitre Joint (a)

Profiled Joint (b)

Universal Beam to Column (c)

Profiled Truss Wed Members (d)

Bracing Connections - Tube end is flattened in a Press and drilled (e)

Column Base Plate (f)

Typical Connections for Steel Tubes

Figure 15.6
15.5 COLD-ROLLED STEEL SECTIONS

These sections are fabricated from thin strips of steel rolled to shape. The C and Zed purlins and girts system incorporates advanced design methods and accurate cold roll forming techniques to provide efficient, high performance, lightweight and economical roof and wall cladding support systems for framed structures.

<table>
<thead>
<tr>
<th>Catalogue No.</th>
<th>Dimensions</th>
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</thead>
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<td></td>
<td>D</td>
</tr>
<tr>
<td></td>
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</table>

**C Profile Section**

Figure 15.7
Steel Construction Terminology

Figure 15.8
15.7 COMPONENT CONNECTIONS

COLUMN TO CONCRETE FOOTING

The concept of connections is to make assembly as simple as possible.

*Column bases* must be enlarged by means of a base plate to reduce bearing pressure on footings. The two types of bases are the gusseted base and the bloom base. See Figure 14.9.

Column bases are bolted to the footing by hold-down bolts set into the concrete. See Figure 15.10.

---

**Welded Column Bases**

*Figure 15.9*

---

**Column Base Fixed to Concrete Pad**

*Figure 15.10*
COLUMN TO COLUMN CONNECTION

Column splices, which are joints in the axes of column, are necessary where long lengths are required. See Figure 15.11 (a) and (b).

Bolted Splices

Figure 15.11 (a)

Welded Splices

Figure 15.11 (b)
Beam to Column Connection

Figure 15.12

Beam to column connections are either direct compression connections when the beam is located over the column or shear connections when the beam butts onto the column. Positioning and seating cleats are used in the latter case to maintain accuracy. See Figure 15.12.

Beam to Beam Connection

Figure 15.13
BRACING

Wind bracing, when required, may be provided in several ways. Some special types of bracing are:

- cross or "K" braces
- knee bracing
- rigid frames
- shear walls

Where unobstructed spaces are required it is not practical to use cross or "K" bracing.

Knee bracing, which may be in the form of gussets, can be used for beam to stanchion connections to take the wind loads.

Significant resistance can be afforded by wall panels and floor slabs. Solid internal shear walls are a very effective method of resisting racking or twisting caused by wind loads.
15.8 CONNECTIONS

Connections in structural steelwork are classified as either shop connections or site connections and can be made by using bolts, or by welding.

BOLTING

Black bolts: the cheapest form of bolt available, the black bolt can be either hot or cold forged, the thread being machined onto the shank. The allowable shear stress for this type of bolt is low and therefore they should only be used for end connections of secondary beams or in conjunction with a seating cleat which has been designed and fixed to resist all the shear forces involved. The clearance in the hole for this form of bolt is usually specified as 1.5 mm over the diameter of the bolt. The term black bolt does not necessarily indicate the colour but is the term used to indicate the comparatively wide tolerances to which these products are usually made.

Turned bolts: these have a machined shank and therefore are of greater dimensional accuracy, fitting into a hole with a small clearance allowance.
*High-strength fiction-grip bolts:* During recent years an important development in the joining of steel members has been the introduction of high strength friction grip bolts. These are bolts of high tensile strength steel, with high-tensile nuts and hardened washers. These are tightened up by special spanners to a precalculated extent so as to give a definite clamping force, compressing the members together. Loads in the connected members are then transferred from one to the other because of friction between the several parts and not by relying on the shear and bearing strengths of the bolts.

(a) **Parallel Shank**

(b) **Nuts**

(c) **Washers**

*High-Strength Friction-Grip Bolts*

*Figure 15.16*

*Figure 15.17*
WELDING

Welded Connections

The two main methods of welding are oxy-acetylene and electric arc. The electric arc method is the one most commonly used for structural steelwork.

Oxy-acetylene

Acetylene, which is a compound of carbon and hydrogen, when mixed with oxygen and ignited gives a flame of high temperature (about 2000° to 3000°C). The flame is used for melting a rod of metal, causing it to be deposited at the junction of two parts to be joined together. The 'parent' metal at the junction also becomes molten so that the weld metal fuses it. Oxy-acetylene welding is used principally for work on light guage sheet metal. The flame is also used for cutting steel.

Electric-arc Welding

The heat required to melt the welding rods is caused by an electric arc which requires a voltage of 70 to 100 volts. The alternating voltage of the mains is reduced to this figure by means of a transformer. If direct current is used, the mains voltage is reduced by a motor-generator set. The rod of metal which is melted to form the weld is called the electrode and forms part of the electric circuit. To form a weld the electric circuit is completed by touching the parent metal with the electrode near the proposed joint. The electrode is immediately drawn away a short distance and the current jumps the gap in the form of an
arc. The heat of the arc melts the electrode and the parent metal near the join so that the deposited metal fuses together the parts to be joined. When welding structural (mild) steel parts, the electrode is also of mild steel coated with a material which acts as a flux and prevents chemical combination between the oxygen of the atmosphere and the molten steel.

Gas Metal Arc Welding (MIG)

Gas Metal Arc welding is an arc welding process wherein necessary heat for fusion is produced by an electric arc maintained between a continuously fed wire electrode and the part to be welded. The heated weld zone, the molten weld metal and the electrode are shielded from the atmosphere by a shroud of gas fed through the welding torch.

The major advantage of the GMA welding process is its high deposition rate compared with other arc welding processes. This is brought about by the high ratio of current to wire diameter and removal of the need to change electrodes, chip slag, etc. by the continuously fed, gas shielded electrode. These advantages are summarized below.

- High deposition rates when compared to manual metal arc welding.
- High operating factor due to no need for stops to change electrode, chip slag etc.
- No wastage from stub ends (disguarded short ends of electrodes).
- Elimination of slag removal, reduction of smoke and fumes.
- Less operator skill required.
- Has a wide range of applications.

Butt Welds and Fillet Welds

Square butt welds are only used for joining thin plates up to about 5 mm thick. For thicker plates, the edges of the plates are prepared for welding by bevelling.

A single "V" butt weld is one example (Figure 15.19). There are other types of butt welds known as double "Vee", single "U", and double "U", etc. according to the shapes of the ends of the plates.

If properly constructed, the strength of a butt weld can be taken as equal to that of the plates it joins together. Fillet welds do not require preparation of the plates or members to be joined together and normally these welds are stressed in shear.
The safe load depends on the size; that is, the thickness of the weld and its length, for example, 25 mm of 5 mm weld can be allowed to take a load of 1150 kg.

Types of Welds

Figure 15.19

15.9 FEATURES OF CONNECTIONS MADE BY BOLTING

Although welded connections are generally superior to bolted connections, a number of factors may lead to the use of bolts. Such factors include:

(a) Speed and simplicity of erection.

(b) Bolted connections allow for dismantling and re-erection; and additions and alterations.

15.22
(c) Less skilled operators may be employed.

(d) Inspection procedure simplified.

(e) Members may be coated prior to assembly.

(f) No metallurgical problems with induced stress as with welding.

(g) Special materials may be connected, overcoming complicated welding methods.

(h) Allows for connection of dissimilar materials.

The chief disadvantage of the bolted connection is that a hole must be provided to accommodate the fastener and therefore extra material must be allowed to compensate. Furthermore bolted connections require the components to be lapped which uses more material and causes lines of stress to deviate through the joint possibly causing stress concentration and associated problems.

**Efficiency of Bolted Joints**

The area surrounding the fastener will usually be the weakest part of a bolted joint. The efficiency of the joint is the ratio between the weakest part of the joint and the solid metal expressed as a percentage or a decimal fraction.

**Modes of Failure of Bolted Joints**

Bolted joints are liable to failure in a number of ways. The following diagram (Figure 15.20) shows common types of failure.
Modes of Failure of Bolted Joints

Figure 15.20
Chapter 16

FIRE PROTECTION OF STRUCTURAL STEEL

16.1 INTRODUCTION

16.2 FIRE PROTECTION

16.3 MATERIALS IN RELATION TO FIRE
  IGNITABILITY
  COMBUSTIBILITY
  SPREAD OF FLAME
  STABILITY OF MATERIALS
  FLASH-OVER
  THERMAL SHOCK
  FIRE RESISTANCE RATING

16.4 REACTION TO STRUCTURAL MATERIALS TO FIRE
  TIMBER
  BRICKS
  CONCRETE, GYPSUM PLASTER, ASBESTOS FIBRE
  STEEL
  ALUMINIUM
  GLASS
  PLASTICS

16.5 FIRE PROTECTION OF STRUCTURAL STEEL FRAMING
  SOLID CASINGS
  LIGHTWEIGHT CASINGS

16.6 FIRE RETARDANT PAINTS

16.1 INTRODUCTION

This chapter is concerned with protection against fire by structural means (sometimes referred to as ‘passive defence’). The builder or architect has little control over fire prevention because most fires are caused by the action of occupants. Architects must, however, design and detail buildings in such a way as to restrict the spread of fire and ensure the safety of the public, firefighters and property.
A common misconception is that a fire is unlikely to occur in a building constructed of non-combustible materials and, that if it does, the effects will be slight. This is not true. The cause of fires and their severity is invariably related to the contents of a building rather than the structure.

16.2 FIRE PROTECTION

To understand the methods of fire protection better it is first necessary to determine the objectives. The major objective is to prevent loss of life; the protection of the structure, the contents and the prevention of spread of fire to adjacent buildings are of less importance. The degree of protection will vary according to the type and size of building, its proximity to other buildings, the value and quantity of its contents and the number of persons likely to be inside the building at any given time.

16.3 MATERIALS IN RELATION TO FIRE

IGNITABILITY

All combustible materials can be made to burn. However, they do not ignite with equal readiness. The 'ignitability index' rates materials according to their ease of ignition on a 0 - 20 scale. Polystyrene foam has an ignitability index rating of 17, meaning that it is very readily ignited. Normal 5 mm hardboard has a rating of 14; however if finished with fire-retarding water paint it may have a rating of 8 and, if impregnated with fire-retardant, the ignitability rating may be reduced to 0.

COMBUSTIBILITY

Materials are rated as 'combustible' or 'non-combustible' according to whether or not they will burn. To determine the combustibility of material, a specimen is plunged into a furnace heated to 750°C. The material is deemed to be combustible if it:

- flames
- releases ignitable vapours
- causes a rise in temperature within the furnace.

SPREAD OF FLAME

This usually refers to the ability of thin combustible wall boards to propagate fire from flames spreading along its surface. It is significant in determining the rate at which fire may spread from one part of a building to another. The spread-of-flame index is on a scale of 0 - 10.
STABILITY OF MATERIALS

Although a material may be incombustible, it cannot be assumed that it will continue to fulfil its function during a fire. A common example is the comparison of timber and steel. Timber will burn and loses strength only by being burnt away. Combustion is retarded by the formation of charcoal on the surfaces, so that a heavy timber structure may resist collapse for a considerable period. Steel, however, becomes rapidly heated and failure is likely to occur at temperatures between 550°C and 600°C. At these temperatures, which are likely to be reached at an early stage in a building fire, steel will have lost over 50% of its cold strength.

FLASH-OVER

A fire in an enclosed space may generate such heat that combustible contents and construction material emit combustible vapours. Often these vapours do not burn immediately but increase in quantity and spread throughout the space. They may finally ignite with mild explosive force at a time when combustible linings (wall boards, etc.) are preheated sufficiently to continue to burn once ignited in this manner.

THERMAL SHOCK

This term refers to a sudden and large change in temperature which affects material or component. In non-conductive materials, differential expansion creates considerable internal stress. The effects are most noticeable in brittle materials such as glass, where the stresses cause sudden shattering. The household example of pouring boiling water into a drinking glass has its parallel in windows subjected to the intense heat of a fire.

FIRE RESISTANCE RATING

This is expressed in hours, and represents the probable time an element will continue to function under the effects of a normal fire. It is important to note that ratings as determined by a standard test are given to elements not materials.

The test requires that a full-sized prototype element of the construction to be tested, or a representative specimen at least 3 m x 3 m, is subjected to its maximum permissible design stress and then be heated at a standard rate. The element or component is deemed to have failed when:

- it collapses
- it allows flames or hot gases to pass through it
- temperature on the unexposed face rises to about 220°C
The third requirement of temperature rise is normally waived for fire-resisting doors because combustible materials should not be stored nearby; that is, in an access way. Metals may, therefore, be used in this situation because they are capable of forming a barrier to flames and gases under extremes of heat. It is obvious, that fire walls must have thermal-insulating properties to resist the passage of heat which for a 2 hour rating would exceed 1000° C on one side.

*A fire window with steel frames and wired glass, 31 minutes after the commencement of a fire-resistance test.*

**FIRE TEST : WINDOWS**

*Figure 16.1*

*Methods of Measuring Fire Resistance*  
*Figure 16.2*
16.4 REACTION OF STRUCTURAL MATERIALS TO FIRE

TIMBER

The critical temperature for timber is about 250° C, beyond which it will be progressively destroyed by fire. Timber will contribute to the severity of a fire and, if burning is unchecked, will be completely consumed.

Resistance to mild fires may be improved by impregnating timber with fire-retardant chemical. Painting the surface with fire-retardant paints will also increase the initial resistance. However in severe fires, these measures are of little value. Effective protection may be provided by suitable claddings such as those with asbestos and gypsum base.

Two factors are especially important when considering the fire resistance of timber. The first is the species. Dense hardwoods such as jarrah and, especially, wando are naturally resistant while - at the other extreme - resinous softwoods will ignite readily and burn fiercely. Second, thin sections such as flooring and lining boards present a large area to the air and its oxygen supply and will ignite and burn readily. But heavier sections such as beams, will char in depth and this inhibits rapid combustion of the wood beneath.

BRICKS

Clay bricks have been subjected during manufacture to temperatures comparable with those that can be expected in a building fire. Consequently, clay bricks are not greatly affected by fire except for some thermal expansion.

Concrete and sand-lime bricks are also similarly resistant to fire although the thermal expansion is somewhat greater than clay bricks. Bricks are ideal for use in fire-rated construction, either as load-bearing walls or as protection for less stable materials such as steel.

CONCRETE, GYPSUM PLASTER, ASBESTOS FIBRE

These materials have two things in common that have great significance in fire resistance.

(a) Water of crystallization.

Both cement and gypsum plaster set by combining with water. Asbestos is composed of long fibrous crystals and, in common with many crystalline minerals, contains water of crystallization.

When either of these materials is heated sufficiently, the chemical bond between mineral and combined water is broken and the water liberated. The absorption of heat energy in this process, while it occurs, prevents a rise in temperature beyond certain limits.
(b) Insulation

These mineral materials are naturally poor conductors. Also, gypsum is rather porous and asbestos fibre is teased to form an extremely porous matt that resists the passage of heat.

NOTE: Asbestos should not be confused with asbestos cement which is a product of asbestos, silica and cement. Asbestos fibre is being phased out as a building material, due to the danger it poses to health.

CONCRETE

Two variables that affect the fire resistance of concrete are the presence of 'free moisture', and the type of aggregate used.

When concrete is heated to about 100° C, the free water is driven off as steam. This undoubtedly has a useful effect in restricting temperature rise. Unfortunately, the excessive pressures developed within the concrete by the generation of steam can be sufficient to cause 'spalling' in normal dense concrete. This is the breaking away of pieces - sometimes quite large - of concrete from the main body.

The use of lightweight aggregates effectively combats spalling. Probably because their inherent porosity is sufficient to accommodate the steam and so reduce the pressure build-up to an acceptable level.

STEEL

Because of the reliance in building on the strength of steel, the importance of its properties cannot be over-emphasised. It is used as the structural framework of multi-storeyed buildings, as reinforcement in all concrete structures and as trusses and portal frames in roof structures.

Steel has a low specific heat and a high thermal conductivity. Simply stated, this means that under the effects of a fire it will heat rapidly and heat will be conducted throughout the length of a steel member or component.

One of the effects of temperature rise is the accompanying thermal expansion. A 10 m member subjected to fire will expand more than 50 mm. This will cause stress distortion and cracking of the adjacent structure. The axial load on a column forced out of position laterally may easily be converted to an eccentric load.

At temperatures up to 400° C, steel retains its cold-strength; above this, loss of strength is rapid. The critical temperature is accepted as 550° C which is a comparatively low temperature where building fires are concerned. Failure is almost certain if the temperature rises further than 550°; at which level steel has already lost more than 50% of its original strength.
For these reasons, steel is considered to have no fire-resistance and must be protected at all times.

ALUMINIUM

There are many reasons why aluminium is not generally used for structural purposes. Only some of them concern its fire resistance.

Structurally, aluminium is unsuitable because its critical temperature is only about half that of steel and its thermal expansion is twice that of steel.

It is not suitable for use in fire doors or shutters because its melting point is 660° C: whereas an extreme fire may generate temperatures of 1500° C.

GLASS

Clear glass will readily transmit heat radiation; it may also shatter at an early stage. Consequently, the use of glass in fire-resisting construction is the subject of stringent regulations.

Toughened glass would seem to be ideal for the purpose. Unfortunately, it becomes de-toughened at temperatures as low as 300° C.

Glass blocks in panels up to 2400 x 2400 mm only have a fire resistance rating of ½ hour.

Where glazing is necessary in fire resistance construction it must be in wired glass or electro-copper glazing. The size of the glazed panel is also strictly limited, by building by-laws.

PLASTICS

The production of plastic materials has recently doubled about every six years and a considerable proportion of this has gone into building construction. Hydro-carbons, from which plastics are made, are all combustible and, none are suitable for use at temperatures above 120° C.

The presence of plastics in a fire is likely to constitute a hazard to occupants or firefighters and some highly flammable ones will assist to spread the fire rapidly or at least increase its severity. Polyurethane, to cite one example, is used in considerable quantities in paints and insulating foams. In a fire it releases the highly toxic hydrogen cyanide gas. Other plastics produce choking fumes, dense blinding smoke, and other toxic gases such as phosgene.

Many victims have died from gas without being affected by the fire itself.
16.5 FIRE PROTECTION OF STRUCTURAL STEEL FRAMING

Building regulations specify the fire resistance ratings for all structural components in a building. These usually vary from $\frac{1}{2}$ hour to 4 hours according to the type of building, the nature of the component, its position in the building and so on.

Protection of a steel frame can be achieved by:

- a solid casing of concrete, brick or blocks
- lightweight casings of plaster or building boards.

SOLID CASINGS

The most commonly used method of protecting steel is a casing of concrete cast around beams and columns. The concrete casing is usually reinforced with small section reinforcing bars or mesh to restrain shrinkage cracking of concrete and to ensure a firm bond around the steel. The cover of concrete around the steel members is the thickness of concrete measured from the face of the concrete to the face or extreme edges of the flange of members. The cover of concrete required by regulations varies with the use of the building and its size from half an hour to four hours as set out in the building regulations.

The concrete casing around structural steel bonds to the steel and acts with it under load so that the concrete casing bears some of the stress induced under load.

LIGHTWEIGHT CASING

Various proprietary lightweight fire protection casings to steel employ:

(a) building boards of plaster or compressed asbestos cement

(b) solid plaster applied to expanded metal wrapped around the steel work;

(c) lightweight building blocks around the steel to which plaster is applied.

Plasterboard and Compressed Cement Sheeting

Plasterboard is fixed around the steelwork with metal clips or screwing and finished with gypsum plaster. Compressed cement sheeting can be used in the same way, finished with proprietary corner beading. See Figure 16.3.
SYSTEM 1

2 Hour Fire Rated 13mm Gyproc Super Fyrchk

Steel Column

38mm Steel Stud

25mm Screws at 300 cts.

Gyproc corner bead

Gyproc Casings

Figure 16.3

Solid Plaster Casings

Expanded metal with metal angle beads is wired around steelwork and covered with vermiculite plaster. The metal angle beads afford protection to the vulnerable arrises and provides a surface to which the plaster is finished. This type of finish affords excellent fire protection and has sufficient mechanical strength against all but the hardest knocks.
Fire Protection for Structural Steelwork

*Figure 16.4*

*(Figures 16.4 and 16.5 are reproduced with permission from "The Construction of Buildings", Volume 4, by R. Barry.)*

**Lightweight Concrete Blocks**

The blocks are built around the steelwork and finished with plaster as illustrated in Figure 16.5. The fire protection rating is low using this method.

*Fire Protection for Structural Steelwork  Lightweight concrete block casing*

*Figure 16.5*
<table>
<thead>
<tr>
<th>Encased Columns</th>
<th>Minimum thickness in mm. for a fire resistance of</th>
<th>Encased Beams</th>
<th>Minimum thickness in mm. for a fire resistance of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>2</td>
<td>1/2</td>
</tr>
<tr>
<td>1/2 cover</td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
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<td>50</td>
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<td>50</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>32</td>
<td>19</td>
</tr>
</tbody>
</table>

Fire Protection - Columns and Beams

Figure 16.6

16.6 FIRE RETARDANT PAINTS

Fire retardant paints may be applied by conventional methods: brushing, spraying or by the use of a roller, to obtain the required paint thickness.

Once applied to the structure, the liquid applied membrane provides an insulating layer, in which, in the case of a fire, the coating softens and expands to form a thick cellular layer of incombustible foam, protecting the structure from intense heat.
Chapter 17

ROOF STRUCTURES

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17.2 STRESS AND STRAIN

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MANSARD TRUSS
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FABRICATION AND TERMINOLOGY
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CHOICE OF ARCH SHAPE
CONNECTION DETAILS
ADVANTAGES OF GLUED LAMINATED CONSTRUCTION
DISADVANTAGES OF GLUED LAMINATED CONSTRUCTION

17.12 PLYWOOD BOX BEAMS

DESIGN CONSIDERATIONS
COMPONENTS
FABRICATION OF BOX PLYWOOD BEAMS

17.1 ROOF CLASSIFICATION

As in floor construction, roofs are classified under the following:

- Single
- Double
- Triple

In a single roof the roof covering is carried directly on the rafter.

In a double roof, the rafter, when spans are excessive, relies on under-purlins supported by the inner walls, or purlins for a sheet roof on top of the rafter.

In a triple roof, the under purlin, having no support medium, relies on the introduction of a third member - a truss or trussed girder.

Trusses or roof structures may be constructed from a number of mediums:

- Steel
- Timber - Laminated Arches, Gang Nail, Plywood
- Concrete - Pre-stressed Concrete

or a combination of steel and timber and known as a Composite Truss, steel members.
17.2 STRESS AND STRAIN

When a load or force is applied to a member, it causes the fibres to be stressed. This stress tends to produce a strain, which is an alteration in the shape or form of the member. If this strain is too great, the material will fracture.

The chief stresses found in trusses are tension, compression, cross or transverse stress, and shearing.

*Tension* - is a stress that tends to pull the fibres assunder, as in the case of a member used as a tie; for example, a king rod or tie beam.

*Compression* - is a stress which tends to crush the fibres as when a load is applied to a post or strut.

*Cross*, or *Transverse Stress* - is caused when a load is placed in such a manner that it tends to bend the member, as in the case of a beam supporting a load.

*Shearing* - is a force that tends to push or slide one portion of the fibres past the other. When shearing is longitudinal or parallel with the grain in timber it is called detrustion; for example - at the end of a tie beam; the force exerted by the principal rafter tends to slide off the portion of the tie beam left on for the abutment of the rafter.

**BEHAVIOUR OF TIMBER IN BENDING**

Stresses within a beam increase as the transverse load increases; the bending moments produce tension on one side and compression on the other. See Figure 17.1.

![Beam Stresses](Figure 17.1)

The neutral plane moves towards the tension face and the tensile stress increases until failure results. See Figure 17.2.

![Tension Failure](Figure 17.2)
17.3 TRIANGULATION

It has been stated that the triangle is the only polygon which does not alter under load until it is broken. Figure 17.4 (a) shows a rectangle which can be racked or distorted by pressure at one of its angles. The addition of a diagonal brace as in 17.4 (b) will prevent this distortion. The brace turns the rectangle into two triangles.

17.4 COMPOSITE TRUSSES

Composite trusses combine both timber as compressional members and metal as tensional members (mostly wrought iron bolts). The king bolt or king rod truss is the best known. The rod is used to replace the king post and a straining sill used for the feet of the struts. The upper end is secured by a fitted metal head on top of the principal rafters. However, because a ridge cannot be secured on top of this plate very well, purlins are used near the apex for the roofing material, or if common rafters are used, they are secured at the top with a ridge in the ordinary way.

The tie beam should rest on a concrete template to distribute the load and be bolted securely to it. The tie beam should be supported along its length at a distance of not more than 4.5 m.

The principal rafter should be supported at not more than 2.4 m centres.

Span - The distance over all the loadbearing walls.

Mean Span - The distance between the walls.

Effective Span - The distance between the centre-lines of supports.

17.4
17.5 ROOF TRUSS TYPES

Roof trusses are plane frames consisting of sloping rafters which meet at the ridge, a main tie connecting the feet of the rafters, and internal bracing members. They are used to support roof covering in conjunction with purlins, these being secondary members laid longitudinally across the rafters and to which the roof covering is attached. See Figure 17.6.

The arrangement of the internal framing of a roof truss depends upon its span. Rafters are normally divided into equal panel lengths and, ideally, the purlins should be supported at the panel joints (see Figure 17.7) so that the rafters are subjected only to axial forces. This is not often practicable, however, because the purlins spacings vary with the type of roof covering being used and it is quite usual for purlins to be supported between panel joints (see Figure 17.8) so that the rafter members have to be designed to withstand local bending action in addition to axial forces.
17.6 TRUSS SHAPES

Figure 17.9 shows a line diagram of a King Rod Truss. This truss is limited to spans of under 9 metres because the tie beam has only one support in its length.

King Rod Truss

Figure 17.9

Figure 17.10 shows a Saw Tooth Truss. These trusses are also known as South Light Trusses. The vertical portion of the truss is glazed, either with fixed or movable sashes, and faces south, so as to get light, without the direct rays of the sun.

Saw Tooth Truss

Figure 17.10

The truss shown in Figure 17.11 is known as a Mansard Truss. The Mansard is a type of roof with two pitches employed to economise in space, as the sides of the lower portions are nearly vertical and the upper slope relatively flat to avoid an acute ridge. Spans average about 10 metres.
TRUSSED BEAMS

Are beams which are used for long spans or where considerable depth is available. The compression stresses are taken by the timber, and the tension stresses by the steel rods.

Mansard Truss

Figure 17.11

Trussed Beams

Figure 17.12
Truss Framing for Various Spans

Figure 17.13

17.8
17.7 TIMBER CONNECTORS

The use of timber connectors has been applied to all types of timber trusses and has made possible the construction in timber of certain types of large-span trusses previously considered practicable only in steel. It has also led to the design of special large-span trusses for timber construction. Large-span trusses suitable for timber construction, with timber connectors, are shown in Figure 17.13 (e) and (f).

Timber connectors are devices for increasing the joint strength in timber structures. They make it possible to develop greater loads than bolts or nails in the limited space of overlapped members in a joint. The several types of connectors are shown in Figure 17.15. Installation of these connectors consists of either placing them in pre-cut grooves or daps or forcing them into the wood by pressure.

The purpose of these notes is to illustrate the fundamental steps necessary for installing timber connectors. Each job depending on its size, facilities available and the number of identical pieces to fabricate - will determine how the systems should be modified. A small number of trusses or structural units can usually be laid out and fabricated following the general procedures shown. For a large number of identical units, templates or gang-boring machines will be found advantageous.

SPLIT RINGS (Figure 17.15)

Split ring connectors are steel rings with a tongue and groove break or 'split' in the metal band. Manufactured of mild steel, they are available in 65, 100 and 160 mm diameters. The connectors fit into pre-cut grooves and are used only for wood-to-wood connections. The split in the ring permits simultaneous bearing of the ring against the core and the wood outside the core spreading the load over as large an area as possible.

TOOTHED RINGS (Figure 17.15)

Toothed ring connectors are toothed metal bands with each tooth 'corrugated' or curved along its cross sections to give greater rigidity. Manufactured of 1.6 mm steel they are available in 50, 70, 80 and 100 mm diameters. These connectors must be embedded in wood by pressure. They are used only in wood-to-wood connections and usually only in lighter structural members. Hydraulic jacks offer an efficient method for installing toothed rings where a large number of joints are to be assembled. They should be combined with special yokes or C-clamps to provide complete joint closure. A single bolt joint will require a 2.5 to 3.5 tonne jack. A 50 tonne jack is recommended for a joint with two bolts.

Where fewer joints are to be assembled, the high strength rod assembly illustrated, Figure 17.14 is recommended. The assembly consists of a high-strength rod with Acme threads on one end, double-depth nuts, ball bearing thrust washer, heavy plate washers.
and lock washer and nut. Metal sleeve adaptors permit the use of 10, 15 or 20 mm rods with a standard ball bearing washer. The length of rod required equals the total thickness of the wood members plus 25 mm for each layer of toothed rings plus 125 mm for nuts and washers. Ratchet wrenches will help speed assembly and impact wrenches have also been used with success.

Figure 17.14

SHEAR PLATES (Figure 17.15)

Shear plates are circular metal plates with a flange on one face around the perimeter. The 60 mm diameter shear plate is pressed steel and the 100 mm diameter shear plate is malleable iron. They fit into pre-cut daps so they are flush with the wood surface. Shear plates are used in wood-to-wood connections where demountability is desired, or in wood-to-steel connections such as footing anchor straps, gusset plates or strap-and-pin connections.
GROOVE TO SUIT SPLIT RING IN BOTH PIECES OF TIMBER

SPLIT RING CONNECTOR

GROOVES TO SUIT SHEAR PLATE CUT INTO TIMBERS

SHEAR PLATE CONNECTOR

SINGLE FLANGED SHEAR PLATE

TIMBER TO TIMBER CONNECTION

DOUBLE FLANGED SHEAR PLATE

TIMBER TO TIMBER CONNECTION

TIMBER TO STEEL CONNECTION

DOUBLE SIDED TOOTHED RING

TIMBER TO TIMBER CONNECTION

SINGLE SIDED TOOTHED RING

TIMBER TO STEEL CONNECTION

Timber Connectors

Figure 17.15

17.11
Trip-L-Grip framing anchors are formed of 1.2 mm, zinc-coated, corrosion resistant, sheet steel. Anchors are of three types as illustrated, with each type available in lefts and rights.

Trip-L-Grip Framing Anchors

Figure 17.16

Full-bodied, trip-L-grip nails are furnished with anchors. These nails are designed to provide maximum shear without splitting the timber. They provide a drive fit when driven through the holes provided.

Trip-L-grips are installed by the carpenter on the job with his usual equipment. Illustrated at Figure 17.17 are a few of the many applications.
17.8 STEEL TRUSSES

Steel in trusses resists tension forces with a minimum cross-sectional area of material. If a steel member is used in compression (top chord), then it must be sufficiently large enough to withstand the load imposed without developing excessive deflection or bending.
The minimum thickness of sealed steel tubes should generally not be less than:

(a) 4 mm for external construction exposed to the weather.
(b) 3 mm for construction not exposed to the weather.
(c) 6 mm for structures not readily accessible for maintenance.

Trussed or Lattice Girders - may be used where a low pitch is required and may have parallel chords or the top chord pitched or curved where a low pitch is required.

Where the chords are parallel it is known as a Parallel Chord Truss.

Trussed or Lattice Girders may be in the form of a U.B. and are generally not economical for spans exceeding 11 m although this may be extended by castellating the beam.

Figure 17.18
The economic depth of a trussed girder or parallel chord truss is 1/6 to 1/10 the span and therefore owing to the depth of the truss at the point of connection to the column the joint can be comparatively rigid.

Parallel chords may be used in a sawtooth roof construction (sometimes referred to as South Light Roofs, as mentioned earlier).

A Monitor Roof employs to a very large extent parallel chords or trussed girders.

![Monitor Roof](image)

*Figure 17.19*

In order to provide the necessary rigidity against lateral wind pressure, a knee brace must be introduced to produce a stiff or rigid joint between the column and roof truss. Provided the joint at the base of the column is non-rigid, the stress will be zero at the base and a maximum at the knee brace.

The tendency of this type of brace is to make the unit act as a whole.

An alternative is to introduce an eave girder at the bottom chord level which reduces, unlike the knee brace, any stress in the truss. This does not act in the same way as the knee brace and to be effective the building must not be too long or alternatively divided at intervals with cross walls.

**WIND BRACING**

All steel framed skeleton buildings should be windbraced. There are no hard and fast rules of calculations available; however, the theory applied is that any skeleton framework which has no party walls, or other means of stabilisation, should be adequately braced to resist wind loadings.
Figure 17.20 diagrammatically illustrates the methods generally adopted. The salient points to note are:

1. That the wind-loading is transmitted from the ridge to the bases via the diagonal brace from the ridge to the toe of the truss and, then, either perpendicularly or diagonally to the foundation.

2. That each end bay is braced on three sides.

3. That intermediate bays are braced as required, usually every third bay.

---

Bracing on far side of building not shown. Generally for both walls and roof-brace each end bay and then every third bay. Ends of building must also be braced and if a door intervenes use alternative bracing.

Figure 17.20
Portion of Tubular Steel Truss

Figure 17.21

17.17
17.9 PORTAL FRAME CONSTRUCTION

The characteristic of this type of construction is the continuity of the structure due to the stiff or rigid joints and as direct results less material and more open area underneath are achieved.
Portal Frames

Figure 17.23

A portal frame rigidly fixed to its footings can be compared with a beam structure simply supported on two columns.

Deflection

Bending

Typical form

Simply supported beam

Figure 17.24

Deflection

Bending

Typical form

Rigid frame

Comparison of Rigid Frame and Beam Construction

Figure 17.25

It can be seen that the bending in the beam in the portal frame is transferred through the rigid joints to the columns. There is little or no bending in the columns of the beam structure and only a single curve deflection in the beam, but there is considerable variation curvature in the rigid frame. The points at which the direction of curvature changes (that is the points of contra-flexure) are points at which there is no bending moment and at which the bending stresses in the members change. This can be seen in Figure 17.25. It is in these areas where stiff junctions of beam and columns in the rigid frame are zones at which the bending are large. In contrast, there are no bending moments at the unrestrained junctions between columns and beam in the beam structure.
These differences in stress distribution produce differences in form. In the beam and column structure, the columns may be comparatively light and the beam quite large to cater not only for the dead loading but also bending or transverse shear.

In the rigid frame, stresses at the top of the columns will often be greater than those at the base, requiring a greater amount of material at that point. See Figures 17.27 and 17.28.

As with the knee-brace construction, the stiff joints between columns and beam in the rigid frame provide lateral rigidity.

**FIXED OR HINGED PORTALS**

The fixed or hingeless portal is a fixed-base frame with feet rigidly secured to the footings and with all other joints rigid. Bending moments are less and more evenly distributed in this than in other types, but a moment or rotational tendency is transferred to the footings. See Figure 17.26 (a).

Pined frames: In these types, hinge joints are introduced at the base to relieve the footings of any tendency to rotate, and make the frame simpler to design and erect.
Portal Frame Layout - Rafter to Column

Figure 17.27

Detail A of Welded Knee Joint and Fascia Cleat

Detail B of Bolted Apex Connection

Typical Bolted Variations of Knee Joints

Figure 17.28
17.10 NAILED AND RIVETED TRUSSES

During comparatively recent times, the Commonwealth Experimental Building Station developed a series of short span, light-weight roof trusses that were suitable for domestic roofing.

After extensive experimental and test programs, two types of truss systems were produced using small sections of Australian hardwoods which were suitable for tiled or sheeted roofs. Two methods of joining the truss members were used. The first method employed the use of lapped and cleated connections between the truss members which were secured with 62 mm b/head nails. This method is suitable for factory or on-site production and is known as the 'nailed truss system'.

![Nailed Roof Truss Diagram](image)

_Nailed Roof Truss_

_Figure 17.29_

_(Courtesy of the Technical Schools Division, Education Department of Victoria.)_

17.22
The second method used light sheetmetal gusset plates which were placed on both sides of each connection and secured by riveting through the timber. This method is more suited to factory production than for construction on-site, and is known as the 'riveted truss system'. The riveted truss is the prototype of the modern roof truss, where all members lie in the same plane; there is no overlapping of members, and no special jointing is required between the truss members, the ends being 'butted' together with a simple angle cut.

**Riveted Roof Truss**

*Figure 17.30*

(Courtesy of the Technical Schools Division, Education Department of Victoria.)
GANG-NAIL ROOF TRUSS

The gang-nail roof truss system is rapidly gaining acceptance as an effective alternative to on-site roof construction. This truss derives its name 'gang-nail' from the patent gang-nail connector plate which is used to connect the various truss members. The connectors are high tensile steel plates from which a number of nail-like spikes have been punched out at right angles to the plate itself. (See Figure 17.31.) When correctly placed, and firmly pressed into the timber, the gang-nail connector provides a simple and effective joint between the truss members. While there are other types of connector plates available, the gang-nail truss system is the one most commonly used today.

Applications of Gang-nail Truss Systems

Gang-nail truss systems are designed by the fabricator’s own engineers to suit the roof slope and the roof profile specified in the builder’s plan. A licensed truss fabricator can produce trusses to suit a wide range of roof designs, from simple gable and saw tooth roofs to hip and valley roofs. Gang-nail truss systems can also provide an economical roof for certain types of industrial buildings where the manufacturers claim that they can compete favorably in price with steel truss systems.

Figure 17.31
(Courtesy of the Technical School Division, Education Department of Victoria.)

TIMBER FOR ROOF TRUSSES

The strength of the timbers chosen for any design depends on the region in which the truss is manufactured.
At the factory the timber is graded visually and timber possessing any of the following defects is rejected: Sloping grain, knots, felling faults, sapwood, splits, excessive spring, brittle heartwood.

In Australia where unseasoned hardwoods are commonly used in the manufacture of roof trusses, the common thickness of all truss members for domestic roofs is generally 38 mm. Top and bottom chords and web members are 125 mm and 100 mm wide. However, variations to these sizes will occur according to the type of timber used, the imposed roof loads, and the type of truss design.

FABRICATION AND TERMINOLOGY

Truss Terminology

Figure 17.32
17.11 GLUED LAMINATED CONSTRUCTION

Lamination is the process of building up comparatively thin pieces of timber into larger members which may be either straight or curved. The pieces are bonded together with glue, or sometimes with mechanical fastenings. The grain of the laminates is parallel, in contrast to plywood in which the grain alternates with each lamination.

Most laminated construction involves the use of members in which the laminates are laid horizontally. This enables the members to be curved and allows the design of segmental or parabolic arches which are in themselves economical structural forms and in addition have aesthetic appeal.
Laminated construction also simplifies the design of fixed joints in such members as portal frames, thereby gaining economy through continuity in the structure. This method also allows the fabrications of beams of greater length and cross-section than would be possible in solid timber. Spans of 50 m are not uncommon in laminated construction, while one bowstring truss in America spans 80 m.

With laminated construction the effect of defects on the strength of a beam decreases as the number of laminates increases. The consistency in strength which thus may be obtained enables higher working stresses to be assumed for a given grade of timber than would be permissible if the member were solid.

Components may be built up to any desired length or cross-section and members may be tapered or moulded to give the greatest strength where it is most needed.

Arrangement for Clamping Straight Sections in the Laminating Process

Figure 17.34

(Figures 17.34, 17.36, 17.37 and 17.38 are reproduced with permission from 'Heavy Timber Construction' by F. Oberg)

Lamination allows the designer to mould timber to the dimensions and shape best suited to his purpose. The resulting structural forms are clean, efficient and often beautiful. If required, as is often the case in church interiors, a fine finish can be given to the structural members.

Laminated timber has a special advantage in its high resistance to fire. The great heat of a destructive fire can cause steel to distort or collapse while, under the same conditions, timber beams may merely char and still retain a major part of their original strength with little or no distortion.
When compared with steel, timber has a very high resistance to heat absorption and a low co-efficient of expansion, which can prove of great assistance to a designer. A laminated bowstring arch, 30 m in length, is said to have less than 1/20th of the movement under expansion of a steel arch of the same dimensions, and would not require pivoted or sliding base plates to take up expansion.

The resistance of wood to corrosion by such agents as steam or acid fumes offers another great advantage in the use of laminated members in factory construction. In illustration, the laminated arches in a dye factory in New South Wales, were found to be unaffected by steam and sulphuric acid fumes which, in four years, seriously damaged the steel fittings in the roof structure.

Texada Mines - Potash Storage Shed, Cape Cuvier (West. Aust.) The world's largest hardwood building, constructed of 24 twin portal arches. It has a span of 41 m, a length of 112.78 m and a maximum height of 23 m. Seven hundred rock anchors are used to secure the structure to a solid rock cliff 32 m above sea level. The completed building is designed to withstand wind velocities up to 240 km/h. Glue laminated Jarrah was selected for the project because it does not deteriorate when subjected to the highly corrosive effects of potash.

Figure 17.35

(Courtesy of Bunnings Forest Products Pty. Ltd.)
In the fabrication of large members, the individual pieces of timber can be of comparatively short length and small cross section. This facilitates seasoning. Also, high grade timber is not necessary in the fabrication of large members, though some qualitative selection is advisable in certain of the component laminates to ensure maximum efficiency.

Any timber which can be glued satisfactorily can be laminated, and the thickness of the laminations can vary from 1 - 25 mm or more. For general building purposes the usual thickness used in Australia is 19 mm and the width of the laminations 100 mm. The timber used must be free of doze and not susceptible to attack by borers. Moisture content should not exceed 12 per cent. In the case of curved members the thickness of the laminations depends on the radius to which they will bend, fifty times the thickness being a reasonable minimum. The gluing surfaces should be dressed uniformly flat and parallel. Mis-cut and tapered pieces must be discarded. Casein or cold setting synthetic resin glues are generally used; animal glues are not recommended.

![Glue Spreader in Operation](image)

**Figure 17.36**

Moulds or forms on which the laminations are laid up and pressed are usually of wood, rigid enough to withstand the pressure without distortion. Large structural members such as arches can be made up on blocks or posts set at intervals along the curve, but smaller members are best made on continuous moulds. Sufficient pressure should be applied to the laminations to ensure uniform, close contact with the gluing surfaces, and this should be checked with dry laminations before glueing up. Pressure may be applied by bolts, clamps, screw or hydraulic presses, or band cramps. With clamps or bolts, care should be taken to distribute the gluing pressure and to prevent local distortion or crushing.
Gluing should not be carried out in the open air, though sometimes this cannot be avoided when large members have to be fabricated on site. Most water-resisting glues have a short working life, and are subject to a sudden setting reaction when exposed to draught and/or heat. The best practice is for all gluing to be carried out in the factory where draught and humidity can be kept under control.
SELECTION OF MATERIAL FOR STRUCTURAL MEMBERS

Some of the material should be of a good grade. In the case of flexural members such as beams and stringers, at least one third of the total volume of timber should be of high quality. This material should be divided equally between the extreme tension and compression faces. The remainder of the flexural members may contain timber of lower grades.

It is not considered the best practice to mix back-cut and quarter-cut timber in the same laminated member because expansion through moisture changes differ considerably in the radial and tangential directions and mixed timber is conducive to the occurrence of secondary stresses within the laminated timber.

JOINTING LAMINATIONS

Edge-Jointing of Laminations

It is not practical to construct very large laminated members without employing two or more boards to make up the required width of lamination. For instance, a laminated member 300 mm width can be fabricated by using boards of nominal 150 and 200 mm widths, dressed on the edges to a nett width of, say 140 and 160 mm respectively. In order to avoid the occurrence of a cleavage plane running completely through the member, it is customary to stagger these edge joints in each successive lamination.

End-Jointing Laminations

Tests have shown that plain scarf joints give results that are quite satisfactory and it is not usually necessary to employ more complicated forms of joint. The steeper the slope of the plain scarf, the less efficient will be the glued joint. If the laminations are considered as acting in tension, a plain scarf joint of a slope of 1:12 will give 90 per cent efficiency. However, if the joint is fairly close to the neutral axis of the beam, a steeper slope may be used. Finger jointing may also be used, if available, giving 75 per cent of the strength of the timber.

![Detail of Scarf on Laminate](a)

![Finger Jointing](b)

**Figure 17.39**

[CC BY - Attribution]
CHOICE OF ARCH SHAPE

The ability to manufacture curved glue laminated members has made possible the construction of graceful arches for assembly halls, storage sheds and buildings for storage of corrosive chemicals.

The type of arch chosen depends upon span and the function of the building.

In domestic, church and school architecture exposed laminated arches have been used to good effect. Requirements for industrial buildings involve aesthetics to a lesser degree.

For medium spans a three pin arch such as that shown in Figure 17.40 may be suitable and convenient for transport if each half is capable of being delivered in one piece.

The pin connection at the apex enables the two halves to be separated without the need for a splice; the structure is statically determinate.

Long spans may require splices for transport purposes and may be two or three pin type arches. Very large span three pin arches of the type shown in Figure 17.41 have been constructed using glue laminated members.
CONNECTION DETAILS

ARCH PEAK. When the vertical shear is too great for one pair of shear plates, or when deep sections would require extra shear plates for alignment, additional pairs of shear plates centred on dowels or through bolts may be used.

ARCH PEAK. For arches with slopes such that excessively long through bolts would be required, shear plates may be used in conjunction with a tie plate and through bolts. When appearance is a factor, a bent plate may be recessed into the top of the arch and secured with coach screws.

OUTRIGGER CONNECTION TO CURVED ARCH. Post and outrigger are let into the arch surface. Do not feather ends of post or outrigger.

OUTRIGGER CONNECTION TO HAUNCHED ARCH. Coach screws used in this connection should be as long as possible. Do not feather arch end of outrigger.

TIE ROD TO ARCH SHOE. Thrust due to vertical load is taken directly by the tie rod welded to the arch shoe.

ARCH SHOE WITH EXPOSED ANCHOR BOLTS. Thrust is taken by the anchor bolts in shear into the concrete.

TRUE HINGE ANCHORAGE FOR LARGE ARCHES. Recommended for long span, deep section arches where true hinge action should be considered.

Figure 17.42
(Courtesy of Bunnings Forest Products Pty. Ltd.)

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ADVANTAGES OF GLUED, LAMINATED CONSTRUCTION

(a) Ease of fabricating large structural elements from standard commercial sizes of timber.

(b) Excellent architectural effects can be obtained.

(c) Freedom from defects associated with large, one-piece wood members - in that the laminations are thin enough to be readily seasoned before fabrication.

(d) Members can be designed on the basis of the strength of seasoned wood.

(e) The opportunity to design elements that vary in cross section along their length in accordance with strength requirements.

(f) Future timber economy (large structural members built up from smaller pieces).

Example

The two cross-sections of timber beams illustrated below to the same scale show a 350 mm x 100 mm natural dry jarrah beam and the equivalent 323 mm x 75 mm laminated jarrah beam which will both carry the same load over the same span.

The laminated beam shows a reduction in cross section of approx. 31%. This is made possible in two ways.

Figure 17.43

DISADVANTAGES OF GLUED LAMINATED CONSTRUCTION

Unfortunately, however, there are a number of disadvantages to this jointing medium which may take some time to overcome. Generally, it is necessary to use fully seasoned timber, to consider the relative shrinkage of timbers glued together, to exercise rigid control over machining of members to uniform thickness, and over the mixing and application of the glue.
Consideration must also be given to temperature, and the application of adequate pressure during glue setting. In many cases, also, insufficient information is available on simple and satisfactory methods for design of joints, so that, for important structures, proof-testing of the trusses may be necessary. Because the value of a laminated product depends upon the strength of the glue joints, the process requires special equipment, plant facilities and fabricating skills not needed to produce solid green timbers.

17.12 PLYWOOD BOX BEAMS

In many buildings there is a need for stiff, long span members to serve as strutting or ridge beams, as lintels over wide windows and doorways, as upper floor joists, and the like. Plywood box-beams are very suitable for such purposes as they can be readily made of adequate strength and stiffness with simple equipment, are light in weight, and easy to handle and install.

(a)  Box Beam  
(b)  Double I-Beam  
(c)  I-Beam

Description of Beams

Figure 17.44

DESIGN CONSIDERATIONS

Where appearance is important, the box beam with its flush sides is often preferred to the I-beam, but, under adverse exposure conditions where deterioration is possible, the I-beam has the advantage that all parts of it are open to inspection.

There are two methods of connecting the plywood webs to the timber flanges and stiffeners.

The first, and what would be described as the traditional method, is by gluing using a rigid permanent adhesive. The second method is a modern innovation which utilises nails only as the connector.
COMPONENTS

Timber Flanges and Vertical-Stiffeners

The material for flanges and stiffeners should be seasoned to at least the equilibrium moisture content of the locality where it is to be used, and in any case not over 12% for resorcinol based glues or 15% for casein glues.

The following table (Table 17.1) shows, stress grades and sizes of timber flanges and stiffeners for use in lintel, strutting and combined strutting and hanging beams.

**TABLE 17.1**

<table>
<thead>
<tr>
<th>TYPE</th>
<th>STRESS GRADES</th>
<th>DIMENSIONS, (SIZES) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unseasoned hardwood</td>
<td>F11, F14</td>
<td>75 x 50, 75 x 75, 100 x 50, 100 x 74</td>
</tr>
<tr>
<td>Seasoned hardwood</td>
<td>F14, F17</td>
<td>63 x 40, 85 x 40, 108 x 40</td>
</tr>
<tr>
<td>Seasoned softwood</td>
<td>F5, F8</td>
<td>70 x 45, 90 x 45, 90 x 70, 90 x 90</td>
</tr>
</tbody>
</table>

Plywood Webs

All plywood is to be entirely from strength group C or D species. The thickness of the ply depends on the span of the beam and the load imposed upon it.

17.36
FABRICATION OF BOX PLYWOOD BEAMS

Stiffeners of the same cross-sectional dimensions as the flanges should be placed at the ends of the supports and at the positions of any concentrated loads. Additional stiffeners the same width as the flanges may need to be provided, depending on the shearing forces at bearing points, to give support to the ply webs.

The joint between the flanges and stiffeners is a butt joint and made with nails only. Flanges must not be notched to take stiffeners.

Flange Joints and Web Splices

If full-length timbers are not available for the flanges, some form of jointing is necessary. The best joint for this purpose is a glued scarf joint with a scarf slope of 1 in 12 in the tension flange and not less than 1 in 8 in the compression flange. Butt joints may be adopted to save the cost of fabricating scarf joints.

Jointing of Seasoned Flanges

Figure 17.46

Webs are also preferably scarf-jointed. However, butt joints may be quite effective if adequate cover plates are glued over both sides of the joint. Where butt joints occur, both plywood sheets must be nailed to the stiffener as detailed and must be staggered each side of the beam.
Requirements for Nailed Beams

Fabrication Requirements for Glued Beams

Timber flanges must be dried and dressed. The adhesive must be of the resorcinol or epoxy type. Pressure may be achieved by pressing, clamping, nailing or stapling.

Fabrication Requirements for Nailed Beams

The nails used must be corrosion resistant (e.g. galvanised coated or plated) and have a flat head. Nails are to be a minimum length of 38 mm. The nails are to be spaced at 50 mm centres on the centre line of the flange. In seasoned flanged beams it is good practice to stagger the nails about the centre line by 6 mm. See Figure 17.47.
Chapter 18

FLAT ROOFING

18.1 INTRODUCTION

18.2 MATERIALS
   BITUMEN
   FELT

18.3 THERMAL INSULATING MATERIALS

18.4 SURFACE FINISHES

18.5 LAYING
   BONDING
   MOVEMENT
   DRYING OUT
   CONDENSATION
   FIRE RESISTANCE

18.6 TIMBER FLAT ROOFs
   METHODS OF FORMING FALLS
   FLAT ROOF COVERING OF BUILT-UP ROOFING FELT

18.7 CONCRETE FLAT ROOFs

18.8 BUILT-UP ROOFING WITH STRAMIT DECKING

18.9 STRUCTURAL STEEL FLAT DECKING

18.1 INTRODUCTION

A flat roof consists of a suitable timber or concrete deck covered by a waterproofing membrane. A timber deck usually consists of tongue and groove flooring over rafters whose size is determined by their span and spacing. For all types of construction the fall should not be less (preferably more than) 25 mm in 2 metres.

A suggested waterproofing membrane is bituminous felt which usually consists of layers of felt, laid to break joint and bonded together with thin layers of bitumen, poured on whilst hot. Two or three layers of felt may be used: in Australia this is referred to as built up felt roofing.
Orthodox felt roofing and asphalt roofing are closely related in their materials and applications. Many companies lay both products and some proprietary systems combine some of the features of both.

Built up roofing is very dependent on correct detailing, specification and workmanship rather than just the quality of the materials used. It is, therefore, important that the work should always be done by a contractor experienced in this type of work, and, because supervision is very difficult.

18.2 MATERIALS

BITUMEN

Bitumens for use in built-up roofing are derived from the distillation of some crude oils. The bitumens will vary in hardness and in the temperature at which they soften.

Penetration grade bitumen, which is the basic form, is sometimes used as a saturant for the felt. Oxidised bitumen is used as a coating for the felt and as the bonding compound. Oxidation makes the bitumen more rubber like in consistency and raises the melting point. Cut-back bitumen has volatile solvent added to increase workability and is used for the dressing compound for roofs with stone chippings.

FELT

The two main types used in built-up roofing are:

- bitumen felt with fibre base
- bitumen felt with glass fibre base.

These two classes can be further subdivided as follows:

(a) fibre-based
- saturated
- fine sand surfaced
- self finished
- coarse sand surfaced
- mineral surfaced
- reinforced
(b) glass fibre-based

- fine sand surfaced
- mineral surfaced
- venting base layer

The manufacture of the fibre-based felts consists mainly of two operations: saturation and then coating of the felt. Saturated felts are not impervious. Glass fibre felts are made by a different method and are not saturated before coating.

Glass fibre felts are preferable to organic-based felts because they are less likely to contract and ripple if the felt becomes wet and they are also more resistant to decay. However, the life of the felt roof may depend on other factors before the felt itself shows any serious deterioration.

The use of organic fibre-based felts is not recommended for the lower layers of a built up felt roof in damp climates, because they tend to hold moisture and may cause blistering.

Glass fibre felts have been in use for more than ten years. They differ in material content and in the manufacturing process. One characteristic is that they appear to have less 'body'; although this is not necessarily a disadvantage it is not recommended for vertical upstands. Each type of felt is further divided according to the different weights which are available.

18.3 THERMAL INSULATING MATERIALS

An insulating material is often laid directly under the felt and this work is best carried out by a specialist.

Fibreboard and cork are commonly used, but both, are likely to rot if they become wet; cork has the greater resistance. Where there is a risk of these materials becoming wet, for example, from humidity in the building - a vapour barrier should be used.

Dry insulating boards used in conjunction with built-up felt roofs have many advantages in addition to their thermal insulating value.

Very good results have been achieved by using boards of extruded polystyrene, a material which offers a closed cell structure with hardly any moisture or vapour absorption and commonly placed under the roof finish.

The insulating material must be fairly dense to withstand foot-traffic and handling during construction; it must also be able to withstand the lifting effect of the wind. When used over metal roof decking it must be able to span between corrugations and care must also be taken to see that absorbent materials are not exposed to the weather during construction.
Proprietary makes of insulating boards for the thermal insulation formed of extruded expanded polystyrene, expanded polyurethene, expanded glass and many more materials more or less suitable are available. The suitability for the purpose will be dictated by the specific requirement and cost.

Thermal insulating layers need to be -

- resistant to the heating/cooling cycle (i.e. durable)
- resistant to moisture, permeability
- resistant to point loadings, impact strength
- responsive to initial heat in application; melting or softening point
- resistant to thermal movement and compatible in behaviour with adjacent materials
- easy to fix, work, lay and bond.

Because of the low breakdown temperature of polystyrene, felt cannot be fixed and covered by conventional methods. One method is to use pre-coated bituminous felt and bond this to the polystyrene using transfer heat. In this case, sufficient heat is generated by a hot bitumen coating applied to the top of the felt to bond the following layer. Thus the heat transferred will be sufficient to soften the pre-coated medium under the first layer and pressure applied to the second layer will ensure an adequate bond between the first felt and the insulation.

18.4 SURFACE FINISHES

The surface of a built-up roof should fulfil some or all of the following functions:

- give a reflective surface
- protect the bitumen from sunlight
- provide a wearing surface
- provide a loading coat to withstand lifting by the wind
- improve the appearance of the roof.

Stone chippings are commonly used on roofs up to a roof slope of 1 in 6. A wide range of sizes is used; 10 to 13 mm is the most common. The best reflective surface is achieved if the chippings are light in colour. Stone chipping surfaces are only suitable for very infrequent foot traffic. The chippings are laid in a dressing coat of cut-back bitumen which may be either hot or cold applied.
On sloping roofs it is necessary to use a prepared mineral-surfaced felt. The size of these mineral granules is relatively small and several colours of this felt are available. Mineral-surfaced felt is sometimes treated with silicones to prevent water rising up the outer surface.

If a flat roof is to be used frequently, a better wearing surface must be provided and several proprietary types are available. The finish may be of concrete tiles, in-situ cement screed divided in 500 mm squares, or bitumen macadam. Precaution is necessary to prevent interaction between the movement of the roof and the tiles.

18.5 LAYING

BONDING

All layers of the built-up roof may be fully bonded. 50 mm laps should be made at each side with 75 mm end laps. On sloping roofs, each layer must be started at the bottom of the slope to lap properly.

Normally, three layers of felt are specified on flat roofs. Two layers are normal on sloping roofs, although three will be more durable. The bottom layer of felt may be only partially bonded to the roof deck by spot or strip sticking or frame bonding. It is not necessary to use partial bonding on fibre-insulating board, cork or compressed straw slabs. Partial bonding of the bottom layer may also be undesirable in situations exposed to very high winds. This may help to prevent tearing of the felt caused by movement of the deck and will help to prevent local build up of pressure beneath the felt. On timber boarded roofs, the first layer of felt will be nailed to the boards.

Flat roofs are extremely sensitive to the effects of wind forces (suction). It is considered good practice to rely on a combination of bonding techniques in the built up roofing in more exposed wind conditions. In this case, insulating layers (thermal and vapour insulating layers) should not only be bonded with bitumen to previous layers but in addition, should be fastened to the sub structure with shot fired fixings, stud weld fixings to the metal deck or screwed down securely to these decks. Fasteners dipped in bitumen or sealers before application will ensure a hermetically sealed vapour barrier.

MOVEMENT

Movement of the roof deck may be classed as structural, thermal, or moisture movement. In this respect, reference is made to the dangers deriving from solar heat gain which can cause movement in the thermal insulation layer. Following are the figures of thermal expansion for some of the commonly used thermal insulation materials.
### TABLE 18.1

<table>
<thead>
<tr>
<th>Insulation Materials</th>
<th>Thermal Expansion in mm/m°C</th>
<th>mm/m 100°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense polyurethane</td>
<td>0.06 to 0.25</td>
<td>6 to 25</td>
</tr>
<tr>
<td>Cork</td>
<td>0.10</td>
<td>10</td>
</tr>
<tr>
<td>Extruded polystyrene</td>
<td>0.06</td>
<td>6</td>
</tr>
<tr>
<td>Insulation Board</td>
<td>0.05</td>
<td>5</td>
</tr>
<tr>
<td>Foamed Phenolic Resin</td>
<td>0.03</td>
<td>3</td>
</tr>
<tr>
<td>Boards of expanded mineral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>fibre</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>Foamed glass</td>
<td>0.008</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Thermal movement will be reduced by a reflective finish - for example, light-coloured chippings on the roof - and a thermal insulation material above the deck.

Moisture movement of the screed will be reduced by careful control of the mix and water content, and it is helpful if time can be allowed for shrinkage before fixing the felt.

Where fibre-board is incorporated in the built-up roof, it will help to absorb small movements. This is common practice for light decking, especially metal decking.

Details in Figure 18.1 show three types of movement joint.

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Movement Joints

*Figure 18.1*

18.6
**DRYING OUT**

Water trapped below the felt roofing during construction is liable to cause blistering of the felt when the water vapour expands in hot weather. There are several methods of reducing this risk.

With lightweight screeds (which need special care), drying out during construction will be assisted if holes are made through the roof slab at low points in the surface. Where there is a risk of absorption of rainwater during building, absorbent materials must obviously be laid on the roof for the shortest possible time before the waterproof finish is applied.

**CONDENSATION**

Condensation may, in conditions of humidity, cause the same symptoms as water trapped during construction; a vapour barrier is then necessary.

One of the controversies in roofing centres round the problem of how to prevent condensation, or the leaching of water vapour into the thermal insulation. It is often desirable to provide a venting base layer in the built up finish itself to allow water vapour to escape.

This type of felt has coarse mineral granules on the underside to allow pressure release. The felt has small holes at close intervals so that when the bitumen is applied above it goes through the holes and grips the deck.

An even better method is to envelop the thermal insulating layer top and bottom with venting layers - the lower layer is perforated for ease of bonding the upper layer of felt which is stuck on by dots of bitumen at 100 mm centres. Both systems - single venting layer or double venting layers - should be connected to vents in such a way as to allow for free release of excess vapour pressure.

**FIRE RESISTANCE**

If stone chippings are used as a topping, all felt roofs will have a high fire rating. On sloping roofs with mineral-surfacd felt, the fire rating will vary according to the type of each layer of felt and the combustibility of the roof deck.

Even on combustible decks it is possible to obtain a satisfactory fire rating by using asbestos felts or asbestos in conjunction with glass fibre.
18.6 TIMBER FLAT ROOFS

When level flat roof structures are required, the main roof joists are set level and falls for the roofing are formed in a variety of ways. See Figures 18.4 to 18.10.

There are three main reasons why the joists may not be set 'off-level' and to a fall corresponding to that required to ensure a proper drainage of water from the roof to the gutters:

1. A ceiling is required to be level and made so without any special, and what can be costly, method of 'framing-down' from an off-level structure to achieve the result.

2. The flat roof structure may eventually be required to form a floor if a storey is added by removing the roofing materials and boarding, etc. and building up on the old walls.

3. The flat roof structure may be an old one and it is required to reconstruct the roofing, either because it is defective or because a modern roofing material is to be used to form a verandah or sun deck.

METHODS OF FORMING FALLS

Probably the most common method is as shown in Figure 18.2 where firring pieces are nailed on top of the joists. The firring pieces should be accurately sawn. The boarding will run at right angles to the fall which is not so good as running in the direction of the fall.

Figure 18.3 shows a good method by using small section bearers which, running across the fall, cause the boarding to run in the direction of the fall, thereby ensuring that if any of the boards do warp and twist and the edges rise or sink a little above or below adjoining boards, the fall will not be affected adversely. The bearers, in this case, are of different thicknesses to suit the fall and their depth must be set out with care so as to make sure that the boarding laid on them is the required fall and that none of it be uneven.

![Diagram of Timber Flat Roofs](attachment:image.png)

Methods of Forming Roof Falls

Figure 18.2
FLAT ROOF COVERING OF BUILT-UP ROOFING FELT

It is assumed that a roof structure with its boarding, which is correctly designed, is of adequate strength and will not deflect excessively, and is laid to proper falls according to specifications. At least two layers are essential for waterproofing flat or slightly pitched roofs.

Figure 18.4 depicts two layer roofing with a fibre roofing felt underlay and with a cap (top layer) sheet of 2-ply roofing felt or other desired quality. The material is laid with its length running in the direction of the fall of the roof with 50 mm side laps, the laps of the underlay not coinciding with those of the cap sheet, as shown by plan in Figure 18.4. The underlay should be random-nailed to the boarding at 150 mm centres with 20 mm galvanized clout nails, the nailing starting from the centre of a sheet and working outwards to the edges and laps. The cap sheet is laid with its length in the direction of the fall and with 50 mm side laps. It is not nailed, but is wholly attached to the underlay with an asphalt compound applied hot or mastic of the same compound used cold, and the laps are sealed with the same material. In the case of three layer work, an extra underlay is used which is adhesed to the lowest underlay, care being taken to ensure that the side laps do not coincide with those of the lower and upper layers.
Built-up Roofing

Figure 18.4

18.10
18.7 CONCRETE FLAT ROOFS

For many types of buildings, houses, flats, shops and industrial work, there is a preference or a need - because of fire-resisting requirements - that the structural roof be of reinforced concrete. As this is not weatherproof, a suitable roofing is necessary to make it so. The roofing may, or may not, be subject to use for many purposes by pedestrian or other traffic.

The structural concrete roof must be designed in accordance with proper codes of practice and the by-laws regarding dead and imposed loads.

The type of roofing shown in Figure 18.6 is very economical and effective for non-usual roofs, and two-layer work is generally accepted as suitable. The underlayer must be spot cemented or adhesed to the concrete roof with a compound recommended or supplied by the manufacturers of the felt.

Details of finishes at parapet, eaves and vent pipes are shown in Figures 18.5 (a), (b), (c), (d) and (e).

Figure 18.7 shows a roof suitable for traffic, made of built-up felt roofing which is protected by a layer of tiles.

Figures 18.8 shows the components which allow for all ordinary needs of flat roof work. Examples of the practical uses of the components are shown in Figure 18.7 and Section AA. The tiles and components are normally laid in bitumen over standard built-up felt roofing. The upstand of coving tiles may be adhesed direct to the brickwork with bitumen or a compound. Although seldom necessary, the upstand may have a felt, lead or other suitable metal flashing extending about 50 mm down the tiles and tucked 25 mm into the joint of the brickwork, wedged if necessary and then pointed.
BUILT UP ROOFING DETAILS

a) PARAPET WALL DETAIL

b) VENT PIPE DETAIL

c) GUTTER DETAIL

d) STOP EDGE DETAIL

e) EXPANSION JOINT DETAIL

f) ROOF DRAIN DETAIL

Figure 18.5

18.12
Concrete Roof Set to Fall of 1 in 40 with Built-up Felt Roofing

Figure 18.6

Concrete Roof not set to Fall. Screeding to Fall of Fine Concrete Covered with 50 mm Tiles

Figure 18.7

Standard Coving Tile 300 mm long
Standard Eaves or Verge Drip Tile 600 mm long
Standard Bull-Nosed Tile

Figure 18.8
18.8 BUILT-UP ROOFING WITH STRAMIT DECKING

Verge may be formed as shown dotted, in which case stramit may have to be cut to width to suit joists, or latter rearranged to suit 12 m width of boards.

50 mm thick stramit with shower-proof liner
Ruberoid roofing with underlay fully adhered to stramit (not nailed)

Skirting Joists running off-level with fall of roof
Level

NOTE: If joists are level firings to falls would be necessary

Build-Up Felt Roofing on Stramit Decking

Figure 18.9

This system is shown in Figure 18.9 and the roofing should conform to the same principles as explained for concrete roofs. The underlay is fully stuck to the stramit decking.

18.9 STRUCTURAL STEEL FLAT DECKING

Structural steel decking can be used as a combination of formwork and reinforcement to floor slabs and built-up roofing applications.

30 32 32 32

52

200 200 200 200

600

Profile of ‘Bondek’

Figure 18.10

As with all roll formed profiles the decking can be made to any length but 12 metres is considered the practical limit. The metal decking functions as a water tight formwork for concrete, and the triangular ribs act as positive reinforcement in one direction. The long length panels enable large areas to be covered quickly and easily without specialist labour.
When used as a plain steel deck the panels are usually fixed 'ribs down' over structural framework. Insulation layers can be fixed over the flat surface and a built-up roofing membrane then applied over the insulation.

Another type of metal decking is made in the form of structural steel panels, which are available in a wide range of profiles; a typical shape is shown in Figure 18.11.

![Steel Panel Profile](image1)

*Figure 18.11*

Functional and economical roofs are achieved by using the panels with the ribs laid up, insulation laid between the ribs and insulation board placed over the decking and topped with bituminous felt roofing. See Figure 18.12.

![Insulation of Steel Panel Roofing](image2)

*Figure 18.12*
Chapter 19

STAIRWAYS, RAMPS AND FIXED LADDERS

19.1 INTRODUCTION AND FUNCTIONS

PART A - STAIRS

19.2 BASIC PLANNING PRINCIPLES
19.3 STAIR LAYOUT AND DESIGN
19.4 STAIR DIMENSIONS AND PARTS
19.5 MATERIALS OF CONSTRUCTION

PART B - RAMPS

19.6 INTRODUCTION
19.7 RAMP FINISHES

PART C - FIXED LADDERS

19.8 INTRODUCTION
19.9 TECHNICAL DETAILS

PART D - GLOSSARY OF TERMS

19.1 INTRODUCTION AND FUNCTIONS

The principal functions of stairs, ramps and fixed ladders are as follows:

(a) to provide convenient access to different levels within buildings and structures;

(b) to ensure safe egress from all areas in the buildings during emergency evacuation procedures, such as explosions or fires.

This study is most essential as a guide to interpreting the regulations governing acceptable standards of design and construction of Stairs, Ramps and Fixed ladders. The loadings for these facilities should conform to the requirements of the floors to which they give access.
Stairs, ramps and fixed ladders are all means of vertical access with prescribed limitations in the angle of inclination. Figure 19.1 illustrates the recommended safe angles of slope for each type of vertical access, and also indicates the unsafe zone between inclinations of 45° and 60°.

![Recommended Safe Angles of Slope](image)

**Figure 19.1**

Various methods can be applied to describe the required angle of inclination for stairs, ramps and fixed ladders:

(a) Stairs are usually set out from prescribed dimensions representing the rise and going for a particular stair, as shown in Figure 19.2 (i.e. Rise = 165 mm Going = 260 mm).

![Stairs](image)

**Figure 19.2**
(b) Ramps are generally described as having a rise proportional to their length, as 1 in 8 (i.e. 1 metre in 8 metres).

\[ \text{RAMP SLOPE} \]
\[ \text{ANGLE} \]
\[ \text{LENGTH} \]
\[ 8000 \text{ mm} \]

Ramps

\[ \text{Figure 19.3} \]

(c) Fixed ladders are erected at prescribed angles as 60° to 90°.

Because of the specific functional requirements of each type of access facility, stairs, ramps and fixed ladders will be studied separately, as follows:

- Part A  Stairs
- Part B  Ramps
- Part C  Fixed ladders
- Part D  Glossary of terms

PART A - STAIRS

19.2 BASIC PLANNING PRINCIPLES

The building regulations specify suitable proportions for step design to reduce fatigue and improve public safety. Treads and risers should remain constant in proportion and dimension throughout individual flights. Isolated steps are not permitted, and the number of steps in any flight is limited to a maximum of 18 risers.

The widths of stairs and landings must comply with the local authority by-laws, and provide adequate headroom. Winders, or tapered steps, should be avoided wherever possible, and only ever installed above a floor or landing. Landings and treads should have a non-slip surface, and door openings should not be situated close to the head of stairs.

HANDRAILS

- are required on one side of stairs less than 1500 mm wide and both sides of wider stairs;
• an intermediate handrail is required where the stair exceeds 2040 mm wide;

• must be continuous with no obstruction to break a hand hold;

• must comply with bylaws for minimum height above landings or stairs.

Balusters or rails should be spaced to prevent a child getting its head caught (125 mm maximum).

19.3 STAIR LAYOUT AND DESIGN

Considerable variations occur in the design, construction and finish of stairs, according to their materials of construction basic functional requirements. However, all stairs could be considered according to aspects of their layout, as illustrated in Figure 19.4.

Straight flights are the simplest form of stairs; they occur in single flights or in parts of more complex stair arrangements. Refer to Figure 19.4 (a).

Quarter-turn stairs change direction 90° by either incorporating a landing (as ‘D’ and ‘F’) or winders (as in ‘E’ and ‘G’). Note that the illustrations in 19.4 (e) and (f) all contain two straight flights, plus a landing or winders.

Half-turn stairs change the direction of ascent by 180° from the base of the stair, as illustrated in details (b), (c), (h), (j), (k) and (l) of Figure 19.4. In details (b) and (h) the inner strings of both flights are placed vertically in line between the newels, and these stairs are termed ‘dog-leg’. In the remaining half-turn stairs the strings and handrails are separated to form an ‘open-well’ or vertical space between each flight. Note that in (b) and (h) the winders have been placed immediately above a landing, but in details (e) and (j) they present a potentially dangerous situation.

Bifurcated stairs comprise a series of straight flights arranged to provide access in more than one direction. This design enhances the foyers of many public buildings and places of entertainment.

Geometrical stairs are either helical in form for circular stairs, or contain circular or wreathed portions linking the straight parts of flights. The steps may be constructed with either ‘closed risers’ or ‘open risers’ between pairs of curved strings, or consist of cantilever treads supported on a central spine beam.
Types of Stairs

Figure 19.4

19.5
19.4 STAIR DIMENSIONS AND PARTS

The Uniform Building By-Laws stipulate the minimum and maximum dimensions which determine the rise and going of stairs. However, comfort and safety may impose stricter control of stair design for the young, the elderly and disabled persons, as Figure 19.5 (a). An extreme example of tread and riser proportions suitable for escape stairs, is illustrated in 19.5 (b).

![Low-Pitch Stairs](image)

**Figure 19.5**

Rise and Going

In the majority of situations an average step rise is obtained from the total rise, and a suitable going dimension can be determined from the by-laws. Refer to Figure 19.6.

![Stair with Proper Riser-Tread Ratio](image)

**Figure 19.6**
PROPORTIONS OF STEPS

Many formulas have been used to determine suitable proportions for steps and stairs. The formula now in general use is $2R + G = 585 - 630$. (2 x rise-of-step plus going of step = 585 mm minimum, up to 630 mm maximum.) This rule is based on the assumption that the effort required for ascending a step is equal to twice the effort needed to step forward the same distance. An increase in rise will reduce the going and vice versa. For example, for a step having 170 rise and 280 going $2R + G = x$, $(2 \times 170 + 280 = 620)$.

The effective width of treads may be increased by a maximum of 25 mm through the inclusion of nosings or sloping risers, as shown below:

![Diagram of stair treads with nosings and sloping risers]

**Tread Details**

**Figure 19.7**

For further details of the stipulations and limitations on stair design refer to Part 24 of the *Uniform Building By-Laws*.

The various components of stair construction are illustrated in Figure 19.8 and described in the Glossary of Terms (Part D) of this Chapter.
Parts of Stair Construction

Figure 19.8

19.5 MATERIALS OF CONSTRUCTION

The basic characteristics or functions of a stair may directly or indirectly determine the most suitable materials of construction. Solid timber stairs are economical to construct and can be mainly pre-fabricated away from the site. 'Glu-lam' (glued and laminated) construction provides an attractive finish that is often incorporated in spine-beam stairs.

Metal stairs are generally employed for external escape routes on the walls of buildings, and in areas of limited space such as mezzanine floors. Concrete stairs provide a high resistance to fire and are economical to construct with low maintenance requirements. These stairs may be cast in-situ within formwork on the site, or precast in specialised works and delivered to the site.

A modern trend in stair design is to combine multiple materials in a single 'composite' stair. Composite stairs may combine metal strings with timber or precast concrete treads, or in-situ concrete strings and precast concrete treads. A simple design consists of preformed metal fans set out in brick walls as permanent forms for in-situ concrete treads.

Figure 19.9

(Source: A Glossary of Building and Planning Terms, 2nd edn., 1978.)
Concrete Stairs

Reinforced concrete is a popular material for stairs and ramps because of its inherent strength and fire resistance, and because of the variety of forms possible. Precasting is usually restricted to individual treads or steps to be fixed to steel carriages or to be built into walls. In-situ work, because of its monolithic nature, is not restricted in shape or by requirements of jointing.

Continuous Slab Stair

Figure 19.10
Composite Stair Details

Figure 19.11
PART B - RAMPS

19.6 INTRODUCTION

A ramp is an inclined walkway replacing steps or stairs for vehicular traffic, land trolleys, prams and wheelchairs. Ramps may be constructed of timber, metal or concrete, and must provide a surface with a non-slip finish.

The gradient of ramps varies from 1 in 6 to 1 in 10 according to the particular situation and degree of slip-resistance surface. Where a ramp is essentially required to provide egress, a maximum ratio of 1 in 8 slope is specified in the building by-laws. However, a maximum gradient of 1 in 12 is required for the final 3650 mm of an outgoing vehicle ramp from a building, approaching the roadway.

The Main Roads Department has designed a standard kerb ramp to assist disabled persons in wheelchairs, or mothers with prams. It consists of a maximum slope of 1 in 6, with a step not exceeding 25 mm in height. See Figure 19.12 (a).

\[\begin{figure}
\centering
\includegraphics[width=\textwidth]{ramp_diagram}
\caption{Ramps for Disabled}
\end{figure}\]

(Courtesy of the Commonwealth Experimental Building Station.)
19.7 RAMP FINISHES

Ramp surfaces should be stable, firm, regular and relatively non-slip under all weather conditions.

Methods of obtaining non-slip surfaces are:

(a) In-situ finishes such as concrete and bitumen should have a textured finish. A rough broomed finish arc-shaped across the ramp is preferred. Figure 19.13 (a).

(b) Brick or masonry tile units use only materials with abrasive or textured finish. Joints across the ramp to be raked to a depth of 5 mm maximum and have a width of 5 mm. Joints in the direction of the ramp to be preferably flush. See Figure 19.13 (b).
Masonry Unit Paving for a Ramp

Figure 19.13 (b)

(c) Timber ramps should be constructed with timber slats laid across the ramp. Spacing between slats should be between 3 and 5 mm. Slats for external ramps should be less than 75 mm wide, preferably toothed in profile to provide a better grip. See Figure 19.13 (c).

Timber Finishes for a Ramp

Figure 19.13 (c)

PART C - FIXED LADDERS

19.8 INTRODUCTION

The need for occasional vertical access for operating, inspecting, or servicing personnel does not warrant either the cost of a conventional stairway, or, more especially, the space that would have to be allocated. Such access is usually provided by fixed ladders. These may be in the form of step-type, rung-type or individual rung ladders. Requirements for ladders are covered in the Australian Standards.
STEP-TYPE LADDERS

Step-type ladders are used at angles between 60 and 70 degrees, although overseas recommendations permit angles between 50 and 75 degrees. The vertical distance between landings should not exceed 6000 mm; where it does exceed this value, alternate ladders which change direction or are staggered should be used. Tread width shall not be less than 100 mm, with a slip-resistant surface. Treads shall be spaced not less than 200 mm and not more than 250 mm apart. The width of step-ladders shall be at least 450 mm, and handrails shall be provided on either side. See Figure 19.14 (a).

RUNG-TYPE LADDERS

Rung-type ladders are used at angles above 70 degrees. The width between stiles shall be at least 350 mm and should not exceed 550 mm. Rungs of mild steel shall have a diameter of at least 20 mm, and rung spacing should not be less than 250 mm and not more than 300 mm. In certain circumstances a ladder cage may be required; dimensions are given in the Australian Standard. See Figure 19.14 (b).

INDIVIDUAL RUNG LADDERS

Individual rung ladders are a special type of vertical fixed ladder with rungs attached permanently by welding or by being built in to the adjoining structure or equipment. Individual rung ladders should not be used where the vertical rise exceeds 6000 mm, and the clearance of rungs from their wall surface shall be at least 200 mm. Metal rungs of at least 24 mm diameter shall be spaced not less than 250 mm and not more than 300 mm apart.

It should be noted that, in relation to the example shown the Australian Standard calls for the rungs to be so shaped that the foot cannot slip off the end of the rung, and suggests a 25 mm drop for the shaped portion. See Figure 19.14 (c).

Ladder Types

Figure 19.14
19.9 TECHNICAL DETAILS

TABLE 19.1

<table>
<thead>
<tr>
<th>LADDER TYPES</th>
<th>Step-type</th>
<th>Rung-type</th>
<th>Individual Rung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>60° - 70°</td>
<td>70° - 90°</td>
<td>90°</td>
</tr>
<tr>
<td>Width between stiles</td>
<td>450 mm min.</td>
<td>380 - 540 mm</td>
<td>-</td>
</tr>
<tr>
<td>Rise of steps</td>
<td>200 - 250 mm</td>
<td>250 - 300 mm</td>
<td>250 - 300 mm</td>
</tr>
<tr>
<td>Tread width</td>
<td>100 mm</td>
<td>19 mm</td>
<td>25 mm</td>
</tr>
<tr>
<td>Rung diameter</td>
<td>6000 mm</td>
<td>6000 mm</td>
<td>6000 mm</td>
</tr>
<tr>
<td>Vertical distance to landing</td>
<td>200 mm</td>
<td>200 mm</td>
<td>-</td>
</tr>
<tr>
<td>Clearance from wall</td>
<td>required</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Handrails</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 19.1 shows the characteristics of each of these. In addition, when the height exceeds about 6 000 mm, ladders should be enclosed by a safety cage, as in Figure 19.15.

Figure 19.15
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balusters</td>
<td>Upright members of a balustrade</td>
</tr>
<tr>
<td>Balustrade</td>
<td>The protective enclosure to a landing or flight of stairs, consisting of handrail, string, newels, and balusters. It may, alternatively, be panelled.</td>
</tr>
<tr>
<td>Cantilever Treads</td>
<td>Supported from a spine-beam central in a stair.</td>
</tr>
<tr>
<td>Carriage Piece or Bearer</td>
<td>Inclined bearers usually of rough timber at least 125 mm x 75 mm, used to provide support to the centre of steps where they exceed about 900 mm. Brackets (cleats) are nailed to the top or sides of the carriage.</td>
</tr>
<tr>
<td>Dog-leg Stair</td>
<td>A half-turn stair with the strings of consecutive flights vertically above one another in the same newels.</td>
</tr>
<tr>
<td>Fire Isolated Stair</td>
<td>A stairway protected against fire as required by by-laws.</td>
</tr>
<tr>
<td>Fliers</td>
<td>Parallel steps in a straight flight.</td>
</tr>
<tr>
<td>Flight</td>
<td>A continuous set of steps between floor and floor or landing.</td>
</tr>
<tr>
<td>Geometrical</td>
<td>Curved stairs usually designed without newels.</td>
</tr>
<tr>
<td>Going</td>
<td>The horizontal measurement between the outer edges of two consecutive treads (going of step); or, the total horizontal distance covered by the stair measured between the outer edges of the first tread and landing or floor at the head of the flight (going of flight).</td>
</tr>
<tr>
<td>Gradient</td>
<td>Slope or pitch, angle of inclination. It can be measured in four ways.</td>
</tr>
<tr>
<td>Headroom</td>
<td>The clear vertical distance between the line of nosings and the nearest obstruction above 2 m minimum.</td>
</tr>
<tr>
<td>Landing</td>
<td>A platform between two flights of stairs. It may be a quarter-space landing - as found in quarter turn stairs, or between two straight flights - or half-space as in half-turn stairs. (See Figure 19.4 (c), (d), (h) and (k).</td>
</tr>
<tr>
<td>Line of Nosings</td>
<td>Also called a pitch-line. A line touching all the nosings (edges of all the treads) in a flight.</td>
</tr>
<tr>
<td>Margin</td>
<td>The measurement between the line of nosings and the top edge of a string.</td>
</tr>
</tbody>
</table>
Midrail
A rail midway between string and handrail and parallel to them, in lieu of balusters.

Newel
A post supporting a handrail, often extended downwards to ground or floor to form the main supports for stairs (newel stairs).

Open Newel
Half-turn stairs with an open well.

Pitch
See gradient.

Rise
The vertical distance between the upper surfaces of two consecutive treads, or between consecutive floors (or landings).

Riser
The vertical timber (or concrete, steel, etc.) closing the space between two treads.

Soffit
The undersurface of a flight or landing.

Spandrel
The triangular section formed when a wall is built up below a string.

Special steps
are decorative steps used at the bottom of a staircase. They include bullnosed, round-end, curtail, and commode steps.

Spiral
Composed entirely of winders radiating from a central newel.

Spine Beam
The treads are supported entirely by a central exposed carriage piece.

Steps
A step consists of a rise and a going, or, a riser and a tread.

String
The inclined beams on each side of a flight to which treads and risers are fixed. They are referred to as wall string, outer string, and may be wraithed.

Tread
The horizontal member of a step.

Undercarriage
See carriage piece.

Winder
A tapered step.

Wreath
A curve as seen on plan; wreathed string or handrail.
Chapter 20

MASTONRY AND NATURAL STONE

20.1 INTRODUCTION

20.2 CLASSIFICATION OF ROCKS
   PHYSICAL CHARACTERISTICS
   CHEMICAL COMPOSITION
   GEOLOGICAL CLASSIFICATION

20.3 SPECIES OF STONE
   GRANITE
   BASALT
   QUARTZ
   SLATE
   SANDSTONE
   LIMESTONE
   QUARTZITE
   LATERITE
   MARBLE
   RE-CONSTRUCTED STONE

20.4 PROPERTIES OF STONE
   CHARACTERISTICS
   OTHER FACTORS

20.5 MASONRY BONDS

20.6 FINISHES FOR BUILDING STONES

20.7 MAINTENANCE OF STONWORK
   CLEANING
   PRESERVATION

20.1 INTRODUCTION

Natural stone masonry was once a principal form of construction for loadbearing walls to buildings both in Australia and overseas. Many fine examples of masonry construction have survived centuries of exposure, to remind us of the extremely high standards of workmanship and materials.
In Perth, natural stone masonry is preserved in many historic buildings including:

- Parliament House, West Perth
- Post Office building in Forrest Place
- Commonwealth Bank in Forrest Place
- Museum Buildings
- Many fine churches.

Stone masonry is still a common material of construction for low rise buildings, engineering projects, retaining walls, ornamental and monumental works. However, there are many factors which restrict the use of masonry in loadbearing construction of large buildings, including:

- the inherent weakness of individual stones resulting from quarrying, transportation and handling;
- the increased cost of transporting stone over vast distances;
- the cost of worked stone masonry compared with viable alternative materials;
- restrictions imposed by building regulations due to the risk of damage or injury when:
  
  (a) the stones are capable of exuding toxic fumes (as during a fire)
  
  (b) spalling, which may occur due to sudden changes in temperature (as during a fire, when sprayed with fire hoses).

Today, the facades of many, large, modern buildings display a masonry appearance with 'reconstructed' panels of stone. This exposed-aggregate concrete is usually precast in thin-walled panels for facings, veneers, claddings and infill panels. Many varieties of local and imported masonry have been selected and provide attractive and durable wall finishes.

20.2 CLASSIFICATION OF ROCKS

For purposes of identification and comparison, rocks may be classified by several differing methods, including the characteristics of:

- physical appearances
- chemical composition
- geological formation.
PHYSICAL CHARACTERISTICS

The physical characteristics of rocks vary considerably in appearance from stratified layers, granular, crystalline or a glass-like appearance. Their structure varies from fine to coarse-grained, porous to dense, and durable to a liability to decomposition. The compressive strength of rocks can vary from almost nil to well in excess of 40 MPa.

CHEMICAL COMPOSITION

The chemical composition of rocks is generally very complex. Strength, durability and porosity depend on the type of base material, the quantity and type of binder, and the intensity of pressure which compacts the grains. Silica is the main constituent, and produces the strongest and most durable stones. Other binding substances include calcium carbonate, iron oxide, and clay.

GEOLOGICAL CLASSIFICATIONS

These are:

- igneous
- sedimentary
- metamorphic

according to the way in which they are formed.

(a) *Igneous* rocks are those that have been formed by the consolidation of a molten mass, such as the natural cooling of the earth's crust, or of lava, ejected by volcanic action. Common examples are granite and basalt.

(b) *Sedimentary* rocks, such as sandstone and limestone, are formed, with minor exceptions, by water-borne deposits of rock particles. The material usually results from the disintegration of igneous rocks; it is consolidated by pressure and bound by a cement.

(c) *Metamorphic* rocks have undergone a change in structure or chemical composition. It is sometimes difficult to determine whether the original rock was igneous or sedimentary. Typical rocks in this classification are marble - which originated from limestone - and slate which started as clay, became shale, and finally slate.
20.3 SPECIES OF STONE

GRANITE

These are igneous rocks composed of three minerals: feldspar, mica and quartz. After solidifying slowly under enormous pressure, the minerals have formed into the crystalizing structure characteristic of granite.

The usual colour of granite is grey, ranging from nearly white to almost black. Minor variations in chemical composition, however, can produce red, pink, brown, blue and green.

Granites are among the heaviest, strongest and most durable of rocks. They weigh about 2.6 t/m³, with crushing strengths exceeding 200 MPa. A wide variety of face finishes is possible, including gloss polish which will resist deterioration for tens of years in heavily contaminated atmospheres.

Low thermal expansion, no moisture movement, a comparatively high (for stone) tensile strength and the ability to be cut into thin slabs (for example, 25 mm) make granite suitable for use as facing slabs. Its hardness, however, while it limits the effects of vandalism, also raises working costs. As a consequence, it is common practice to use granite as aggregate for reconstructed stone which can be produced much more cheaply.

BASALT

A rather brittle, black volcanic rock with similar physical characteristics but of unattractive appearance. It is, however, used in rubble feature walls, where the prominent mortar joints or other stone species provide interesting contrasts.

QUARTZ

A naturally white, glass-like, igneous rock which is often coloured by iron oxides, such as pink quartz.

SLATE

Normally grey - but sometimes blue or green - it is very dense, fine-grained, laminated rock capable of being split as thin as 5 mm.

SANDSTONE

This is a sedimentary stone composed of quartz grains. The most notable in south-western Western Australia is the Donnybrook stone which is a fine-grained cream to light-brown stone of about 2.2 t/m³. It is suitable for ashlar and delicate carving and has
been used in many Perth buildings. However, the 210 km between the
quarry and the metropolitan area market, prevents it from being
more extensively used.

LIMESTONE

Western Australian coastal limestone is a very porous, white to
cream rock of about 2.1 t/m³. It often results from sedimentation
of the skeletons of marine organisms. Because of its comparatively
low strength and porosity, it does not lend itself to veneer work;
However, its proximity to the city and coastal towns has made it
valuable for mass work such as footings and retaining walls. The
usual method of working is on-site with hand tools such as an axe
and a saw; because it is so easily worked, it is normally laid as
uncoursed ashlar or random rubble.

QUARTZITE

Toodyay quartzite is a highly ornamental easily worked, meta-
morphic stone found about 100 km from Perth. It splits easily,
almost like slate, and shows green and brown colouration on the
split face. The green colour is not stable in constantly wet
conditions, which eventually turn it brown.

The stone is used either as bookleaf walling or as veneer-facing.
Invariably, hand methods are used with the face left as it is
split.

LATERITE

This red-brown, sedimentary rock is found in the Darling Ranges,
either as rounded boulders or as massive rock. Although it is more
often used in roadworks, it has also been extensively used for
feature walls. Ease of working is not a characteristic feature of
laterite. Consequently, it is invariably laid as polygonal
rubble.

MARBLE

In constructional and decorative work, the term ‘marble’ is often
used to include any limestone capable of taking a high polish.
True marble is a limestone metamorphosed into a dense, moderately
strong stone which is readily worked or carved.

The natural colour is white; however, impurities, usually carbon-
aceous or ferrous (compounds of iron), produce black and a wide
range of irregular colourations.

The characteristics of marble warrant consideration.

(a) Although absorption is only slight, light marbles can be
stained by atmospheric dirt. This usually occurs adjacent to
horizontal irregularities such as recessed joints, where the
dirt is deposited and resists rain-washing.
(b) Marine and industrial atmospheres can attack and disfigure external polished surfaces.

(c) Marble has a very low rate of thermal expansion (0.000 004) but may be subject to residual or permanent expansion. To accommodate this, the allowance for expansion should be increased by 20%.

Western Australia has a deposit of marble in the Murchison district, about 850 km from Perth. Other varieties are imported from various parts of the world. It is not surprising, therefore, that it is not in common use.

RE-CONSTRUCTED STONE

This is essentially a high quality concrete, utilizing carefully selected aggregates and white, grey or coloured cement to achieve the appearance of natural stone.

Its chief advantage lies in the fact that it can be cast in any required shape or dimension, leaving only a minimum of work - such as grinding, polishing, bush-hammering - to be undertaken. Reinforcement and lifting and fixing furrules can be cheaply and easily incorporated.

Where heavy, precast elements are involved, the reconstructed stone is in the form of a 30 - 50 mm facing to the ordinary concrete. As this later is placed in the mould before the face concrete has set, there is no problem of bond between the two.

The terms 'cast stone', 'artificial stone', or 'synthetic stone' are also used to describe reconstructed stone.

20.4 PROPERTIES OF STONE

CHARACTERISTICS OF STONE AND STRUCTURAL MATERIALS

Design and practice in stone masonry and veneering must take into account the inherent properties of the selected stone. In veneer work, however, the problem of differential movement demands an appreciation of the properties of both the facing material and the structure.

1. Thermal expansion is common to all masonry materials but occurs at different rates.

2. Moisture movement - expansion occurs when moisture is absorbed, in many, but not all - masonry materials.

3. Long term permanent expansion or shrinkage occurs in marble and manufactured masonry products. Cement and lime products shrink, whereas clay products and marble expand.
4. **Creep** (a type of deformation under sustained load) occurs in most materials. The greater part of the movement takes place soon after the load is applied but may continue at a diminishing rate for an indefinite period.

5. **Compressive strength** is not normally a problem with masonry materials.

6. **Tensile Strength** of stone is comparatively low.

7. **Release of stresses**, when thin slabs are sawn from a large block release of stresses may result in bowing or cupping.

8. **Absorption** rates vary considerably and affect the resistance to frost, atmospheric staining efflorescence and the growth of moulds and lichens.

**TABLE 20.1**

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Expansion mm per °C</th>
<th>Moisture Expansion %</th>
<th>Ultimate Strength Mpa</th>
<th>Compressive Strength Mpa</th>
<th>Tensile Strength Mpa</th>
<th>Absorption % of Weight</th>
<th>Hardness (Mohs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>0.025</td>
<td>-</td>
<td>70+</td>
<td>over 70</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Steel</td>
<td>0.011</td>
<td>-</td>
<td>100+</td>
<td>over 100</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.011</td>
<td>0.35 Shrink</td>
<td>40</td>
<td>approx 4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Clay bricks</td>
<td>0.005</td>
<td>0.05 Exp.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Calsil bricks</td>
<td>-</td>
<td>0.15 Shrink</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Granite</td>
<td>0.008</td>
<td>Nil</td>
<td>70 - 200</td>
<td>up to 10</td>
<td>0.1 - 0.8</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Slate</td>
<td>0.018</td>
<td>Negligible</td>
<td>50 - 240</td>
<td>up to 100</td>
<td>over 1.0</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>Sandstone</td>
<td>0.011</td>
<td>0.65</td>
<td>17 - 100</td>
<td>up to 7</td>
<td>2.3 - 8.5</td>
<td>13</td>
<td>-</td>
</tr>
<tr>
<td>Marble</td>
<td>0.004</td>
<td>Nil</td>
<td>Exp.</td>
<td>70 - 200</td>
<td>up to 6</td>
<td>0.1 - 0.25</td>
<td>15</td>
</tr>
<tr>
<td>Dense Limestone</td>
<td>0.004</td>
<td>Nil</td>
<td>7 - 120</td>
<td>up to 8</td>
<td>2.4 - 13.0</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>Porous Limestone</td>
<td>0.003</td>
<td>0.08</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Glass</td>
<td>0.008</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**OTHER FACTORS**

As well as the characteristics of the stone, a number of other factors affect the performance of the masonry or veneer:

(a) **Structural deformation** will result from normal foundation settlement and applied loads. Depending on the type of foundation and other factors, most of this movement occurs during the erection of the structure but may continue over a longer period.
(b) Mortar for jointing or pointing is important. Over-strong mortars may spall or split the stone. As with brickwork, mortars should never be stronger than is necessary for their purpose.

Porous mortars will permit entry of water, especially to the backs of slabs. Among other things, this may promote efflorescence, staining and excessive moisture movement of the stone.

Shrinkage cracks in poor mortar will also admit moisture.

Excessively alkaline cements or impurities in the sands may promote staining of stone faces.

A common practice is to stop the mortar about 6 mm back from the face of the stone and paint the joint with non-staining mastic such as polysulphide synthetic rubber.

(c) Size of veneer slabs. This will depend on the fixing methods, type of stone and differential movement. The larger the slab, the greater will be the effects of differential movement, the likelihood of fracture, and problems of adequate fixing.

20.5 MASONRY BONDS

The arrangement of stones to tie them and to evenly distribute the loads is just as important in stone masonry as in brickwork.

The name of the bond is related to the face pattern which is largely determined by the shape of stones used. (See Figure 20.1).

- **Ashlar** is the ultimate in masonry. The stones are carefully and accurately brought square to permit thin neat joints down to 3 mm. (Figure 20.1 (a)).

- **Rubble work** utilizes either unworked or roughly squared stones with mortar joints of up to 50 mm. Though stones are required at intervals to give strength, the thickness of a rubble wall should be 1/3 thicker than an equivalent brick or ashlar wall.

- **Regular Coursed Rubble** can be compared to ashlar, in that stones must be of regular height although the workmanship and finish is rough. (Figure 20.1 (b)).

- **Rubble-Built to Courses** may be random, snecked or polygonal. The stone is roughly levelled to form a course at intervals of 300 - 1000 mm in height. (Figure 20.1 (c)).

- Squared or Snecked Rubble consists of roughly squared stones. It derives its name from the ‘snecks’ used to assist bonding. This is a common bond for coastal limestone walling. (Figure 20.1 (d)).
- Random Rubble requires squarish stones roughly bonded. (Figure 20.1 (c and f)).
- Polygonal Rubble is produced when stones are rounded or polygonal in shape.

(a) Ashlar
(b) Coursed Rubble

c) Squared Rubble in Courses
(d) Squared Rubble

(e) Random Rubble in Courses
(f) Random Rubble

Masonry Bonds

Figure 20.1

20.9
- *Bookleaf* consists of long, thin, flat stones usually less than 40 mm thick. Toodyay quartzite is frequently used for this work because it is readily split into thin layers.

**NOTE:** The shape of loadbearing stones is important. The length to depth ratio of soft stones should not exceed 3:1, and width/length ration 1:1 up to 2:1. The ratio for harder stones may be increased to 5:1 and 3:1 respectively.

![Images of Ashlar Dressings](image)

**Ashlar Dressings**

*Figure 20.2*

### 20.6 FINISHES FOR BUILDING STONES

A variety of face finishes, including glass polish, is possible on ashlar work. With coastal limestone, the usual finishes are rock-faced or sawn, because of the coarse nature of the stone. (See Figure 20.2).

Most facing veneers cannot take many of these finishes because of the likelihood of fracturing the stone. Normally, machine ground or polished finishes are customary:

**SAWN:** granular, saw-marked, varying in roughness depending on type of saw used

**SAND-BLASTED:** flat, non-reflective

**HONED or EGG SHELL:** smooth, non-reflection, velvety finish

**POLISHED:** reflective, mirror-glass

20.10
BRUSH-HAMMERED: similar to sawn, but without saw marks

20.7 MAINTENANCE OF STONEWORK

CLEANING

Soiling mars a building’s appearance as it hides the true colour of materials and obscures detailing. Urban grime, the most common form of soiling in cities, is typically soot and smut carried by wind from domestic fires, traffic exhausts, power stations, and many industrial processes. Various methods, differing widely in their effectiveness and their ability to cause damage, are used to clean the masonry of buildings.

Methods of Cleaning

(a) The dry method

Is where the surfaces are brushed with a wire brush or rubbed with a soft stone or carborundum blocks, and sandblasting.

(b) The wet method

The surfaces are washed with clean water only, or scrubbed down with sand, grit stone or carborundum in combination with water and high-pressure water spraying.

(c) Steam cleaning

Is where steam of about 400 KPa pressure is applied to the surface of the stonework in the form of a jet of steam through the medium of a steam brush.

(d) Chemical cleaning

Chemical reagents that are used commonly to assist in the removal of grime from masonry include organic solvents, detergents, acids, alkalis, and beaches. The general procedure is to wet the masonry surface, spray or brush on a minimum amount of chemical, allow it to act for a short time, and then wash it off.

PRESERVATION

Clear silicone liquids have helped to preserve the new appearance of exterior stonework. Clear waxes are useful on interior marble surfaces.
Chapter 21

THERMAL AND SOUND INSULATION

21.1 INTRODUCTION

PART A - THERMAL INSULATION

21.2 THE PROCESSES OF HEAT TRANSFER
CONDUCTION
CONVECTION
RADIATION

21.3 VALUES OF HEAT TRANSFER
THERMAL CONDUCTANCE
THERMAL CONDUCTIVITY
THERMAL RESISTANCE
THERMAL RESISTIVITY
THERMAL TRANSMISSION

21.4 METHODS OF REDUCING HEAT FLOW

21.5 TYPES OF THERMAL INSULATION

PART B - SOUND INSULATION

21.6 TYPES OF SOUNDS
AIRBORNE SOUNDS
IMPACT SOUNDS

21.7 ACOUSTIC OR SOUND INSULATION

21.8 SOUND REDUCTION TECHNIQUES
AIRBORNE NOISE
IMPACT NOISE

THERMAL AND SOUND INSULATION

21.1 INTRODUCTION

The different compositions of building materials cause variations in the movement through their structure of heat and sound. According to the extent to which materials assist or impede the transfer of heat or sound, they are classified as thermal or acoustic insulators. It is a fortunate coincidence that many of the
materials which provide good thermal insulation also tend to possess high co-efficients of sound absorption.

The application of principles relating to thermal and acoustic insulation enables buildings to be designed with comfortable environments and low rates of energy consumption. Apart from the obvious advantages offered to the occupants, insulation is often essential for the protection of foods and delicate equipment.

The actual degree of insulation provided will depend upon many factors relating to the nature of particular materials selected for use in various buildings. The quantity of material required will therefore vary according to specific values of insulation, and the requirements of various locations throughout each building. It will sometimes be necessary to incorporate additional insulating materials to obtain the required results economically and with greater aesthetic effect.

Thermal and sound insulation will be set out in separate studies in this chapter, as follows:

Part A - Thermal Insulation

Part B - Sound Insulation.

PART A - THERMAL INSULATION

21.2 THE PROCESSES OF HEAT TRANSFER

The intelligent application of the basic principles of insulating buildings necessitates a complete understanding of the methods and processes of heat transfer. Any difference in temperature between different zones in a building will result in a transfer of heat from the warmer to the cooler areas. Seasonal temperature variations provide loss of heat in winter and heat gain during hot summer months.

Any portion of a structure separating zones of unequal temperature will offer some measure of resistance to the heat transferring through the materials. The processes of heat transference must be clearly understood as each plays an important role in heat gains and losses in buildings.

The types of heat transfer comprise:

- Conduction
- Convection
- Radiation.

CONDUCTION

Conduction is the process by which heat flows through or along a material, or from one material to another in contact with it. Air
is a poor conductor of heat; for this reason, insulating materials often include a high proportion of air cells or spaces within their structure. Water is a relatively good heat conductor, so if some of the air spaces in a material become damp the insulation value will be reduced.

**CONVECTION**

Convection occurs in a liquid or gas; differences in density due to variations in temperature cause movement of the liquid or gas and therefore movement or transfer of heat. Convection heat transfer will occur at the surfaces of walls, floors and roofs when the surface is either warmer or cooler than the adjacent air. The rate of this surface transfer will be increased if the air movement is aided, for example by wind on the outside of a building, by ventilation of a cavity or roof or floor space, or by a fan. The amount of air movement in small cavities is affected by the shape and size of the cavity.

**RADIATION**

The process by which heat is emitted from a body and transmitted through space as energy is called radiation. All bodies emit radiant energy; the rate of emission depends on the temperature of the body and on the nature of its surface.

When two bodies face each other across space, whether they are the sun and the earth or the two sides enclosing the cavity in a wall, an exchange of radiation occurs. As each body is emitting and absorbing energy it will have either a nett gain or nett loss of heat.

Resistance to heat transfer can be effected with the use of selected materials which may be classified as either:

- poor conductors of heat
- good reflectors of heat
- combinations of both.

Poor conductors of heat include various materials containing cellular, fibrous or granular composition. These include foamed plastics, expanded mineral fibres, cork, and some light-weight lining boards and tiles.

Good reflectors of heat include aluminium foil, and laminates containing foil on one or more faces.

The extent of resistance to heat transfer can be ascertained from tables and values of various building materials.

These values and tables relate to various materials of specific thicknesses, and also allow comparisons between materials of a base thickness, taken as one metre.
21.3 VALUES OF HEAT TRANSFER

Comparative values of both the conductance and resistance of heat are essential for designers to select the most appropriate type and size of insulating materials. These values have been assigned abbreviated symbols as standard international identification, as follows:

- Thermal Conductance - 'C' factor
- Thermal Conductivity - 'k' factor
- Thermal Resistance - 'R' factor
- Thermal Resistivity - 'r' factor
- Thermal Transmission Co-efficient - 'U' value.

**Thermal Conductance** (C) is a measure of the quantity of heat energy passing through one square metre of a material of specific thickness, for every degree Celsius of temperature variation on the surfaces.

$$\therefore 'C' = \frac{W}{M^2 \; ^{\circ}C} \text{ or watts per square metre per degree Celsius.}$$

**Thermal Conductivity** (k) is a measure of the ability of a material, one metre in thickness, to conduct heat over one square metre area, for a temperature difference of one degree Celsius.

$$\therefore 'k' = \frac{W}{M \; ^{\circ}C} \text{ or watts per metre per degree Celsius.}$$

**Thermal Resistance** (R) is the measure of time for one watt of heat energy to pass through one square metre of material of specific thickness, for one degree Celsius temperature variation.

$$\therefore R = \frac{M^2 \; ^{\circ}W}{W} \text{ or square metres per degree Celsius per watt.}$$

**Thermal Resistivity** (r) is the measure of thermal resistance to a heat flow through materials of one metre thickness, for one degree Celsius temperature differential.

$$\therefore 'r' = \frac{M/^{\circ}C}{W} \text{ or metres per degree Celsius per watt.}$$

It will be noted that thermal conductivity and resistivity refer to materials of one metre in thickness, and allow a comparison of effectiveness between various materials. Thermal conductance and resistance refer to material thicknesses and allow for comparisons of effectiveness for various thicknesses of a specific material.

i.e. R = 1.0; R = 1.5; R = 2.0
Thermal conductivity and resistivity are reciprocal values which may be simplified with the formulae as follows:

\[ k = 1 + r \text{ and } r = 1 + k \]

i.e. \( k = 0.5 \quad \therefore r = 2 \)

**Thermal Transmittance** or the termal transmission co-efficient \((u)\) is the measure of heat flowing through an element of construction, one square metre in area, for degrees Celsius temperature difference between internal and external surfaces.

\( \therefore 'u' = \text{W/m}^2 \text{°C} \) or watts per square metre per degree Celsius. The lower 'u' value indicates a superior insulation property for an element of construction.

Refer to Figure 21.1 for comparisons of 'u' values for four different types of wall construction. The 'u' value is the reciprocal of the sum of all the resistance values.

**Thermal Insulation Values for Walls**

*Figure 21.1*

*(Courtesy of Bunning Forest Products Pty. Ltd.)*
21.4 METHODS OF REDUCING HEAT FLOW

Heat transfer occurs through the walls, floors, roofs and ceilings of buildings, and especially through openings in the walls. A reduction in heat gains and losses results from the selection of particular materials for construction, or materials applied over the structural element.

Figure 21.2 illustrates the approximate values of heat transfer in a typical building, to indicate the principal areas where insulation may be required.

EFFECTS OF HEAT LOSS AND HEAT GAIN

Heat losses from a typical uninsulated brick and tile house

Figure 21.2 (a)

Heat gains in a typical uninsulated brick and tile house

Figure 21.2 (b)

(Courtesy of the Housing Research Information Centre.)
The walls, roof-ceiling construction, and other elements of buildings resist the passage of heat through them according to the nature and thickness of the material used, the existence of air spaces in the construction, and the natural resistance to the flow of heat when heat passes from air into the construction and, later to air from the other side of the construction. When insulation is incorporated in construction, the thermal resistance of the construction is materially increased. If a second increment of insulation is added, the thermal benefit will not be as great as that derived from the original quantity of insulation.

The flow of heat to or from a room takes place mainly through the four surrounding walls and windows, through the roof-ceiling construction, and via the ventilating air. The practice of heavily insulating ceilings and non-glazed areas of walls is insufficient, all channels by which heat flows needs attention within the limits of economics and practicability.

Heat energy transfer can be reduced by careful orientation of buildings, and positioning of openings.

21.5 TYPES OF THERMAL INSULATION

The principal types of thermal insulation can be classified under the headings of:

- bulk insulating materials
- reflective insulating materials.

The bulk insulating materials comprise many fibrous and granular minerals, foamed plastics and light-weight tiles and boards. They are available in batts, sheets, blankets, pre-formed panels and loose-fill.

Foil insulation is available in rolls, sheets and as surfacing layers to pre-formed panels and laminates.

These various types of insulating materials are illustrated in Figure 21.3.
(a) Stud walls must be insulated before the installation of the lining. The insulation is pressed into position between the studs to finish flush with the lining. All joints are tightly butted to eliminate air gaps.

(b) Stud walls lined with aluminium foil.

(c) Expanded polystyrene placed in external cavity wall construction.

(d) Foam being inserted, under pressure, through brickwork into the cavity.

Types of Insulating Materials

Figure 21.3

21.8
CEILINGS

(e) In ceilings the insulation is pressed into position between the joists to rest on top of the ceiling. All joints between batts are tightly butted.

(f) The insulation is spread evenly to the required depth with a rake or screed avoiding any tendency to compress the granules.

(g) The fibreglass insulation blanket is rolled out across the purlins on top of the foil laminate (or mesh where a vapour barrier is not required), butting tightly at the edges.

Figure 21.3 (continued)

Thermal insulation materials, except foil types, exhibit considerable resistance to the flow of heat through themselves and through the construction with which they are associated. This resistance increases with the thickness in which the materials are used and decreases as the density of the materials increases. Thermal resistance is an inherent characteristic of a material, and it can be regarded as constant for a particular bulk of insulating material, irrespective of the position in which the material is placed and the direction in which heat will tend to flow.

The rate at which heat will flow into a house during hot days can be reduced considerably by insulating the external walls and ceilings of the house; however, heat will continue to flow indoors by conduction through glazing and with the ventilating air, and it will be absorbed by the internal construction. The consequent rise
in indoor temperature is influenced by the rate at which this absorbed heat increases the temperature of the internal construction. The rate of increase in indoor temperature decreases with increasing mass in the internal construction.

Heat that is stored inside a house by day must be removed soon after sunset if comfortable night-time conditions are to be established. There must be considerable reliance on natural ventilation to achieve this result because temperature differences between indoors and outdoors to conduct heat outwards during evenings are less than the temperature differences that cause heat to flow inwards by day. The insulation in external walls and on ceilings, further retards the cooling process.

PART B  SOUND INSULATION

21.6  TYPES OF SOUNDS

The sounds occurring within a building comprise both those produced within a room, and any sounds intruding from externally. The two basic types of sounds which create problems in urban environments are:

- Airborne sounds
- Impact sounds.

Airborne sounds are energy waves transmitted from a specific source, and include sounds from aircraft, traffic, explosions and loud music. Impact sounds eminate from direct contact, as in hammering, or footsteps on a floor in the adjoining room.

Any unwarranted sound which causes discomfort and distraction is regarded as noise, and should be reduced or eliminated for health considerations and increased productivity. Many examples of noise intrusion occur in factory situations, apartment buildings, and inner-city traffic situations.

Sounds generated within a space or entering through an opening travel in waves until they encounter an obstruction. The sound energy reflected back into space will be proportional to the amount of sound not absorbed by the incident surface. Where sounds are reflected from hard, smooth surfaces, reverberations occur to create confusion by overlapping the sounds of speech and music.

The following table contains typical levels of sound intensity measured in decibels.
TABLE 21.1

TYPICAL LEVELS OF SOUND INTENSITY

<table>
<thead>
<tr>
<th>Noise Source</th>
<th>Sound level in decibels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold of pain</td>
<td>130</td>
</tr>
<tr>
<td>Rivetting steel plate</td>
<td>120</td>
</tr>
<tr>
<td>Heavy industrial workshop</td>
<td>100</td>
</tr>
<tr>
<td>Peak hour traffic</td>
<td>88</td>
</tr>
<tr>
<td>Typing office</td>
<td>75</td>
</tr>
<tr>
<td>Telephone</td>
<td>67</td>
</tr>
<tr>
<td>Electric typewriter</td>
<td>63</td>
</tr>
<tr>
<td>Average conversation</td>
<td>44</td>
</tr>
<tr>
<td>Quiet office or home</td>
<td>35</td>
</tr>
<tr>
<td>Quiet conversation</td>
<td>25</td>
</tr>
<tr>
<td>Whisper at 1.5 metres</td>
<td>18</td>
</tr>
</tbody>
</table>

Where, for economic or practical reasons, it is not feasible to eliminate intrusive sounds, they can be acceptable if reduced to the intensity of background noise.

21.7 ACOUSTIC OR SOUND INSULATION

Materials intended to reduce the intensity of airborne or impact noises are classes as acoustic, or sound, insulation. These materials vary significantly from soft porous linings and coverings to dense materials and forms of discontinuous construction.

The types of insulation may be applied directly at the source of the noise to reduce the sound transmission to adjoining areas. Alternatively, sound absorbent linings and barriers can be installed to reduce the intensity of noise, and eliminate any reflection and reverberation.

Table 21.2 indicates the sound absorption characteristics of various building materials, with sound intensity reductions listed in decibels.
TABLE 21.2

SOUND ABSORPTION CHARACTERISTICS OF MATERIALS

<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>DECIBELS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brick Walls</strong></td>
<td></td>
</tr>
<tr>
<td>270 mm cavity, plaster 1 side</td>
<td>60</td>
</tr>
<tr>
<td>230 single leaf, plaster 2 sides</td>
<td>55</td>
</tr>
<tr>
<td>110 single leaf, plaster 2 sides</td>
<td>50</td>
</tr>
<tr>
<td><strong>Double Glazing</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45</td>
</tr>
<tr>
<td><strong>Lath and Plaster</strong> on metal studs</td>
<td></td>
</tr>
<tr>
<td><strong>Plaster sheets</strong> on timber studs</td>
<td></td>
</tr>
<tr>
<td><strong>Glass 6 mm single sheet</strong></td>
<td></td>
</tr>
<tr>
<td>&quot; 3 mm double glazed</td>
<td></td>
</tr>
<tr>
<td>&quot; 3 mm single glazed sash</td>
<td></td>
</tr>
<tr>
<td>&quot; 3 mm single glazed pane</td>
<td></td>
</tr>
<tr>
<td>Open window - with drapes</td>
<td>10</td>
</tr>
<tr>
<td>Open window - no drapes</td>
<td>5</td>
</tr>
</tbody>
</table>

It is obvious from the table that costs outweigh the advantages of increasing a wall from 110 mm to 230 mm thickness solely to gain 5 decibels sound absorption. Where large windows are open for ventilation, airborne sounds can intrude with very little reduction in intensity, in spite of expensive treatment in other areas of a room. Figure 21.4 illustrates the specific areas of rooms requiring sound insulation treatment.
Sound Absorption and Insulation

Figure 21.4

(A) External source of airborne sound
(B) Refraction at angle of incidence
(C) Transmission through structure less absorption by materials
(D) Internal source of noise - typewriter

21.13
21.8 SOUND REDUCTION TECHNIQUES

It is suggested that noise problems might be pursued along the following broad lines:

(a) Establish the source of the noise.
(b) Endeavour to reduce the noise at its source.
(c) Failing success with (2), determine how the noise is transmitted to the affected space.
(d) Seek to impede the transmission of the noise, or to absorb it, as may be appropriate, using the methods discussed.

Sound Insulation
1. Exterior noise travels in a direct line and is also reflected on to a building from硬 surfaces, such as pavements.
2. All the external elements of a building are equally important in insulating it against noise. Landscaping is also a factor in insulation trees, plants and shrubs can absorb and deflect sound.

Airborne Noise

Figure 21.5

(Adapted from 'Do your own Double Glazing and Thermal Insulation', by Harold King (W. Foulsham & Co. Ltd., Slough, 1972).)
Pitched roofs provide additional sound reduction with insulating batts, quilts or sprayed loose-fill placed above the ceiling, in the roof space.

Concrete flat roofs are usually covered with bitumastic products, slabs or low-pitched roofs for insulation and weather protection.

Concrete raft slabs on the ground provide increased levels of sound reduction compared with timber-framed flooring systems.

Walls obtain sound reduction values from the discontinuous construction of cavity walls and spacings between the studs. Additional gains could be obtained with the construction of double-stud walls or staggered-stud walling. Refer Figure 21.6.

![Cavity Walls: Timber Stud](image)

**Cavity Walls: Timber Stud**

*Sound Reduction in Walls*

*Figure 21.6*

The location and size of door and window openings in walls are of particular importance in sound reduction. Double glazing may be required in localities affected by traffic or industrial noises. Close-fitting doors and sashes are essential, and compressible strips of draught excluding material can minimize noise intrusion.

**IMPACT NOISE**

The most effective way to insulate against the transmission of impact noise is to isolate or cushion the structure at the source of sounds.

Upper floors in buildings can be improved with soft floor coverings on suitable underlays. Floating floors may be required above auditoriums, theatres and rooms with delicate electronic equipment.
(a) Sound Insulation of Timber Floors

Skirting fixed to wall, not touching floating floor
Resilient quilt turned up at edges
Floating wood raft

Plaster
Partition

Vertical strips at edges of floating floor
Waterproof paper
Floating screed
Resilient quilt
Structure slab
Partition

(b) Sound Reduction Concrete Floors

Sound Reduction of Floors

Figure 21.7
Critical application requiring complete freedom from transmitted sound and vibration consists of floating floor, high-deflection spring isolators on all equipment, and a resiliently suspended ceiling of dense impervious material.

Figure 21.8

(1) isolation pads supporting floating floor
(2) low-density fibreglass infill material
(3) fibreglass ceiling isolation hangers
(4) perimeter isolation board with mastic sealer
(5) spring-isolated inertia base for pump
(6) spring-isolated inertia base for fans
(7) spring and fibreglass hangers isolating fans, piping.

(Adapted from 'Building Materials and Equipment', Oct/Nov 1976, p. 61.)

In commercial and apartment buildings, airborne and impact noises create problems associated with the building services.

Lift shafts are often installed adjacent to habitable rooms and work areas. Plumbing services are a principal source of distraction.

Airconditioning facilities and circulating fans create noise and supply ducts transmit these sounds to other areas in buildings.

In most situations careful planning and design can orient the rooms in buildings to minimise the intensity of intrusive noise. Sound absorbent pads and sprung bases reduce impact sounds, and discontinuous ducting prevents the transmission of noise.
Chapter 22

PARTITIONS AND SUSPENDED CEILINGS

22.1 INTRODUCTION

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22.3 FUNCTIONS OF PARTITIONS
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   ACOUSTIC PROPERTIES
   PROVISION OF SERVICES
   FIRE RESISTANCE
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   FINISH
   COST

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   ILLUMINATED CEILINGS
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   COMBINED SERVICE CEILINGS

22.1
22.1 INTRODUCTION

There are many reasons for classing partitions and suspended ceilings within the same area of study. They are both internal, non-loadbearing systems providing similar functions with relatively similar materials of construction. Partitions and suspended ceilings are often installed at about the same time on a project schedule, following the structural trades and building services.

The lining materials of partitions and suspended ceilings are often so similar that the selection of one may determine the nature of another. Consideration should be given to the compatibility or incompatibility of their principal functions and aesthetic appearances.

With regard to their acoustic properties, partitions are generally designed to absorb sounds and prevent the transmission of sound to other areas. Most suspended ceilings are designed to absorb sounds, but often transmit noise to adjoining areas unless partitions are extended to the floor slabs.

Where demountable partitions have been selected, attention should be directed to the performance specifications for acoustic properties of both partitions and suspended ceilings.

Partitions and ceilings may both be required to contain tubes or ducts for services, from lighting and telephone cables to ventilation ducts. Some difficulty may be experienced in combining these services, and the compatibility of partitions and suspended ceiling systems should again be examined.

PART A - FIXED AND DEMOUNTABLE PARTITIONS

22.2 TYPES OF PARTITIONS

Partitions are interior non-loadbearing walls which do not extend beyond the height of one storey. They vary considerably in a range of sizes and surface finishes according to the principal functions they are designed to serve.

In large buildings of a commercial or residential nature, partitions are used to enclose certain areas, and to separate spaces provided for occupants and the general public. In wash rooms, change rooms and toilets, partitions provide cubicles for privacy.

The height of partitions may vary from the height of a counter or enquiry desk, to shoulder or door height, or extend to a ceiling level or soffit of a floor slab.

Figure 22.1 illustrates a typical example of partitioning, varying in height and appearance to suit particular requirements.
Partition Walls

Figure 22.1

(Reproduced by courtesy of the Aluminium Development Council.)

In framed construction, the internal walls framed up between the columns are classed as partitions because they are not designed as load-bearing walls. These walls are often framed with metal stud sections and faced with gyprock or similar sheeting.

Office and store partitioning may be attractively faced in absorbent or melamine surface materials on metal or timber framing. These partitions are usually pre-fabricated for rapid on-site erection, and designed on a standard modular grid for economical mass production of stock sizes. Demountable partitions can easily be re-arranged in configuration, or removed when not required.

Store room partitioning is often constructed with head and sill metal channels receiving solid or hollow gyprock panels which interlock in their vertical joints. Lightweight gyprock blocks can also be erected as partitions using a special B.S. 1000 adhesive in their interlapping joints.

Ablution rooms usually require their partitions to provide a hard, durable, attractive and waterproof surface, such as terrazzo. These partitions contain the inserts for attaching adjoining panels together, and rust-resistant hardware for the doors. They are very hygienic and easily cleaned and maintained, but are susceptible to vandalism.
22.3 FUNCTIONS OF PARTITIONS

Partitions will be considered under the following headings:

- Demountability
- Acoustic properties
- Provision of services
- Fire resistance
- Finish
- Cost.

Because it is not possible to construct a partition which is ideal in all respects, most standard systems are a compromise between the properties. For example, as has been discussed above, the greater the demountability, the lower the acoustic insulation. There will also be less provision for servicing. Because of this it is worth considering carefully whether it is more valuable to have an easily demountable partition or the advantages of higher acoustic insulation, greater servicing provisions and so on. Manufacturers have had some success in developing partitions which are adequate for many requirements; however, any system with a specification more complex than the average will have to be chosen with care. In the case of fixed partitions, almost any demand can be met for other properties, though often with increased weight, drying out time and inflexibility.

DEMOUNTABILITY

The Demountable System consists of a series of posts, slotted or otherwise profiled to accommodate solid panels and/or glazing and doors. This system is designed for rapid assembly and if necessary, demounting and re-assembly.

The system incorporates a height adjustment which is hidden by the removable metallic skirting which may, also in the space accommodate electric and telephone wires.

The framing is usually of aluminium or mild steel tube framing with panels of plastic coated steel, plywood, vinyl coated aluminium or particle board.

The demountability of dry partitions will depend basically on individual methods of construction and erection. In general, the greater the number of sections of which the partition is made up, the less easy it is to demount and move.
ACOUSTIC PROPERTIES

The sound insulating properties of a material depend primarily on its superficial density; however, when double skin partitions are used, or when there are a number of materials used in one partition, the actual arrangement of the materials within the partition may affect the sound insulating properties. For example, the sound insulating properties of a double-glazed partition depends very much on the distance between the two sheets of glass.

Solid panelling in most partitioning is of selected veneered particle board, and where good sound insulation is required lead sandwich panel particle board sheets are used.

PROVISION OF SERVICES

A fixed wet construction partition will usually prove the most suitable for a large number of services, and routing and outlets can be in any position. The main disadvantage, however, is that alteration of the services during the life of the partition involves much work and is dirty. Demountable partitions nearly always have some provision for servicing, though this may be found inadequate for highly serviced areas. Servicing ducts are mostly incorporated within the partitions themselves, in which case, they can be within pilasters and skirting, or can be incorporated - usually by prior arrangement - in any part of the core. Some partitions have clip-on skirtings carrying services, and, if alterations are to be made during the life of the partition, this type or one where the duct covers are similarly removable, will prove most convenient. The most common standard provision for servicing is for mains cables, but many partitions have separate ducts for Telecom and internal telephone wiring. Facilities for water pipes and similar services are unusual, although some manufacturers will make special provision for them. Any form of piping will seriously reduce the demountability of the partition, and the inclusion of any form of duct may reduce the sound insulating properties.

FIRE RESISTANCE

Demountable partitions of most construction and finishes can be obtained with a fire-resistance rating of ½ an hour or 1 hour. High ratings can be obtained with fixed or with certain demountable partitions, and statutory requirements may play a large part in the selection of a system of partitioning.

Partitions dividing individual occupancy and corridor partitions require a one hour fire rating.

Partitions along corridors used as a fire escape route must have a two hour fire rating.
FINISH

Painted partitions can easily be redecorated after re-erection; however, where partitions with permanent finishes are used, it is important to make sure that the finish chosen will satisfy future requirements and will not result in inconsistencies in a new layout.

COST

The initial cost of a partition system depends mainly on the type of partition. If the system is to be demounted and repositioned it is important to determine the replacement cost for each repositioning.

22.4 DETAILS OF CONSTRUCTION

Many of the partitioning systems on the market are produced under patent and specific details of individual models cannot be revealed. However, catalogues representing the materials used and methods of assembly can be obtained from manufacturers and distributors.

The details of assembly relate to various classes of partitions which may include:

(a) **Fixed**
   - Framed
   - Self-supporting

(b) **Pre-fabricated**
   - Modular and demountable

**Fixed partitions** are usually fabricated on site and erected against structural members for stability and rigidity. These partitions can be dismantled and removed, but may not be suitable for re-use elsewhere. As they are not specifically designed as demountable, fixed partitions often suffer damage during removal, or the surrounding structure requires 'making good'.

The self-supporting type of fixed partition includes a range of different materials with various functions and appearances. A common type of partition installed for internal walling in framed structures, comprises light gauge metal channels continuing panels of building boards such as plaster panels, Stramit and Woodtex. The type installed in office situations comprises square metal-tube posts supported in continuous capping, and incorporating built-up panels of selected materials, doors and glazing.
Terrazo partitions comprise precast concrete panels 40 mm to 50 mm thick, faced with exposed aggregate of selected stone chips in fine aggregate which may be coloured. Similar types of partitions are now available in fibre-glass and phenolic foams, and may comprise the whole enclosure, as for shower compartments.

Unit-block partitions are built of masonry or gypsum blocks laid in mortar or compounded together. These walls may be plastered in each face, or with interlocking joint construction, merely painted or wall-papered.

**PRE-FABRICATED PARTITIONS**

The pre-fabricated partitions are usually manufactured under patent by specialist manufacturers. To enable mass-production techniques to be employed, modular dimensional units are prepared and delivered in a finished state.

This system of partitioning is produced in straight and curved sections approximately 900 mm to 1200 mm in width and to various height modules. Usually, furniture and desks are positioned to provide additional support to these lightweight partitions.

In large office situations, the term 'office landscaping' is applied to the large floor areas sub-divided by these types of partitions. To allow for flexibility in changing space requirements, most pre-fabricated partition systems are designed as demountable, for easy removal and re-erection. The joints between panels are usually concealed behind flexible compression tapes in dovetailed slots, or screwed metal cover beads.

Details of partition wall construction are illustrated in the following pages.
Concealed Fixing Frame and Panel System

Figure 22.2
For ceiling-height partitions, a similar configuration may be used, or alternatively a recessed cornice with a gasket as shown in the accompanying sketch.

**Skirtings, Cornices**
Where access is required to the base of the partition system, either for installation adjustment or demountable purposes, or access to wiring services, detachable metal skirting pieces are used. These are normally clip-fixed to the bottom of the partition and the fixing plate (see sketch). If required, detailed timber skirting may be used.

**Methods of Fixing Demountable Partitioning**

*Figure 22.3*

*(Courtesy of the Aluminium Development Council.)*
JOINING

Six junction conditions are constantly encountered in partition erection:

1 Starter (Junction at Wall)

2 One-Way Junction (free standing)

3 Two-Way Junction (in line)

4 Two-Way Junction (at right angles)

5 Three-Way Junction

6 Four-Way Junction

(Courtesy of the Aluminium Development Council.)

Solid partition unit

Clip fixing

Wiring duct

Cover strip fixed by p.k. screw

Breakdown Post

Figure 22.4

22.10
PART B - SUSPENDED CEILINGS

A ceiling framework and lining system which is not in direct contact with a structural floor deck or roof, is referred to as a 'suspended' or 'false ceiling'. These ceiling systems suspend from a structural support on metal rods or straps, which are generally adjustable for height alignment.

Suspended ceilings provide enclosures to conceal projecting floor beams or ducts and pipes connecting building services. They are also the most economical method of attaching the lining materials under widely spaced roof trusses. Suspended ceilings are frequently installed in large shopping complexes, in landscaped office areas, and many commercial and industrial situations.

22.5 TYPES OF SUSPENDED CEILING SYSTEMS

The principal types of suspended ceiling systems can be classified under the following headings:

- Jointless or flush
- Modular panel
- Strip panel.

These different systems will be studied individually, but should be compared according to particular functional requirements, which could include the following:

- demountability and access
- acoustic properties
- fire resistance
- moisture resistance
- mass (or weight)
- finish
- cost.

THE JOINTLESS SYSTEM

Several methods have been adopted for attaching flush-jointed sheeting to a suspended ceiling framework. The gyprock system comprises modular metal channels to which gyprock sheeting is fixed at 300 mm centres. Angle trims, attached to the walls, support the edges of the sheets and provide a flush or recessed bead effect. Refer to Figure 21.5.
Jointless Ceiling System (Type A) ‘Sheeted’

Figure 22.5

(Reproduced by courtesy of CSR Building Materials.)

An alternative type of jointless ceiling involves the application of solid plaster to expanded metal sheathing. This method incurs a disadvantage in the use of 'wet' trades and the associated delay in curing. While it may not be a critical factor in new construction the delay and scaffolding could disrupt work during alterations and additions. Refer to Figure 22.6 for a typical illustration of this method of jointless ceiling.
Jointless Ceiling System (Type B) Solid Plaster

Figure 22.6

(Reproduced from brochure produced by The Expanded Metal Company Limited, London.)

MODULAR PANEL SYSTEMS

This popular method of suspended ceiling construction has been adopted by many firms who patent designs incorporating their individual lining materials. Specific details of construction and suspension equipment can be obtained by reference to commercial literature produced by firms, such as Stramit, Caneite, Woodtex and Gyprock. Figure 22.7 illustrates a typical modular system with rectangular grid and exposed framing. Some systems are available with linear grids and concealed framing members.
Figure 22.7
(Courtesy of CSR Building Materials.)

STRIP PANEL SYSTEMS

A modern concept of suspended ceiling design incorporates linear panels of narrow profiled metal or timber, fixed to horizontal carrier rails. The strength derived from continuous panel and rail construction enables large areas of ceilings to be covered. The system also provides for illumination to be incorporated by providing light boxes, diffusers and suitable trimming materials.

The lining panels can be solid, perforated or acoustic-padded metal, or profiled timber. Provision is made for the insertion of a narrow closure strip between the panels, and for a fibreglass facing sheet and acoustic quilt behind the panels. Refer to Figure 22.8 for typical details of strip ceiling systems.
Stair Ceiling Systems

Figure 22.8

22.15
DEMOUNTABILITY AND ACCESS

The most easily accessible system is the modular panel. With a few exceptions the modular size is either 300 or 600 mm square. Most panels can be removed without too much difficulty, unless the top surface has been covered with a thermal or acoustic insulating material. If accessibility is of major importance, it is worth studying modular ceilings in more detail to determine the relative ease of accessibility of the various systems.

Strip ceilings are less accessible because the removal of several strips of room length may be necessary to gain access to one point; however the strips are usually easy to remove and much will depend on the layout of the services above the ceiling. If cables, etc., are laid in the same direction as the ceiling strips, it may be possible to gain access to the whole length of cable by the removal of one strip.

Where jointless ceilings are fitted and access is required, the position of points of access will have to be determined beforehand and they can then be incorporated. If the space above the ceiling is heavily serviced, jointless ceilings will probably be impracticable; however, if only one of two access points are required in fixed position, there should be no problem in providing them.

ACOUSTIC PROPERTIES

Ceilings often have to be sound absorbers and sometimes insulators as well. The insulating properties of the structural ceiling will usually be very much greater than the suspended ceiling and an important reason for insulating the ceiling will be to prevent the transmission of sound over the top of partitions. If both absorption and insulation are required, then heavy insulating material may be faced with an absorbent material.

This will not produce perfect absorption or perfect insulation, but usually an adequate degree of both can be obtained. Ceilings which are sound absorbers are usually of lightweight material or perforated if insulation is also required, the top of the ceiling can be lined with material of high superficial density, such as lead.

FIRE RESISTANCE

The best fire resistance is afforded by plaster or metal tray panels, or fibrous cement panels. There should be little practical difficulty in obtaining a ceiling with up to 2 hours rating or more, while still retaining acoustic and other necessary properties.
MOISTURE

In conditions of heavy humidity, the main factor governing the choice of a ceiling may be its resistance to moisture. Plaster and fibrous cement panels are good, but cork panels are by far the most effective although these may be difficult to obtain. If very heavy condensation is expected, the most effective solution is to insulate the ceiling thermally by lining it on the top surface with suitable materials.

WEIGHT

Jointless ceilings are the heaviest of the systems - usually about 55 to 60 kg per square metre - because they are usually based on plaster; an exception is the stretched plastic membrane type of ceiling which is lighter than any other. Most panel ceilings are in the range of 5 to 10 kg per square metre, though a few may be heavier. Strip ceilings are the lightest and average 2 to 3 kg per square metre.

FINISH

The range of finishes available in suspended ceilings is limited mostly to variations in texture. Perforations made for acoustic absorption may be laid out in different patterns or the holes may be of different sizes. Embossed or profiled panels are also obtainable. It may not be possible to paint or effectively clean some types of ceiling, particularly those which are moisture resistant or sound absorbers. Jointless ceilings can accept the widest range of finishes because they are not restricted by the demountability of panel and strip ceilings. The ease of cleaning may be an important factor - not only in particularly dirty surrounds but, also where strong air movements within a room are likely to cause staining.

COST

As with partitions, the cost of a ceiling system will depend largely on the complexity of the ceiling. The cheapest types are those consisting of lath and plaster; of the modular systems, the cheapest are those manufactured from fibre board. However, the aesthetics and low-maintenance characteristics of ceiling systems outweigh the slight advantage of cost for many situations.

22.7 ACCESSORIES AND SERVICES

The firms supplying suspended ceilings produce a range of accessories which allow rapid erection schedules and attractive surface finishes. The following details are indicative of the range of products available, although the design of patents may vary with individual firms.
Different methods of attachment to the structural framework are provided to suit the particular types of materials encountered. Metal brackets have been designed for attachment to most types of materials, as illustrated in Figure 22.9. In addition, explosive power tools have a range of threaded and perforated fixing pins which can be discharged into concrete, masonry and metal supports. Alternatively, terrier bolts, loxins and tiger bolt expansion fasteners could be utilized.

(Courtesy of CSR Building Materials.)

(As used in the 'Ramset Fastening System'.)

Methods of Anchorage

Figure 22.9

Several methods have been designed for providing rapid means of height adjustment to ensure the alignment of suspended ceilings. Figure 22.10 illustrates a suspension spring clip and threaded rod with locking nuts.
Wall trims support the edges of suspended ceilings and provide a neat finish at the edges of the sheets. A right-angle shaped trim provides a flush finish against the surface of the ceiling lining. Shadow effects are provided at the wall junction with recessed trims - as illustrated in Figure 22.11.
SERVICES

Suspended ceiling systems provide for the installation of services such as illumination and ventilation. Serviced ceilings may produce abnormal air currents, and can prevent the use of sound insulation, sound absorption or moisture resistance.

_Illuminated ceilings_ have been designed to accommodate recessed light fittings. They can be located in any position in a ceiling and the number of fittings can be varied to provide the levels of illumination required. Where the luminaires exceed a recommended safe mass per square metre, extra supports from the structure may be required.

_Ventilated ceilings_ incorporate the enclosed space between the lining and the structural floor slab, as a plenum chamber for systems of mechanical ventilation or airconditioning. The conditioned air covers the whole area of the ceiling and is distributed through perforated infill panels or slotted framework members of the suspension system. Refer to Figure 22.12.

![Ventilated Ceiling System](image)

*Figure 22.12*

_(Courtesy of the Aluminium Development Council.)_

**COMBINED SERVICE CEILINGS**

Some ceilings are now being produced which incorporate two or more of the services discussed above, frequently in addition to sound absorption properties. Although these may appear to provide a solution to complex servicing problems, they should be studied with great care to ascertain that the efficiency of any of the individual services is not impaired by the attempt to include too many different systems.

![Combined Services Ceilings](image)

*Figure 22.13*

22.20
Chapter 23

GLASS

23.1 COMPOSITION OF GLASS
TERMS
23.2 GLASS TYPES
23.3 PROPERTIES OF GLASS

23.4 METHODS OF GLAZING TO ALUMINIUM
DRY-GLAZED USING ROLL IN WEDGES
DRY-GLAZED USING CAPTIVE WEDGES
TAPE AND WEDGE
SPACER AND ELASTOMERIC CAP BEAD
WRAP-AROUND CHANNEL GASKET

23.5 ENVIRONMENTAL CONTROL GLASSES
SOLAR CONTROL
INSULATING GLAZING

23.1 COMPOSITION OF GLASS

Normal glass is a soda-lime-silicate; that is, it is made from silica (sand), which is the main ingredient, with the addition of lime and soda. The result is a durable transparent but brittle material which will resist most corrosive substances including acids, with some exceptions such as hydrofluoric acid, phosphoric acid and strong alkalis as are found in some paint cleaners. Water from fresh concrete can affect glass if it is not washed off.

There are other glasses, such as quartz glass (pure quartz) and borosilicate glass, both of which have special properties, but are not used in architectural work.
TERMS

Opaque: does not transmit light at all

Transparent: transmits light without diffusion - one can see through it

Translucent: transmits diffused light only - it is not transparent.

23.2 GLASS TYPES

Plate Glass - manufactured by casting a plate of rough glass, which is ground, smoothed and polished to a flat parallel sheet, providing clear and undistorted vision and reflection.

Special application is for optical works, as float glass is superceding this method of manufacture.

Float Glass - In the float process, molten glass up to 3.3 m wide moves out of a melting furnace and floats along the surface of a bath of molten tin. Controlled heat and air pressure displace any irregularities and make the surface flat and parallel.

Gives clear undistorted vision and reflection. Used for glazing, silvering (mirrors) and toughening.

Sheet Glass - A transparent fire finished glass which is not perfectly flat and parallel; this accounts for the unavoidable distortion in vision and reflection.

The molten mass is drawn up vertically through a 9.5 m high annealing tower. The edges are supported between powered, asbestos covered rollers. Used for some domestic glazing and horticultural purposes.

Sheet glass, polished plate and float glass is available in 2, 3, 4, 5, 8, 10, 12, 15, 19 and 25 mm thicknesses.

Patterned Glass - Formed by molten glass passing between surface patterned rollers. Used to admit light while retaining privacy. A figured and decorative glass, light transmission decreases as diffusion increases. Some tints available (3 mm, 5 mm and 6 mm).

Wired Glass - A safety glass with centrally embedded wire mesh. Valuable for soft impact and as a fire retardant. Clear transparent or clear and tinted translucent available (6 mm).
Spectra Glass - Metallic ions are impelled into the glass without halting production, giving the glass a bronze tint and solar control properties (6, 10 and 12 mm).

Antisun - A range of body coloured solar control glasses each with slightly different properties - grey, bronze or green - used where maximum light transmission is essential and relief from solar heat is desirable (6, 10 and 12 mm).

Antisun Cast and Patterned - of various surface textures, the diffusing properties of the textures help to reduce sky and reflected glare and provide privacy (6, 10, and 12 mm).

Solar Shield - A high-performance reflective laminated glass which reduces ultra-violet light in addition to its other solar control properties.

Double or Multiple Glazing Units - Hermetically sealed units incorporating two or more panes of glass separated by a spacer and containing dehydrated air. They reduce heat loss, or heat gain and condensation. Heat gain can be lessened by including a sheet of solar control glass in the unit (6 or 12 mm spacings in each unit.)

Reflective Double Glazed Units - As per Double-Glazed units, with the inside face of the outer pane treated with a thin coating of nickel or copper which reflects a significant proportion of direct solar radiation and reduces glare.

Armour Float - Float glass toughened by heat treatment to give greatly increased mechanical strength and the ability to resist severe thermal shock. In the event of breakage, disintegrates into harmless dried particles.

Armour float doors and assemblies - made from 12 mm float glass, toughened and fitted with nails or patch fittings. Doors are frameless, thereby eliminating the visual barrier of conventional stiles, rails, etc.

Glass Blocks - Hollow translucent glass units with a variety of face textures available. Laid like bricks in fatty mortar with reinforcement which relieves the glass of dead weights and wind loads. They provide diffused light and privacy in hospitals, public buildings and stairwells.
23.3 PROPERTIES OF GLASS

Daylight Transmission - CLEAN clear float and sheet glass has 90% daylight transmission. This quantity is reduced in textured glass depending on the quantity of diffusing surfaces.

Heat Transmission - Easily transmits direct sun's heat, gains heat when external temperatures are lower inside and conversely loses heat when temperatures are lower outside but in forms of glass fibres (fibre glass) it is used as a thermal and acoustic insulation material and as reinforcing in plastics.

Strength - Is dependent on its actual shape not so much upon the area. Long narrow shapes need less strength than similar areas of square shapes. The thickness should be capable of resisting winds of up to 120 km/h for ordinary purposes.

Thermal Movement - May be ignored for ordinary purposes but glass to frame, glass to glass, and glass to metal contact is to be avoided.

23.4 METHODS OF GLAZING TO ALUMINIUM

Basic glazing systems are:

(a) Dry glazed using roll in wedges
(b) Dry glazed using captive wedges
(c) Tape and wedge
(d) Spacer and elastomeric cap bead
(e) Wrap-around channel gasket.

DRY-GLAZED USING ROLL IN WEDGES

This method requires the fitting of resilient pre-formed glazing strips inserted between the aluminium members and the glass. The strips remain in compression and retain the glass by friction exerted on the surface of the glass by the lips of the strip.
Dry glazed using roll-in wedges

Figure 23.1

**DRY-GLAZED USING CAPTIVE WEDGES**

This is a variation of the dry-glazed technique in which the resilient flexible strips are pre-fitted to, and retained captive by, the groove in the aluminium member.

This system is used to glaze doors and the captive wedges are factory fitted.

Dry-glazed using Captive Wedges

Figure 23.2

**TAPE AND WEDGE**

This method requires a pre-formed mastic tape applied to the external fin, the tape adhering to the aluminium and the glass and capable of remaining adhered while allowing for reasonable movement of the glass relative to the metal. The internal treatment is usually a roll-in dry glazing wedge.
The system produces a reliable high performance glazing seal suitable for the most severe exposures. An advantage is that the glazing operation can be carried out entirely from the inside of the building - an important cost saving when glazing or re-glazing high-rise buildings.

![Diagram of Tape and Wedge System](image)

**Tape and Wedge System**

Figure 23.3

**SPACER AND ELASTOMERIC CAP BEAD**

This system requires a continuous spacer shim to locate the glass at the correct face clearance from the frame. The continuous spacer is set some distance below the daylight opening to allow for the application of a high grade elastomeric capping bead.

![Diagram of Spacer and Elastomeric Cap Bead](image)

**Spacer and Elastomeric Cap Bead**

Figure 23.4

**WRAP-AROUND CHANNEL GASKET**

This system requires the use of a continuous channel shaped gasket to be wrapped around the glass, and the frame is then assembled around the glass and gasket.

23.6
This system is often used for inner sashes and sliding doors where assemblies are not exposed to severe weather conditions.

![Wrap-around channel gasket](image)

Figure 23.5

23.5 ENVIRONMENTAL CONTROL GLASSES

The admission of natural light into a building is desirable. However, the visible light amounts to only about 43% of the total energy contained in solar radiation.

Of the remainder, ultra-violet accounts for about 3%, and infra-red 54%. Since all radiant energy absorbed by a material is converted to heat, it follows that to admit light is also to admit a considerable proportion of unwanted heat.

Another way in which heat enters (or escapes from) a building is by conduction. Windows are again a weakness here. Although glass is a rather poor conductor of heat, it is only a few millimetres thick and, therefore, offers little resistance to the passage of heat.

Finally, in the list of unwanted intrusions is sound. Glass, being relatively thin and stiff and yet elastic, acts as a diaphragm in the passage of sound.

Environmental control glasses must control brightness, radiant heat energy, conducted heat and sound.

**SOLAR CONTROL**

These glasses control brightness or glare and the intrusion of radiant heat. These rely on body-tinting, or surface colouration or treatment to cause the glass to either absorb or reflect a proportion of the solar radiation. Some of them are selective, in that they restrict more of the visible wavelengths to control brightness, or more of the invisible wavelengths to reduce heat-gain.

Special consideration must be given to the fixing of solar-control glass:

1. Because solar-control glasses achieve their purpose largely by absorption of solar energy, an above-normal rise in temperature is to be expected. This will naturally be
accompanied by much greater thermal expansion than for ordinary glass. For this reason, special glazing techniques must be used to cope with the movement.

2. An associated problem is that of differential expansion occurring when stationary shadows cause one part of a pane to become hotter than an adjacent part. This can be caused by a deep rebate or an object close to the glass.

3. With body-tinted glasses, integrally coloured, the density of colour increases with the thickness. It is essential, therefore, that glass of the same thickness be used for an entire elevation, even though thinner glass would be adequate for some positions.

INSULATING GLAZING

This requires the use of two panes with an air space between. Better thermal insulation is achieved by using more than two panes, however, the improvement seldom warrants the added cost.

A problem with double glazing is the possibility of condensation of moisture and the intrusion of dust between the panes. This can be overcome by either hermetically sealing the intermediate space or by making provision for access to the inside, such as by the use of two separate sashes. If the space is sealed, it is most important to dehydrate the air. This is often achieved by including some silica gel crystals.

The spacing of the panes has a marked effect on the efficiency of an installation. For thermal insulation the optimum space is about 20 millimetres, although good results can be obtained with spacings of as low as 3 mm. Sound insulation however, requires a minimum of 100 mm. (See Figure 23.13.)
Double Glazing

Figure 23.6

There are a number of patent double-glazing systems, all of which comprise factory-assembled, hermetically-sealed units containing dehydrated air. See Figure 23.7 (a), (b) and (c).
Typical factory-sealed double glazing units

(a)

Typical glazed in-situ double glazing

(b)

Typical double windows, coupled type

(c)

Double Glazing Systems

Figure 23.7 (a), (b), (c)

23.10
Comparison of Solar Heat Penetration of Glass

Figure 23.8
Double glazing also reduces sound transmission, i.e. it insulates against noise. See Table 23.1 which shows typical sound reduction values.

**TABLE 23.1**

**SOUND INSULATION VALUES**

<table>
<thead>
<tr>
<th>UNIT</th>
<th>SPACE</th>
<th>SOUND REDUCTION AVERAGE (100-3200 Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 mm + 4 mm</td>
<td>12 mm</td>
<td>28 dB</td>
</tr>
<tr>
<td>6 mm + 6 mm</td>
<td>12 mm</td>
<td>29 dB</td>
</tr>
<tr>
<td>10 mm + 10 mm</td>
<td>12 mm</td>
<td>31 dB</td>
</tr>
<tr>
<td>12 mm + 12 mm</td>
<td>12 mm</td>
<td>31 dB</td>
</tr>
</tbody>
</table>
BUILDING CONSTRUCTION
Volume 2

DESCRIPTION
Topics include: Demolition; Shoring and Underpinning; Foundations; Footings; Piling; Retaining Walls; Bricks and Concrete Masonry; Cements; Concrete. This text is used with Study Guides 28-023 Building 2A and 28-024 Building 2B.

CATEGORY
Building and Construction