Learners Guide

CPCCBC4010B Apply structural principles to residential low rise constructions

CPCCBC4011B Apply structural principles to commercial low rise constructions
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Introduction

A structure consists of many parts (or members) which act in different ways depending on the loads and forces on them. This chapter covers information related to the main principles of the behaviour of various structures and their components.

This guide is designed for workers in the construction industry who are training to develop the necessary skills to work effectively with plans and specifications in the construction workplace.

If you feel that you may already have some of the skills and knowledge covered by these units, you should speak with your trainer about having these formally recognised.

The workbook has the following sections which give information and practical tips for developing these skills and knowledge for work:

- Industry Professionals
- Prepare Documentation
- BCA Requirements
- Units of Measurement
- Structural Principles – Loads
- Structural Principles – Forces
- Structural Principles – Properties
- Structural Principles – Structural Members
- Structural Principles – Demolition
- Footing Systems
- Floor Systems
- Wall Systems
- Roof Systems
- Cladding Systems
Industry professionals

The building and construction industry uses a wide range of skilled workers who are employed in an equally wide range of working environments. There are many professionals involved in building design and a variety of tradespeople responsible for the numerous stages in the construction process.

Here we take a closer look at the work done by some of the industry professionals.

Architects are tertiary qualified professionals who are registered with a professional organisation or institution. They must satisfy strict licensing requirements.

An architect is mainly concerned with the design of buildings, but other skills are often required. Architects may be employed on a project to provide full or partial services.

Full services include concept design, design development, contract documentation, tendering procedures and contract administration.

Partial services are employed most often on domestic constructions and this includes concept design, design development and possible tendering procedures.

Other typical tasks of an architect

- Developing a client design brief
- Preparing concept sketches and working out what is possible
- Preparing site analysis reports including documentation of site constraints
- Preparing contract documentation, including the contract, specifications and working drawings
- Organising tendering
- Overseeing contract administration
- Organising design development and permit applications

Engineers

There are a number of categories of engineers who could be asked for specific construction advice. These include:

- geo-technical engineers who provide recommendations on the foundation of a construction site. They take soil samples and analyse them to determine the best footing system for the type of soil
- services engineers who are further categorised into more specialised areas which include:
  - fire services, eg sprinkler systems, fire hose design
  - hydraulic engineers, eg design of water tanks on roofs
  - electrical engineers, eg design of lifts
- mechanical engineers, eg air-conditioning plant

- structural engineers who design the structural components of a building such as the concrete slab or the footings.

**Other typical tasks of a structural engineer**

- Preparing reports on how to protect neighbouring properties
- Designing the structure of retaining walls, columns, beams and loading walls in building projects
- Preparing reports on the structural adequacy of existing buildings

**Drafts people**

Drafts people may be employed by a firm of architects to produce various types of drawings for buildings. They may also be employed by engineers to detail all the structural requirements of a building. Alternatively they may operate on their own, providing design and drafting services to the building industry.

**Other typical tasks for a draftsperson**

- Developing a design brief
- Preparing feasibility studies
- Inspecting sites
- Preparing site analysis reports
- Preparing measured drawings of existing buildings
- Plans for initial ideas
- Preparing concept plans for consultation with authorities
- Preparing permit documentation
- Preparing building permit documentation

**Building surveyors**

A building surveyor checks that new buildings comply with the Building Code of Australia (BCA). A building surveyor also checks the maintenance, repair, alteration and renovation of existing buildings against the BCA. They employ building inspectors to be their eyes and ears on the site to ensure that the minimum requirements of the BCA are being met.

Building surveyors advise on and interpret laws and regulations controlling building construction and safety.

They may undertake structural surveys; draw up schedules of dilapidations (related to buildings which are in a state of poor repair) and reports for necessary repairs. They also negotiate with local authorities and obtain approvals required under the town and country planning acts, building regulations and by-laws and other relevant legislation.
Other typical tasks for a building surveyor

- Assessing building plans which have been submitted for approval to ensure they conform to building regulations and codes of practice
- Providing advice and assistance to builders and owners before finalisation and lodging plans so that potential problems can be avoided
- Making recommendations on providing amenities for the community
- Pre-purchase inspecting of all types of buildings
- Inspecting buildings during construction to ensure that proper methods and materials are used, paying particular attention to conformity with building regulations
- Keeping records and writing reports of building progress and instances where regulations have been breached and plans have been altered
- Giving evidence in court when prosecutions are necessary for breaches of building regulations
- Inspecting existing buildings to assess conditions
- Giving advice on building matters
- Issuing compliance certificates on completion

Land surveyors

Land surveyors are licensed professionals who conduct on-site measurements of building sites and buildings. They measure distances, angles and levels.

Other typical tasks for a land surveyor

- Taking levels on a site to produce detailed contour plans
- Determining location of existing buildings and other features on a site
- Setting out the building line, marking the location of columns or the external perimeter of a building
- Checking the vertical alignment of a building during construction
- Conducting boundary surveys and re-establishment of survey pegs
- Checking the positioning and overall height of a structure at completion to ensure compliance with the conditions of permits

Quantity surveyors

Quantity surveyors are mostly employed on major construction projects as consultants to the client. As advisers, they estimate and monitor construction costs from the feasibility stage of a project through to the completion of the construction period.

Their name comes from the bill of quantities, a document which itemises the quantities of materials and labour required in a construction project. The bill of quantities is prepared using measurements from the contract drawings and is used by the contractors for tendering, progress payments and variations.

During construction the quantity surveyors are called on to determine fair progress payments at regular intervals. They will also cost the changes to the design or to quantities which may arise throughout the construction process by referring to appropriate bill of quantities rates.
Other typical tasks for a quantity surveyor

- Initial cost advice during the pre-contract stage including preparing approximate estimates
- Costing planning information concerned with the development of a design
- Preparing the necessary tender documents, critically examining the tenders and priced bill of quantities when lodged for tender
- Valuing the work during the construction stage at required intervals
- Recommending the amounts to be paid to the main contractors including assessment of any variations
- Controlling costs during the construction stage
- Outlining the economics of alternative methods of construction

Prepare documentation

A range of documentation is needed to see a building project through to completion, including:

- permits
- specifications
- title
- plans
- engineering reports.

Title

This document is obtained from the Titles office before construction begins.

A title is a legal document which clearly defines a block of land. The title can be used by a land surveyor to reinstate survey pegs. The north point, property boundary distances and bearings are provided on the title.

Building and planning permits

A building permit is the document which shows that your plans have been approved by a building surveyor. The building surveyor checks that the plans meet building regulations.

Planning permits are legal documents which relate to certain land use such as residential or commercial. Not all projects require a planning permit, but you are advised to check with your local council.

Project specification

If all the information relating to a project was shown on the drawings, they would be very difficult to read. The specification provides supplementary information to the drawings, and takes precedence over any notations on the drawings.

The sections included in a project specification are:
- a description of the job, the site, the proprietor and any other parties in the contract arrangement
- a trades section detailing standards and quality of work. This may be set by the Australian Standards or by samples constructed for the architect's approval
- the schedules containing detailed information in tabular form on
  - windows, showing frame material and type of glass
  - doors, specifying size, material and the swing on the door
  - finishes to walls, floors and ceilings
  - door types and models of locks, latches, hinges, push plates and pull handles.

**Plan of the subdivision**

Plans come in different formats to cover different purposes.

The **plan of the subdivision** is prepared for planning approval prior to the development of the land. It is a good source of information relating to adjoining properties.

**Site plans**

The **site plan** shows a 'bird's eye view' of the building site showing the location of the structure on the block of land. A good site plan can minimise the risk of building on the wrong block of land. It is usually drawn to a smaller scale than a floor plan. A 1:500 scale is generally adequate, although 1:200 may also be used.

Because the roof line is shown, the downpipe locations and stormwater drainage system can also be indicated. Setback distances from the front and side boundaries are also shown.

**Floor plans**

**Floor plans** are like cross sections which are taken horizontally half way up the wall. They are typically drawn to a scale of 1:100 or 1:50 depending on the type of project.

Floor plans show a vast amount of detail including:

- all horizontal dimensions such as room size and wall thickness
- size and location of windows and doors
- location of fixtures and fittings
- any particular requirements in a room such as floor coverings
- an indication of the materials used for wall construction
- the overall floor areas.

**Cross sections**

**Cross sections** are a slice taken vertically through a given point along the building. They are generally drawn to a bigger scale than floor plans and elevations so that more detail can be shown. Cross sections indicate the type of structural materials that are incorporated into the construction.
Footing plans

Footing designs for residential projects are made to comply with AS 2870-2006 (Australian Standards) slab and footing - construction. Dimensions are not generally shown on the footing design, so they must be read with the architectural plans. **Footing plans** provide details on footing depths and widths, slabs and stiffening beams and the type and positioning of steel reinforcement. These documents must also be included in a building permit application.

Drainage plans

**Municipal drainage plans** provide details of legal points of discharge for stormwater drainage. They may also provide surface levels of a subdivision.

**Water authority** documentation such as a sewer plan provides details of plumbing fixtures, drainage lines and points of attachment to existing building(s) on a site.

Contour plans

**Contour plans** are a graphical representation of the lay of the land. They show the degree of slope on a site. They typically relate back to a site datum referred to as a TBM (temporary benchmark) and may also relate to AHD (Australian height datum). They can be used to determine the extent of cut and fill needed, the height of retaining walls, and the overall finished height of buildings referenced back to natural ground level.

To produce a contour plan a surveyor takes a series of levels over the site at regular grid spacing. These readings are recorded in a surveyor's log book and converted to RLs (reduced levels), which are plotted onto a grid overlaid on the site plan. A draftsman can then draw lines of best fit between equal RLs. This gives lines that represent each contour interval, eg RL 5.500. Any feature matching this contour will have a level of RL 5.5 m.

Reports

The condition report

Prior to construction, the condition report, soil report and engineer's drawings will need to be prepared as they contain:

- information on the existing site such as the location of services
- instructions for building complex structures
- an assessment on the bearing capacity of the soil.

The **condition report** for the site is a record of details about the existing site, the buildings on adjacent boundaries and the setbacks of structures on adjacent properties. It contains information about the condition of fences, any significant vegetation on the site on the boundaries and location of services. It may contain photos as evidence of existing conditions on the site if disputes arise (eg if the footpath is cracked prior to work commencing and the council tries to charge you for the repair of the footpath).
Soil report

The soil report is prepared by a geo-technical engineer. A series of soil samples are taken from the site and assessed in the lab. Conclusions are reached about:

- the soil classification of the site
- the bearing capacity of the site, which is essentially how much weight it can support
- its reactivity, i.e., how much the soil moves when the moisture content within the soil is varied.

The soil classification is the most important conclusion as an engineer uses this information to design a footing system/slab from AS 2870.

This report is passed on to the structural engineer who uses this data to design an appropriate footing system.

Engineer’s drawings and computations

Engineer’s drawings and structural computation documents give details about the structural members required to hold the structure up. The builder needs the specialised information detailed in these drawings and documents which is not normally given in the architectural drawings. The additional information is required due to the complexity of an element within the building. To avoid confusion this element is drawn at a larger scale so that a workable solution is resolved before construction commences. The scales may range from 1:20 up to 1:1 depending on the level of detail required.

The structural engineer interprets the contour plan with the working drawings and determines the height of retaining walls. The higher the wall, the stronger the design must be. Retaining walls over one metre high generally need to be designed by an engineer. Walls lower than this are considered to be garden walls and their design is not so critical.

BCA requirements

The Building Code of Australia (BCA) is produced and maintained by the Australian Building Codes Board (ABCB) on behalf of the Australian Government and each state and territory government.

The BCA provides technical information for the design and construction of building structures throughout Australia. It defines the minimum standards of relevant health and safety including structural safety. The BCA / NCC allows for varying climate, geological and geographic conditions. It is published in three volumes and a extract:

- Volume One has information regarding Class 2 to Class 9 buildings
- Volume Two has information regarding Class 1 and Class 10 buildings which includes houses, sheds, garages and carports.
- Volume Three pertains primarily to plumbing and drainage associated with all classes of buildings.
- The Performance Requirements extracted from Volumes One, Two and Three of the NCC and is referred to as the National Construction Code Performance Requirements Extract and is a supplementary book.
Note that these manuals are updated every year. Make sure you refer to a current edition.

It is particularly important that the relevant sections of the BCA are incorporated into the design and construction of structures being developed in these four classifications:

- bushfire areas
- high wind areas
- earthquake areas
- alpine environments.

When construction of buildings is proposed within these designated areas, it is important that project documentation is analysed to check that designs conform to BCA requirements.

All Class 1 buildings located in a designated bushfire prone area are to be constructed in accordance with the requirements of AS 3959 Construction of buildings in bushfire prone areas. There may be state or territory variations as indicated in the BCA.

AS 3959 provides a method of assessing the bushfire risk of a site by categorising the terrain including the slope and type of vegetation present. The categories of bushfire attack are:

- low
- medium
- high
- extreme.

Note that buildings within the low category of risk require no special construction techniques.

**Bushfire construction requirements**

The BCA provides construction requirements for each of the risk categories under lists of each element of construction for homes:

- floor systems
- external walls
- windows
- external doors
- vents and weepholes
- roof coverings, eaves and fascias
- roof lights
- roof ventilators
- roof mount evaporative coolers
- gutters and downpipes
- service pipes
- verandahs and decks.

For example, under flooring systems the following construction information is given:
<table>
<thead>
<tr>
<th>Risk</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low risk</td>
<td>No specific construction requirements</td>
</tr>
</tbody>
</table>
| Medium risk | a) concrete floors  
               b) suspended concrete floor  
               c) framed floor with all joists and/or bearers not less than 600 mm above finished ground level where:  
               - any timber bearers, joists or flooring are of fire retardant material  
               - the sub-floor space is fully enclosed with a wall complying with the requirements of this table for an external wall  
               - the sub-floor space is fully enclosed with non-combustible sheet material that extends not less than 400 mm above finished ground level and to the bottom of the wall cladding material. |
| High risk | Same requirements as for medium category                                       |
| Extreme risk | As for medium risk except that in the case of a framed floor where any bearer or joist is greater than 600 mm above the finished ground level and the floor is not enclosed, the bearers, joists and flooring must be fire retardant treated timber or sheeted underneath with non-combustible material. |

Refer to the BCA, Section 3.7.4 Bushfire areas for more information.

The BCA and related Australian Standards provide clear guidelines for the construction of buildings within the following wind regions:

- Region A - Normal
- Region B - Intermediate
- Region C - Tropical cyclones
- Region D - Severe tropical cyclones.

Note that high wind areas exist outside the cyclonic regions indicated on the map. High wind areas are regions that have design wind speeds which are calculated in accordance with AS 1170.2.

Refer to the BCA, Table 1.1.1 Design wind speed - equivalent values for more information.

**High wind construction requirements**

The BCA gives additional guidelines to ensure that buildings constructed in designated high wind areas are provided with sufficient restraint to transfer wind forces to the ground to prevent collapse, uplift or sliding of the footing systems.

This is achieved by:
appropriate anchorage systems
bracing systems which provide sufficient lateral restraint
structural elements which are adequately connected together.

For example, in cyclonic areas, metal roof systems and their connections and supporting members must comply with:

a) AS/NZS 1170.2 or AS 1170.2
or
b) be capable of remaining in position and resisting any permanent damage that may occur in the sheet or fastenings under pressure.

Refer to the BCA, *Section 3.10.1 High wind areas* for more information.

**High wind construction requirements**

Most residential construction conforms to earthquake design because the bracing that is used to provide stability against the wind also provides stability against earth movement.
Note: The **acceleration coefficient** is a number which indicates the expected severity of the earthquake ground movement as determined under AS 1170.4.

### Construction requirements for earthquake areas

Construction requirements for earthquake areas are necessary for buildings within areas of seismic activity. The two different areas are categorised by an acceleration coefficient which is:

- equal to 0.12 but less than 0.15 (detailed in Clause 3.10.2.3 of the BCA)
- 0.15 or greater (detailed in Clause 3.10.2.4 of the BCA).

Dwellings which are to be constructed in earthquake areas with a seismic activity acceleration coefficient of 0.12 or more satisfy performance requirements when:

- the soil profile of the site does not have more than 5 m of soft clay, loose sand, silt or uncontrolled fill
- they do not exceed a rise of one storey
- the roof is not clad with concrete or terracotta roof tiles
- they do not possess masonry chimneys, parapets or other masonry projections.

### Acceleration coefficients between 0.12 and 0.15

To comply with building regulations, buildings in areas where the acceleration coefficient is between 0.12 and 0.15 have additional requirements that must be met.
Footings

Additional requirements specify that:

- stumps must be steel, timber or reinforced concrete
- bracing stumps must comply with AS 1684 Part 2, 3 or 4
- floor beams must be fixed to the top of stumps with M10 diameter bolts or equivalent fixing
- bottom plates of framed structures fixed to a concrete slab or strip footing must be fixed with M10 bolts or masonry anchors no more than 1.2 m centres
- concrete strip footings must be continuously reinforced with two layers of reinforcement comprising two 12 mm diameter bars per layer and tied with R6 ligatures at centres not more than 2.5 times the depth of the footing
- raft slabs must incorporate monolithic edge beams.

Framed walls

The additional information separates details for metal and timber framing.

Metal framing must:

- not be less than 1.2 mm thick (other than bracing)
- have wall plates that are continuous between cross walls or spliced to maintain strength.

Timber framing must:

- be fixed with timber framing connectors nailed with not less than three 2.8 mm diameter x 30 mm long nails to each fixing plate of the connector
- be constructed of seasoned timber, fixed with at least two 2.8 mm diameter nails, machine nailed through the top or bottom wall plate into the stud
- use wall plates that are continuous between cross walls or spliced to maintain strength.

Unreinforced masonry

The five additional requirements for unreinforced masonry pertain to:

- internal or external walls (eg mortar mix)
- bricks (eg how they are laid)
- reinforcement (eg size and where they are placed)
- continuous reinforcement (eg where they are placed)
- top wall plates detailing how they must be fixed.

For more information refer to the BCA, Section 3.10.2.3.
Veneers

Veneers that comprise an external leaf or masonry connected to internal walls of timber or metal framing must be fixed in accordance with AS 3700.

Roof framing

Additional requirements specify that roof framing:

- must be fixed with timber framing connectors nailed with three or more 2.8 mm diameter x 30 mm long nails to each fixing plate of the connector
- must incorporate roof bracing to transfer all horizontal loads directly to cross walls.

Acceleration coefficients greater than 0.15

To comply with building regulations, buildings in areas where the acceleration coefficient is greater than 0.15 have the same requirements for footings, framed walls and roof framing as those areas where the acceleration coefficient is between 0.12 and 0.15.

The additional requirements for veneer on frame and metal framing construction are:

- further details on the wall plates (eg transfer lateral loads between frames)
- further details on how the external walls must be fixed to supporting cross walls.

In addition:

- the veneer of external walls must be fixed to the frame with 100 x 100 mm galvanised steel mesh
- masonry veneer must not be placed over openings or in gables.

Refer to the BCA, Section 3.10.2 Earthquake areas for more information.

Alpine areas are defined as those areas which are 1,200 m or more above Australian height datum (AHD) for NSW, ACT and Victoria and 900 m or more above AHD for Tasmania.

Sub-alpine areas are those areas 600 - 1,200 m in NSW, ACT and Victoria and between 300 - 900 m in Tasmania.

The BCA requirements only apply to alpine and sub-alpine areas in which the snow loads are significant. In some sub-alpine areas, successive snowfalls are not likely to accumulate and therefore the snow loads are not considered to be significant.
These areas require compliance to the BCA for the following:

- external doorways
- external ramps
- access bridges
- access for firefighting vehicles.

For example, external stairways, ramps, access bridges or other trafficable structures of a building must have:

- a floor surface that consists of steel mesh or other suitable material if it is used as an exit
- any required railing (balustrade) or other barrier constructed so that its sides are no more than 25% solid.

Refer to the BCA, Section 3.7.5 Alpine areas for more information.

**New technologies**

The BCA has requirements to allow for new and emerging building technologies. Any new technology must satisfy performance requirements and this can be determined by using the following assessment methods:

- documentary evidence
- verification methods
- expert judgement
- comparison to 'deemed to satisfy provisions'.

Further information on these assessment methods can be found in Section 1 of the BCA.
Materials must be chosen that are suitable for their purpose. Every part of the building must be constructed in an appropriate manner which satisfies all the requirements of the BCA.

Evidence of suitability

Substantial evidence must be provided to support the use of the new technology. It may be in the form of one or more of the following:

- a report issued by a registered testing authority
- a current Certificate of Conformity or a current Certificate of Accreditation
- a certificate from a professional engineer
- a current certificate issued by a product certification body that has been accredited by the Joint Accreditation Scheme of Australia and New Zealand
- a current Scientific Services Laboratory (SSL) product listing data sheet and listing in the latest issue of the Scientific Services Laboratory Register of Accredited Products
- any other form of documentary evidence that correctly describes the properties and performance of the new technology and adequately demonstrates its suitability for use.

Fire resistance of building elements

New technologies must demonstrate suitability and conform to the deemed to satisfy provisions in relation to the fire resistance level (FRL). These provisions are the provisions contained in Section 3 of the BCA which comply with the performance requirements.

Early fire hazard indices

New technologies must demonstrate suitability and conform to the deemed to satisfy provisions in relation to early fire hazard indices.
Units of measurement

The units of measurement for structural calculations are based on the SI units (International System of Units).

Basic units have lower case letters as their symbol such as \( m \) for metre, \( g \) for gram.

Prefixes are also used for larger or smaller values of a basic unit:

- mega (M) = one million or \( 10^6 \) times the basic unit
- kilo (k) = one thousand or \( 10^3 \) times the basic unit
- milli (m) = one thousandth or \( 10^{-3} \) times the basic unit.

A millimetre (mm) is one thousandth of a metre and a kilogram (kg) is 1000 grams.

Many of the units used in structural calculations are combinations of two or more other basic units. These are often complex and confusing to write, so they are given a name. Usually the name is based on some prominent person within that field of study, eg newton (N), pascal (Pa) etc.

These units have an upper case letter to denote them, for example:

- a kilonewton (kN) is 1,000 newtons
- a megapascal (MPa) is 1 million pascals.

Units of force

By definition, force = mass x acceleration or \( F = ma \)

The unit of acceleration is metres per second per second (m/s/s) or metre per second squared (m/s\(^2\)). If the acceleration is gravity, the acceleration is 9.8 metres per second squared (9.8 m/s\(^2\)). This figure is sometimes rounded off to 10 m/s\(^2\) which builds in a conservative factor of 2% on all load calculations.

So the units of force (in \( F = ma \)) are:

\[ F = kg \times m/s^2 \] or \( kg.m/s^2 \)

This unit of force has been given the name newton (N).

A force of 1 N is the force when an acceleration of 1 m/s\(^2\) acts on a mass of 1 kg.

\[ 1 \text{ N} = 1 \text{ kg} \times 1 \text{ m/s}^2 \]

The force produced by 1 kg when acted on by gravity is: \( 1 \text{ kg} \times 10 \text{ m/s}^2 = 10 \text{ N} \)

From this it follows that \( \frac{1}{10} \text{ kg} (100 \text{ g}) \) will produce a force of 1 N.
This is a very small unit compared to the weight of a structure. Therefore a larger more useable unit is required. In structures the unit used is the kilonewton (kN) where:

1 kN = 1,000 N

Therefore to convert mass to force units (kN) suitable for structural calculations:

\[
\text{kN} = \frac{\text{mass (kg)} \times 10 \text{ m/s}^2}{1,000} \times \frac{100}{\text{mass (kg)}}
\]

Units of pressure

Other loads that occur on buildings may be due to loads spread evenly over an area creating pressure. One such pressure is wind load which is the pressure wind exerts on a structure. The basic unit measurement for pressure is the pascal (Pa).

Pressure is force per unit area.

1 Pa = 1 N/m², ie one newton per square metre

To get some idea of the size of one pascal, imagine 100 g of sand (about \( \frac{1}{2} \) cup) spread evenly over an area of 1 m². This is the pressure exerted by one pascal. This unit is far too small for most structural calculations, therefore the larger units of kilopascals (kPa) and megapascals (MPa) are used.

A kilopascal is 1,000 N/m², ie 1 kPa = 1,000 N/m²

and 1,000 N = 1 kN

so 1 kPa = 1 kN/m²

The megapascal is 1,000,000 N/m² and there are 1,000,000 mm² in 1 m².

So 1 MPa = \( \frac{1,000,000 \text{ N}}{1,000,000 \text{ mm}^2} \)

1 MPa = 1 N/mm², ie one newton per square millimetre
1 N
1 m x 1 m = 1 N/m²

1 kPa = 1000 N/m² = 10⁻³ N/m²

1 MPa = 1000 000 N/m² = 10⁶ N/m² = 1 N/mm²
Structural principles - Loads

The structure of a building is the part which is responsible for maintaining the shape of the building under the influence of the forces to which it is subjected.

A building must be designed to safely withstand the most severe combination of forces or loads likely to be applied during its lifetime.

The loads that are to be assumed while designing a structure are usually specified in the ‘loading codes’ (see Australian Standard AS/NZS 1170. (The Standards are published documents which set out specifications and procedures to make sure of the quality and consistency of products in Australian society. They are issued by Standards Australia.)

In Australia we use the unit kilopascals (kPa) to measure stress and pressure, and kilonewtons (kN) to measure forces and loads.

Note: $1 \text{kPa} = 1 \text{kN/m}^2$

Primary loads

There are three primary loads which a structure must resist:

- dead load
- live load
- wind load.

Dead load

Volume of beam $10.0 \times 0.6 \times 0.3 = 1.8 \text{ m}^3$

Unit weight of reinforced concrete $= 24 \text{kN/m}^3$

Therefore, dead load of beam $= \text{volume} \times \text{unit weight}$

$= 1.8 \text{ m}^3 \times 24 \text{kN/m}^3$

$= 43.2 \text{kN}$

Dead load on a structure is the result of the weight of the permanent components such as beams, floor slabs, columns and walls. These components will produce the same constant 'dead' load during the lifespan of the building. Dead loads are exerted in the vertical plane.

**Dead load** = **volume of member** $\times$ **unit weight of materials**
By calculating the volume of each member and multiplying by the unit weight of the materials from which it is composed, an accurate dead load can be determined for each component.

The different components can then be added together to determine the dead load for the entire structure.

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit weight kN/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain concrete</td>
<td>23.5</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>24</td>
</tr>
<tr>
<td>Glass</td>
<td>25.5</td>
</tr>
<tr>
<td>Mild steel</td>
<td>77</td>
</tr>
<tr>
<td>Hardwood</td>
<td>11</td>
</tr>
<tr>
<td>Softwood</td>
<td>8</td>
</tr>
</tbody>
</table>

*Table 1: Dead load comparisons of various materials*

**Live load**

Area of floor = 6.0 m x 4.0 m = 24 m²

Live load rating of a house = 1.5 kPa

Therefore, live load of floor = 24 m² x 1.5 kPa = 36 kN

All unfixed items in a building such as people and furniture result in a ‘live’ load on the structure. Live loads are exerted in the vertical plane. Live loads are variable as they depend on usage and capacity, therefore the AS 1170 table provides allowances which are based on conservative estimates.

For example, the live load for a floor in a house is given as 1.5 kPa compared to a dance hall floor live load of 5.0 kPa. It is reasonable to expect that a dance hall would have more people in it than a house.
Houses | 1.5
---|---
Flats, apartments, motel bedrooms | 2.0
Offices | 3.0
Workshops | 5.0
Parking, vehicle > 2.5 t | 5.0
Hospitals, school assembly areas with fixed seating | 3.0
Dance halls, bars, lounges | 5.0

**Table 2: Live load comparisons**

Note that kPa and kN/m² are essentially the same units.

**Wind loads 1**

Wind loads have become very important in recent years due to the extensive use of lighter materials and more efficient building techniques. A Victorian era building with heavy masonry, timbers and slate tiles will not be affected by the wind load, but the structural design of a modern steel clad industrial building is dominated by the wind load.

Wind blowing against the building results in positive pressure which pushes against the building.

A vortex results in negative pressure which pulls at the building.

Wind acts both on the main structure and on the individual cladding units of a building. The structure has to be braced to resist the horizontal load and anchored to the ground to prevent the whole building from being blown away if the dead weight of the building is not sufficient to hold it down. Because of this, careful placement of bracing or other means of maintaining stability is necessary. It is also important to tie the roof materials to the supporting battens or rafters.

**Wind loads 2**

Wind load is considered to be dynamic as it varies greatly in intensity from time to time. Wind loads are very different to dead loads and live loads. Wind loads typically act laterally on walls and may act up and down on roofs.

**Wind pressure**

When wind flows around a building, it can produce some very high suction pressures. These occur mainly at the leading edges. In these areas, the cladding has to be firmly fixed to the structure and the roof has to be firmly held down. The flatter the roof, the higher the
suction forces are on the roof and the more important it is to make sure that the holding-down straps are fixed securely into the structure.

Moving air affects a structure by exerting pressure on it. This pressure varies with the velocity of the air (speed and direction) and also with the shape and orientation of the structure. For example for one-storey or two-storey buildings in Sydney, the design wind velocity could vary between 30 m/s for a fairly well-protected site and 50 m/s for an exposed site. Melbourne experiences fewer storms than Sydney, so the design velocity could be as low as 25 m/s.

The selection of the correct wind load for a particular part of a building is both critical and complex. Compared with live loads, wind loads are considerable.

Factors affecting wind loads

Geographic location: It is typically classified as cyclonic or non-cyclonic

Terrain category: The Terrain category gives a classification for the roughness of the area surrounding the building as obstructions tend to break up the wind. AS 4055 winds loads for housing sets out four terrain categories: TC1, TC2, TC2.5, TC3 with TC3 as the worst case.

Height of building: The height is relative to the ground level around the building to a maximum height of 8.5m for one-storey or two-storey buildings (as specified AS 4055)

Shielding: Shielding refers to the localised effects of the building shape where one part may shield another part from the wind. An open fence has different wind forces than a solid fence.

Building shape: The shape of the building such as roof pitch and openings in walls affects the pressures that form around the building. A flat plane shape offers more resistance to wind.
Calculating loads

Windward/Leeward

A diagram shows wind flow affecting a building. The wind flow is from left to right. The left side of the wall has windward pressure blowing on it, creating an area of high air pressure. The left side of the roof has windward pressure blowing on it. On the right side of the building, the roof has leeward pressure flowing from the roof creating an area of low pressure. The right wall of the building has leeward pressure (low pressure) flowing from the wall.

Wind load rates

The measurements of the building shown is as follows:

- height of the building is 6 m
- length of the building is 9 m
- width of the roof is 12 m

The wind load rates which affect the building are as follows:

- left wall = +1.5kN/m²
- left roof = +0.8kN/m²
- right room = -1.5kN/m²
- right wall = -0.8kN/m²

This gives an indication of the range of wind loads that may be experienced by a structure.

There is significant variation in these depending on the type of structure and its location.

Load paths
The **load path** is simply the direction in which each consecutive load will pass through connected members. The sequence commences at the highest point of the structure working all the way down to the footing system, ultimately transferring the total load of the structure to the foundation.

Ultimately, the lowest structural member must be strong enough to support all members above it. This is why engineers often design the uppermost members first and progressively work their way down the structure following the load path.

**Load path components in a concrete structure**

Part of the load path in a typical multi-storey reinforced concrete structure is made up of the following components.

A diagram shows a section of a multi-storey reinforced concrete structure made up of the following components:

- main beam which is supported by columns
- columns which are arranged in a grid pattern
- floor slabs which are supported by the main beams
- secondary beams which are supported by the main beams.

**Load path in a domestic structure**

The direction that loads are transferred through a structure is important and must be identified.

A simple domestic structure works on similar principles as a large concrete structure although the components are different:

- the foundation supports the footings
- the footings support the flooring structure which consist of bearers, joists and flooring
- the stud walls and bracing transfer their load to the flooring
- the roof trusses support the battens which support the roof cladding and this load is transferred to the walls.

**Load path components in a domestic structure**
A diagram shows the framing of the roof, wall, floor, footing and foundation of a building. The load of the path is shown in the diagram.

The roof has a load path that flows down through the walls to the foundation.

The wall load path flows down through the floor to the foundation.

The floor load path flows down through the footing to the foundation.

The footing load path flows down through to the foundation.

The foundation supports the footings.

Secondary loads

Buildings may also be subjected to additional (secondary) loads that may occur due to the environments in which they are constructed. These loads may not always occur and engineers consider their impact on a structure after they have addressed the primary loads. Secondary loads may include:

Snow loads

Snow loads in Australia are restricted to alpine zones for a small part of the year. In these locations, buildings have to be designed to withstand the appropriate amount of snow. The size of the snow load depends on the altitude of the site.

The shape of the roof also plays an important part in the size of the snow load. Snow falling on a flat roof continues to build up and the load increases. The steeper the pitch, the smaller the load as snow will slide off a steep roof much sooner. A pitch roof has some slope or steepness. A roof with a steep pitch has a steeply sloping roof.

A picture is shown with snow sliding off the roof of a building.
Shrinkage loads

Over a period of time, certain building materials such as concrete will shrink, while bricks will expand. Concrete shrinks over time because the cement paste in the concrete slowly dries out. On the other hand, clay bricks expand over time because the moisture content increases. It is therefore important to avoid a combination of bricks and concrete that act in opposition to each other.

If clay bricks are held within a concrete frame, they have a tendency to bow outward as the bricks expand and the concrete shrinks. This causes stresses which may cause cracking.

Cracking can be prevented by providing shrinkage joints which contain a flexible material that moves with the stresses. Alternatively, concrete can be strengthened with steel reinforcement so that it has enough strength to cope with shrinkage.

A picture of a brick wall with a gap in the middle is shown. In the gap is a rubber tube, which is compressible material for handling the stress to prevent cracking.

Thermal loads

All building materials expand or contract with temperature change. A concrete bridge 1 km long will expand about 400 mm between winter and summer. This is why expansion joints and movable bearings are incorporated into a structure so that thermal movement can take place without causing any damage.

Long continuous buildings will expand in exactly the same way and so the expansion stresses need to be considered. To do this, a reinforced concrete-framed building is usually divided into lengths of 30 m or less and a brick wall is divided into lengths of 10 m or less. Expansion joints are provided at these points so that the structure is physically separated and can expand without causing structural damage.

A picture shows a section of a corridor. From the ceiling to the floor you can see the reinforced concrete-frame. There is space between the concrete-frame at the joint to allow for the material to expand. There is an expansion joint running from the ceiling down the wall and across the floor. This joint connects the steel framing. There is a man standing in the corridor looking at the expansion joint.
Settlement loads

Stresses are likely to occur when one part of a building settles at a faster rate than another. This effect is commonly referred to as **differential settlement**. If the structure contains control joints, the effect of stresses will be minimal, but if the structure has no control joints, the stresses will be severe and may result in significant structural damage.

A high-rise office tower attached to a lower height convention centre will experience these effects unless the two buildings are physically separated or joined together with a flexible structure.

Factors such as the bearing capacity of the soil also need to be incorporated into the design of a building. That is why soil testing is required for domestic construction and engineering advice for problem sites.

A picture of a framed wall showing the foundation and the soil line above the foundation is shown. There is a dotted line representing the original frame that was straight. The soil line has sunk in an area resulting in a section of the frame being lower than the other sections.
Dynamic loads

**Dynamic loads**, which include impact and aerodynamic loads, are complex and varied. Impact loads may result from vehicle collisions or plant and equipment such as gantry cranes (a gantry crane is a crane which is suspended from a large spanning metal framework). Aerodynamic loads may result from the movement of air around slender building elements such as stacks (a stack is a chimney or funnel structure for the release of smoke or exhaust gases) or aerials. This may result in vibration that is transferred through the building structure.

There are ways of minimising the effect of dynamic loads, such as installing anti-vibration pads to a vibrating air-conditioning unit on a roof or additional cable stays to a stack.

A diagram shows a flue stack on a roof connected by two cables. The wind blows onto one side of the cable.
Seismic loads

Seismic loads are loads caused by earthquakes. Buildings should be designed to withstand minor earthquakes because they can occur almost anywhere. During an earthquake the ground can move both horizontally and vertically in any direction. This exerts tremendous horizontal loads onto members.

The methods of protecting against high winds can also be used for protecting against earthquakes. To avoid collapse, oscillations are damped to prevent damage to both structural and non-structural members.

A seismic design should make allowance for large drift by providing gaps between adjoining buildings. Gaps should also be provided between adjoining components that are not required to be rigidly connected together to allow these components to slide. For example, partitions and windows should be free to move in their frames so that no damage occurs when an earthquake causes movement.

A diagram of a building is shown. Waves beneath the building indicate seismic activity. Arrows on the diagram and dotted lines indicate potential movement from the loads caused by this seismic activity. These show the walls moving inwards and outwards, and the floor, ceiling and roof moving up and down.

Nature of load

As well as considering the different types of loading we have to consider the nature of loads.

Point load

A often abbreviated to P or L) is a load acting at a single point. It is sometimes called a concentrated load.

An example of this is a roof truss (a truss is a combination of members such as beams and ties that are connected in a triangular shape to form a rigid framework) supported on a top plate (the top plate is the beam at the top of wall framing on which the roof structure rests).
As the contact area of a truss on the top plate is small, the load is assumed to be concentrated at a point.

A diagram shows a plank of timber appearing horizontally above a roof truss. At the end of the plank is an arrow showing the information P or L units kN. On either side of the roof truss is a top plate. Where the top plate and roof truss intersects is an arrow indicating P or L.

Point loads are represented by an arrow in the direction the load acts and are expressed in units of kN.

**Uniformly distributed load**

A uniformly distributed load (UDL) is a load that is evenly spread along a length or across an area. For example, the loads supported by a typical beam include:

- the beam's own weight
- the weight of the floor slab it is supporting
- the live load supported by the floor slab.

These loads are consistent along the entire length of the beam. The load may be represented as rate per lineal metre (kN/m) for beams, or as a rate per square metre (kN/m²) for slabs.

A diagram shows a beam with the load distributed all along its length. The load is labelled UDL with units shown as kN/m or kN/m².
A reinforced concrete beam is displayed and labelled with UDL equal to 4.3 kN/m. A reinforced concrete slab is displayed and labelled 2.7 kN/m.

**Uniformly varying load**

A uniformly varying load is a load that is distributed along the length of a linear element such as a beam, but instead of the load being evenly spread it varies in a linear fashion.

A common example of this is a retaining wall. A retaining wall is designed to hold back earth, which exerts a horizontal force on the back of the retaining wall. The horizontal force on the retaining wall becomes greater the further down the wall you go. Thus the force will be zero at the top of the wall and will increase linearly to a maximum value at the bottom of the wall.

A diagram shows a vertical section through a retaining wall. The retaining wall is in the shape of an upside down ‘T’. The earth to the left of the wall is labelled ‘retained earth pushes horizontally at back of wall’.

Beside this diagram is a symbolic representation of a uniformly varying load on a retaining wall. This shows a number of arrows pointing to the right. The length of these arrows indicates the strength of the load on the wall at different heights. The load is smallest at the top of the wall and greatest at the base of the wall. A right angled triangle is drawn around these arrows to further illustrate this point.

**Moments**

Moments are a measure of the turning effect of a force around a specified turning point or pivot.
A moment is a force times a distance. The unit used to measure a moment is newton metres (Nm).

\[ M = F \times d \]

\[ M = 10 \text{ N} \times 5 \text{ m} \]

\[ M = 50 \text{ Nm} \]

Note that the units are Nm (newton metres) not N/m (newtons per metre).

The direction of a moment is **opposite** to the direction of the force.
The convention is that:

- **clockwise** moments are positive
- **anti-clockwise** moments are negative.
Structural principles - Forces

In any building design, the strength and stability of an overall building and its individual components must be considered. This involves structural calculations to work out the effects of all the forces acting on any component in the building and on the building overall. To do this we need to resolve the forces in the system to see what the overall effects are likely to be.

An overview of the many different forces acting on a building.

A summary of all the forces acting on the building.

The dotted arrow is the resultant force, a force representing the overall effect of the loads.

Vectors

Forces can be represented by arrows called vectors. Vectors have three properties which enable a force to be completely represented:

1. Magnitude - how big is the force?
2. Direction - in which direction is the force acting?
3. Position - where on the body does the force act?
Graphical solutions of forces

Vectors are drawn on graph paper to a suitable scale. All vectors are drawn:

- to a **length** that shows their magnitude
- with **arrow heads** indicating direction and the **arrow tail** indicating their point of origin.

Note the convention of giving forces a positive or negative value, where forces in the \(\rightarrow\) and \(\uparrow\) directions are positive and forces in the \(\leftarrow\) and \(\uparrow\) directions are negative.

A suitable scale could be 1 mm:1 kN or alternatively 10 mm:100 kN depending on the situation.

Step 1: There are two forces acting on the roof of this structure - a wind load and a dead load shown by the vectors WL and DL.

![Vectors on a graph paper](image)

Step 2: Drag the wind load vector WL onto the grid so that the arrows meet 'head to tail' ie the arrow (or head) of one meets the end (tail) of the other

Step 3: Identify the point where the resultant force starts, then draw an arrow showing the resultant force.
Newton's laws of motion

The unit of force is the **newton (N)** named after Sir Isaac Newton (1642 - 1727). He observed apples falling from a tree and realised that the force produced by a falling apple is equal to its mass times the earth's gravitational pull. He established the analysis and the theory to predict forces and resulting motion.

A **newton** is the force which when applied to a body of mass of 1 kilogram causes an acceleration of 1 metre per second in the direction in which the force is applied.

The earth's gravitational pull is approximately 9.81 m/s\(^2\) so 1 kg will produce a force of 9.81 N. This figure is often rounded up to 10 N for ease of use.

1 kg mass produces a force of 10N.
100 kg mass produces a force of 1,000 N.
1,000 kg mass produces a force of 10 kN.

Newton's first law of motion

Sir Isaac Newton developed three laws of motion.

**Newton's first law - An object will remain at rest or in uniform motion unless compelled to do otherwise by some external force acting on it.**

For example, a book lying on a table will remain there unless some external force moves it. A car travelling at uniform speed will continue to do so unless the brakes or friction are applied (force) or it hits an object (force) which slows its motion or stops it.

In buildings, most of the framework is stationary and must remain so under the applied forces. Some minimum movements called deflection and deformation (mainly bending and buckling) may occur under loading. If movement occurs that is not allowed for, structural failure may result. Buildings are designed to maintain a state of equilibrium, which is the ability to resist any external loads without moving.
Newton's second law of motion

Newton's second law - A force is caused by an acceleration acting on an object.

The most common form of acceleration is gravity. All objects are pulled towards the earth by gravity. Gravity acting on a mass produces the effect commonly known as weight which is really a type of force.

Newton's second law can be written as a mathematical equation.

$$\text{force} = \text{mass} \times \text{acceleration}$$

$$f = m \times a \text{ or } f = ma$$

Force is a push or pull which is applied to an object. Force is measured in newtons (N).

Mass is the mass or weight of the object to which the force is being applied. Mass is measured in kilograms (kg).

Acceleration is any change in the speed or velocity of the object, i.e., speeding up or slowing down. Acceleration is measured in metres per second per second (m/s$^2$).

Newton's third law of motion

Newton's third law - Action and reaction are equal and opposite.

For example, a building has a force applied to the corner.

Diagram 1

A diagram shows a building without a brace. The resultant force pushes down on the left side of the building. The building moves left and right under the pressure. The building ultimately tilts to the left due to the pressure.
Diagram 2

A diagram shows a building with a brace supporting the left corner of the building. The resultant force pushes down on the left side of the building. The pressure from the resultant force is offset by a reaction force moving diagonally up the brace.

Statics

Statics is the study of the causes and effects of stationary forces acting on rigid, stationary objects. A ‘static body’ is a body which has no resulting motion from all the applied forces on it and is therefore stationary or in equilibrium.

Three basic equations must hold true if the system is to remain static. These are called the three basic equations of statics:

1. The sum of all vertical forces ($F_v$) in the system must be zero.
2. The sum of all horizontal forces ($F_h$) in the system must be zero.
3. The sum of all bending forces - also called moments ($M$) - in the system must be zero.

Point load on a beam

This force system has two 3 kN forces shared between the two columns.

To keep the beam in equilibrium, the sum of the reaction forces must be equal and opposite to the resultant.
Stress

Stress occurs in any material which supports a load. Stress is the way a material transfers the load through its molecules. It's like an internal pressure resisting the external applied loads.

\[ \text{stress} = \frac{\text{force}}{\text{area}} \]

Stress, like pressure, is force per unit area, i.e.

Remember that force is measured in units of newtons (N) or kilonewtons (kN) and the unit of area is square millimetres (mm\(^2\)) or square metres (m\(^2\)).

Stress is measured in pascals (Pa), kilopascals (kPa) or megapascals (MPa). The most common unit used for structural materials is MPa as the other units are too small. For example, the concrete strength for a typical reinforced concrete slab is 25 MPa.

Strain

Strain is the term applied to deformation (or change of shape) of an object when a load is placed on it. Delicate measuring instruments such as strain gauges may be needed to detect the amount of deformation.

The amount of deformation compared to the original shape is called strain and is represented by the letter ‘e’.

This is a ratio which has no units:

\[ e = \frac{\text{change in dimension}}{\text{original dimension}} \]

Deformation is usually denoted by \( \Delta \) (delta) and generally refers to small deformations. For example, the strain in a beam under load is the change in length (\( \Delta L \)) compared to the original length (L) measured in millimetres.

\[ \text{strain} = \frac{\text{change in length}}{\text{original length}} \quad \text{or} \quad e = \frac{\Delta L}{L} \]

Types of stress

The term 'stress' can be used in many ways with many forms of stress occurring throughout structures:

Types of stress

Tensile

Tensile stress is when a member is subject to tension forces.
A diagram is shown of a member (a long rectangular box shape) with forces indicated by arrows extending outwards at either end of the member.

Compressive

Compressive stress is when a member is subject to compressive forces.

A diagram is shown of a member (a long rectangular box shape) with forces pushing inwards at both ends.

Shear

Shear stress is the shearing action of vertical loads and horizontal shearing due to bending. The region of shear is parallel to the direction of force.
A diagram shows the shear stresses in a bolt caused by the bar attached to it. Tension stresses act within the bolt, pulling outwards in both directions along its length. Shear stresses are indicated as acting on the bolt.

**Bending**

Bending stress occurs as a beam bends and it is subject to a combination of compressive, tensile and shear stresses.

A diagram is shown of a member with supports at each end. The neutral axis is drawn as a dotted line along the middle of the member, running along the full length of the member.

Loads are pushing down on the member causing it to bend downwards in the middle. The upper part of the member is under compression and the lower part of the member is under tension.

**Torsional**

Torsional stress occurs when a member is twisted along its length. Torsion is usually related to rotational twisting. Twisting moments are produced by forces which are at right angles to the plane of the structure. The centre line of the structure stays straight.
A diagram shows a beam supported at both ends. A load is indicated near the middle of the beam, acting downward. The beam shows distortion in this area as a result of this load.

**Bearing**

Bearing stress is the stress that develops when one structural member rests on another.

A diagram is shown of a member jutting outwards from a wall (ie it is supported at one end only). A bearing stress is indicated underneath the member at the point where it is supported at the wall.

**Yield**

Yield stress is the amount of stress that will cause failure of a material. Failure occurs at the value of stress at the ultimate strength.

A graph is shown with the vertical axis labelled Stress (N/mm$^2$) and the horizontal axis labelled ‘Stress-strain diagram for mild steel’.
The graph starts at the intersection of the axis as a straight line sloping upwards to the right. Along this straight section of the graph, the point where stress = 165 is labelled ‘Max permissible stress’. At the top of this straight section, which occurs where stress = 200, the graph bends suddenly downwards, and this point is labelled ‘Yield point’. After a small straight section here, it then curves upwards again to a high point then begins to curve downwards again. The end of this downwards curve, which occurs slightly below the maximum stress level, is labelled ‘Ultimate strength’.

These stresses can be calculated with a high degree of accuracy. Hence we can predict a structural member’s performance if we compare the stresses that it can take before it reaches its yield point, compared to the actual stresses it will be subject to once all the loads have been calculated. A material can still perform after yield stress. Once material is past the yield stress point it is in the elastic zone, then it is in the plastic zone. Materials return to their original length when stressed in elastic zone, but deform once stressed passed yield stress point.
Structural Principles - Properties

The type of material used and the shape of a structural member have a significant impact upon its structural effectiveness.

Strength

The strength of a structural member is the resistance it is able to offer to the load that will just cause fracture, for example, the resistance that 1 mm$^2$ of section can offer to the load that will just cause fracture. This breaking strength is also referred to as 'ultimate strength'.

Toughness

Toughness can be defined as the resistance to fracture of a material by repeated bending or twisting after its yield point (which is the point at which a material bends or breaks) has been passed. There are several tests for this property, such as observing the number of times a bar of the material will twist prior to fracture, or the number of repeated bendings it can be subjected to under given conditions. Another is the bend test under which a specimen should be capable of being bent through a specified angle and show no sign of fracture.

Elasticity

Almost all solid materials have some degree of elasticity. A material is said to behave elastically if it deforms with loading and then returns to its original shape when the loads are removed. This ability to behave elastically is particularly important in structural design.

A series of three diagrams is shown to illustrate elastic behaviour.

![Elastic behaviour diagram](image)

The first diagram shows a picture of a horizontal member. The second diagram shows the member with a load pressure on it causing it to bend. The third diagram shows the member returned to its original horizontal position as the load is removed.

Plasticity
Plasticity is the reverse of elasticity. If a material deforms when loaded and does not return to its original shape when the load is removed, permanent deformation occurs. This is called ‘plastic behaviour’. A plastic material will retain exactly the shape it becomes under load even when the load is removed.

A series of three diagrams is shown to illustrate plastic behaviour.

The first diagrams shows a picture of a horizontal member. The second diagram shows the member with a load pressure on it causing it to bend. The third diagram shows the same member without the load, however it remains bent and does not return to its original state. The member is slightly bent in the middle. This is permanent deflection.

**Ductility**

Ductility is the property which enables a material to be drawn out in the direction of its length, for example, wire. It is a valuable property because a ductile material will not fail suddenly or snap off suddenly without giving some warning by lengthening before it fails.

**Malleability**

Malleability means that a material can be hammered or otherwise worked into various shapes. In some ways this property is similar to ductility.

**Brittleness**

Brittleness is the property which causes a material to break or snap off without any noticeable lengthening. It is the reverse of ductility. It is clearly a very undesirable property in building materials, as brittle materials give no warning of approaching failure.

Brittleness is often caused by fatigue, a condition for which there is no exact definition. Fatigue is frequently accompanied by a gradual coarsening of the structure of a material under the stress of repeated vibration. It can be described as a deterioration of mechanical properties which results from the varying and repeated stresses being applied.

**Hardness**

The term hardness is usually defined as the degree of resistance to indentation (a gap or space cause by a force being applied) or abrasion (the result of friction by rubbing or
grinding which causes material to wear). It is also used to refer to the resistance of a material to scratching. There are several tests for hardness. One of these is to observe the number of times a bar of the material will twist prior to fracture, or the number of bendings it will tolerate under given conditions. Another test is the bend test, under which a sample of the material should show no sign of fracture when bent through a specified angle.
Structural principles - Structural members

Structural members are the primary load bearing components of a building. The structure of a building constitutes about 30% of the construction cost. Good structural design can result in cost efficient building.

Types of beams

Beams are generally horizontal members which transfer loads horizontally along their length to the supports where the loads are usually resolved into vertical forces.

Simply supported beams

Simply supported beams are supported at each end only.

A diagram of a simple beam supported at each end is shown. If downwards pressure is applied bending would occur at the middle of the beam.

Continuously supported beams

Continuously supported beams are supported by three or more support points. They deflect less than simple beams of the same span because the positive and negative bending cancel each other out. Generally a continuous span is 20% more efficient than a simple span as it is able to span longer distances.
A diagram of a simple beam supported at each end and in the middle of the beam. Bending downwards occurs in between the first support and the middle support, and again between the middle support and the end support. The beam bends upwards at the middle support.

**Cantilever beams**

Cantilever beams overhang their supports. The cantilever section of the beam cannot support the same loads as the **back span** which is the section of beam between the supports. A typical allowance for the amount of cantilever in a beam is 30% of the back span therefore a 45 m beam could have a cantilever section 15 m long.

A diagram shows a simple beam supported at one end and at 30% from the other end. For this beam the bending occurs between the support.

**Bending in beams**

When a beam carries loads, complex stresses build up in the material of the beam. The bending that results from the loading causes some beam fibres to:

- carry tension - these are called **tensile** forces
- carry compression - these are called **compressive** forces
- take **shear** forces.

These all occur simultaneously.
Bending theory is complex and relies on mathematical modelling for solutions. The theory includes the concepts of bending moments and shear forces.

When a structural engineer designs a beam the key concerns are:

- bending
- shear
- deflection.

**Neutral axis**

From the top fibre of a beam to the central fibre, the fibres are in compression. The compression gradually decreases from a maximum at the top of the beam until it is zero at the centre. The centre is called the **neutral axis (N/A)**. From the neutral axis to the bottom fibre, the fibres are in tension. The tension gradually increases from zero at the centre to a maximum at the bottom fibre.

**Internal moment of resistance**

When a beam bends under load, the horizontal fibres will change in length. The top fibres will become shorter and the bottom fibres will become longer. The most extreme top fibre will be under the greatest amount of **compression** while the most extreme bottom fibre will be under the greatest amount of **tension**.
Internal moment of resistance

Beam load 1

A simple graph can be drawn to represent the internal stresses in the beam.

The graph shows a vertical line with a dotted horizontal line drawn midway along it. This midline is labelled ‘N/A’ (neutral axis). Above this neutral axis a triangle is drawn to the left of the line and an arrow labelled ‘C’ (for compression) points to the left. Below the neutral axis is another triangle, drawn to the left of the line, and an arrow labelled ‘T’ (for tension) points to the right. These triangles indicate that the amount of compression and tension in the beam increases in a linear way as you move further from the neutral axis.

Beam load 2

The maximum compressive stress C (from compression) and the maximum tensile stress T (from tension) occur where the beam bends the most. The neutral axis N/A is in the centre of the beam.

A diagram shows the beam under load bent into a U shape. The neutral axis (N/A) is drawn midway along the whole length of the beam. Compression forces (labelled C) are drawn
above the beam pointing towards each other halfway along the beam. Tension forces (labelled T) are drawn below the beam, pointing away from each other halfway along the beam.

A graphical representation of this shows arrows for compression above the neutral axis, and arrows for tension (pointing in the same direction) below the neutral axis. These arrows are shortest near the neutral axis and increase steadily in length further away from the neutral axis.

**Beam load 3**

The final graph is the resultant graph which indicates the internal stresses.

This graph shows compressive stresses above the neutral axis, pointing to the left, and tensile stresses below the neutral axis, pointing to the right. In both cases, the stresses increase steadily in length further from the neutral axis.

An engineer determines the centroids of the triangular shapes of the stress diagram. This provides the value of the total compressive and tensile forces acting in the beam. These centroids are a proportional distance apart which is referred to as the **moment arm**.

The moment arm provides the value for moments that the beam must resist if it is to remain structurally sound. In technical terms it is referred to as the **internal moment of resistance**.
The tensile and compressive stresses result in a turning effect about the neutral axis. These are called moment $M_T$ and $M_C$ respectively. The chosen beam must be able to resist these moments with $M_R$ (internal moment of resistance) if it is to remain in equilibrium.

**Beam shape**

The stress diagrams below show that most of the stress occurs two thirds of the distance from the neutral axis, so this is where a beam requires most of the structural material. Rectangular sections are wasteful of material compared with an I beam which is very efficient.

Generally the further the structural material is from the centroid, the more structurally efficient the beam will be. However, if it is too far from the centroid, the beam will reach a stage when the member becomes too slender and will buckle.

**Bending moments**

The bending moment is the amount of bending that occurs in a beam. It is a calculation used to identify where the greatest amount of bending takes place.
For most beams with a uniformly distributed load (UDL), this bending occurs mid-span. The type of load and its location has a significant impact on the overall bending of a beam.

**Shear forces**

Vertical shear forces are generated in a beam by the applied loads and by the support reaction. The reactions push up while the load pushes down. In most cases the maximum value of shear occurs close to the supports.

Look at the first diagram and imagine a stack of books pressed together between your hands. The books that are furthest from your hands (your hands are the supports) are the ones which are most likely to experience shear forces and are the most likely to slip.

The second diagram is a simple graph that has been drawn to represent the amount of shear force in the beam. There are a number of common situations of shear forces in beams which are discussed in the activity.

**Beam penetrations**

Service holes through beams may be necessary for cabling or plumbing. The positioning of these holes must be carefully considered as they could seriously affect the structural integrity of the beam.

Areas of high stress should be avoided close to the supports where the shear force is at a maximum and also at mid-span where the bending stress is at a maximum. This leaves the zones along the neutral axis and a point of compromise between the mid-span and supports.
Deflection limits

Deflection in beams is a major issue in structural design. Engineers adopt deflection limits which suit the nature of the building. For example, according to AS 1170.1 Minimum design loads on structures (known as the SAA Loading Code):

maximum allowable deflection = span ÷ 300

This means that to calculate the deflection in a beam which spans 6,000 mm, divide 6,000 by 300.

6,000 ÷ 300 = 20

So a span of 6,000 mm has a maximum allowable deflection of 20 mm.

Actual deflection

Next the engineer calculates the actual deflection of the particular beam. The factors that need to be considered when calculating deflections are span, load, beam shape, material properties, end fixity and camber.

Span

The longer the span, the greater the deflection. The load on the beam is 2 kN and the beam is supported at both ends. As the beam increases in length the deflection also increases.
Load

Point loads and uniformly distributed loads have different effects on the deflection of a beam. However, in both cases an increase in the load results in a greater deflection.

A diagram shows a beam supported at both ends.

With a 2 kN load there is a slight deflection.

With a load of 4 kN the deflection is greater.

Beam shape

This property is represented by the second moment of area (or moment of inertia) which evaluates the resistance of a shape to bending. The same beam resting on its edge will bend differently to the beam resting on the flat side as the beam on edge has more resistance to deflection.
A diagram shows two beams, each resting on two supports. Each beam has a 2 kN load being applied at its central point. Both beams have an 'I' shaped cross-section, but for the first beam the 'I' is longer and thinner. The first beam is not deflected as much as the second beam.

Note that although the cross-sectional area is identical for both beams, they function differently in different positions.

Material

This is the relative strength of the material represented by the modulus of elasticity (also known as Young's modulus and is a measure of the stiffness of material), eg mild steel is stronger than aluminium and will bend less under load.

A diagram shows two beams, one of steel and one of aluminium. Each beam is supported at both ends, with a 2 kN load.

The deflection of the steel beam is not as great as the deflection of the aluminium beam.

End fixity

The way the beam is attached to the supports will affect the amount of deflection. A beam that is rigidly held in place will deflect less than one that is free to slide or rotate.

Image 1

A picture of a beam supported by two brick members. There is a 2 kN load on the beam. Deflection does not affect the ends of the beam that is connected to the brick wall. Deflection affects the middle of the beam only.
**Image 2**

A beam is placed on two round members and is free to slide. There is a 2 kN load and the deflection is much greater than in image 1.

**Camber**

A designer may deliberately incorporate **camber** (a bend) into a beam knowing that there will be some degree of deflection in the beam. The camber is placed in the opposite direction to the deflection and is equal to the amount that the beam is expected to deflect.

The deflection in the first beam is shown relative to its original position before the load has been applied. This deflection is the same as the amount of camber built into the second beam so that when deflected the second beam will flatten out.

**Image 1**

A picture of a beam after a load has been applied. The beam is deflected in the middle so it forms a slight 'U' shape.

**Image 2**

A picture of a beam that starts off curved upwards so when the load is applied it flattens out.

**Columns**

Columns are vertical support members subjected to compressive loads. They are also referred to as pillars, posts, stanchions and struts.
The most efficient shape for a column is the circular hollow section (CHS).

The second most efficient shape is the square hollow section (SHS).

**Circular hollow section (CHS)  Square hollow section (SHS)**

**Axially loaded column**

When the load is central to the centre of gravity axis, it produces a direct compressive stress within the column. Axially loaded columns are sometimes referred to as ‘concentric columns’.

A diagram shows the load is applied to the middle of the column where the centre of gravity axis is.

**Non-axially loaded column**
When the load is off-centre the column is called an 'eccentric column'. This results in bending and compressive stress being applied to the column.

A diagram shows the load applied to the right of the centre of gravity axis on a column. The distance between the centre of gravity axis and the point at which the load is applied is labelled 'Eccentricity'.

**Buckling**

Buckling is a major consideration in designing all compression members. Buckling is deformation (deflection, bending) at right angles to the direction of the applied load.

Buckling will always occur about the weakest axis unless some form of lateral (sideways) restraint is used to prevent it. The longer and/or more slender the member, the more likely it is to buckle under compressive forces. Therefore a long member can carry less load than a short one of the same cross-section.

The tendency to buckle increases with the strength of the material. As the material gets stronger, the cross-sectional area required to carry the stress decreases. This produces more slender struts which are more likely to buckle.
Image 1

A picture of load applied to a thin column. The column bends under the pressure.

The failure of long slender columns is due to buckling (typically timber or steel columns).

Image 2

A picture of load applied to a thick column. The column bulges outwards as the pressure is applied.

The failure of short squat columns is due to crushing (typically reinforced concrete columns).

Wind bracing

Most buildings are designed strongly enough to support the vertical loads created by dead loads and live loads. However, they also need to be able to resist lateral loads from wind loads. Numerous techniques can be used to overcome this problem.

Diagonal bracing

Diagonal components of bracing interconnect and stiffen columns and beams. The main types of bracing are:

When using cable for cross bracing, it is necessary to use two cables to stabilise the structure against lateral forces from both directions. One cable will work effectively in tension while the other would just buckle. If rigid bracing is used, a single brace will stabilise the structure.

Any of these methods may be used singly or in combination to stabilise a structure.

Rigid joints between beams and columns

A rigid joint method can be developed for very tall buildings to form a rigid external 'tube'. Instead of having cross bracing, the external structure is stiffened by very deep beams and wide columns.
'Bents' are braced or fixed frames which are designed to carry both vertical and lateral loads across the length of a framed structure.

Lateral forces can be more critical across the width of a rectangular building. Usually shear walls or brace frames are used as they are more efficient.

Any of the force resisting elements which work across the building also work along the length of the building.

Shear wall

In the shear wall method, the supporting structure consists of walls which resist lateral loads. The shear walls are preferred over columns and beams.

Shear wall

A picture shows a section of a building consisting of a roof, a horizontal floor, two walls (one a shear wall) opposite each other and two frames – one rigid and one braced frame – opposite each other. Arrows represent loads that travel across the roof from the braced frame towards the rigid frame, and from the rigid frame across the roof towards the braced frame.
frame. The arrows from the braced frame also run along the top and bottom of the shear wall (towards the braced frame at the top and away from it at the bottom), as well as up the shear wall from the bottom corner near the braced frame and down the shear wall on the bottom corner near the rigid frame.

**Rigid frame**: A steel or reinforced concrete frame with rigid joints will resist changes resulting from forces in different directions.

**Shear wall**: A wood, concrete or masonry wall will resist changes in shape. The wall will transfer lateral loads to the foundation.

**Braced frame**: The frame is timber or steel and is braced with diagonal members.

**Horizontal floor**: A rigid floor structure is like a deep flat beam. The floor transfers lateral loads to the shear walls and to the braced or rigid frames.

**Lift shaft with solid walls**

Most office blocks are made stiff by using an internal concrete shaft as a stiff central core to which all the floors are rigidly fixed.

The floors act as horizontal diaphragms which transfer the stiffness from the core to the whole building.

![Core](image)

**Theory of triangulation**

Triangulation involves the use of triangular shapes to give stability to structures. It relates particularly to pinned or hinged structures. Usually these types of structures offer no resistance to bending moments when a force is applied.

Members trying to resist bending do not need to be as strong. However they can easily be pushed out of shape by external forces and hence are not in equilibrium, ie $\Sigma F_H \neq 0$.

**Structure with no bracing member**

This structure has pinned joints but has no bracing.
A diagram of a structure with no bracing is shown with force applied to the left side of the structure. The structure will bend to the right due to the force.

**Structure with a bracing member in tension (tie)**

Triangles create stability when added to a structure. Diagonal bracing in the form of a tie has been inserted into this structure. This bracing member is in tension. Note that all the joints are still pinned, so they do not need to resist bending moments.

A diagram of a structure with a tie is shown. The tie spans diagonally from the bottom left hand corner to the top right hand corner. When force is applied to the structure from the left the tie pushes the force from the middle back to the corners. The structure remains in the original position.

**Structure with a bracing member in compression (strut)**

In this structure the brace is a strut as it is in compression.

A diagram of a structure with a strut is shown. The strut spans diagonally from the bottom left hand corner to the top right hand corner. When force is applied to the structure from the right the force travels to the middle of the strut. The structure remains in the original position.
It may be necessary to use a sectional shape that works well under both tension and compression.
Roof trusses

Roof trusses are load bearing frames constructed of connected triangular shapes. They take advantage of a triangle's natural attributes, its strength and its stability.

The members forming the triangles have pinned joints. These types of joints have the property that all the bending moments within the truss are eliminated. The members making up the truss are either in compression or tension, unlike beams which experience tension and compression at the same time. This is the reason that trusses are more efficient at supporting loads over wider spans than simple beams.

Note that other types of joints such as gang nailing are used in roof trusses. The tension and compression computations for these are different to those for pinned joints.

Comparison of truss and beam

Truss terminology

Different parts of the truss are known by a variety of terms.
A diagram of a roof truss is shown with the following information:

- **Apex** - the highest point of the truss
- **Top cord** - the piece of timber which runs to the top of the truss
- **Web** - is a short timber which runs from the bottom chord to the top chord
- **Panel point** - is where the web meets the top chord. It is the strongest point for lifting the truss
- **Heel** - is where the bottom chord meets the top chord
- **Bottom chord** - is the large horizontal member (timber or steel) at the bottom of the truss
- **Truss span** - is the length of the bottom beam that spans the wall frames
- **Pitch** - is the angle the top chord makes with the bottom chord
- **Eave overhang** - is the horizontal distance the top chord extends from the wall.

**Types of trusses**

**Architectural trusses**

Architectural trusses are left exposed inside a building to create a visual impact. They are constructed from relatively large cross-sectional timbers which are bolted together. The spacing between trusses generally ranges from three to six metres, however they may be spaced at greater distances depending on the individual design.
Gang nail trusses

Gang nail trusses are designed and manufactured using a licensed system. The trusses' members are relatively small, usually 90 - 150 mm deep. These trusses are spaced closer together than architectural trusses at 600 - 1,200 mm spacing depending on their design and what they are supporting. Due to the appearance of the gang nail plates used in their construction, these trusses are generally concealed. They span distances up to 15 m and no on-site modification should be made as this affects their performance.

Ties and struts

**Tension members** in trusses are called **ties** and these are members which are being stretched. It is an industry convention that the arrows are shown pulling in on themselves. This is in contrast to the tension in a beam in which the tension forces pull outwards from the beam as shown in the bottom diagram.

**Compression members** in trusses are called **struts** and these are members which are being shortened. The industry convention shows arrows which are pushing outwards.
Compare this to the compression in a beam in which the forces push inwards as shown in the bottom diagram.

![Diagram of compression in a beam](image)

Note that the arrow convention for labelling struts and ties in trusses is opposite to the convention used for tension and compression.

You may find it helpful to think of tension and ties together as a memory aid as these represent the same force.

**Truss types**

When trusses are designed it is important to know which members are ties or struts. In typical loading conditions the following truss types have:

- ties shown in blue
- struts shown in red.

Remember: tension and ties, compression and struts.

The following diagrams of roof trusses are shown, all of them applied to an isosceles triangle shaped truss:

- **King post** - one vertical strut goes from the middle of the base of the truss to its highest point
- **Fan** - three struts fanning out from each of two points that are one third of the way along the base of the truss. From each of these points, one strut goes to the highest point of the truss and the other two go to points evenly spread along the sloping sides
• Howe - a vertical strut goes from the middle of the base of the truss to its highest point; another two from the middle of the base to the middle of each of the sloping sides; and another two from the middle of the sloping sides down vertically to the base

• Palladian - a vertical post from the middle of the base of the truss to its highest point; another two from the middle of the base to the middle of each of the sloping sides

• Fink - two struts fanning out from each of two points that are one third of the way along the base of the truss. From each of these points, one strut goes to the highest point of the truss and the other one goes to the midpoint of the sloping side above it

• Pratt - one vertical strut goes from the middle of the base of the truss to its highest point; another two go from the highest point to one quarter of the way along the base from each end; another two go from these quarter way points vertically up to the sloping sides of the truss.
Retaining walls

A retaining wall is a wall built to hold back soil. It is required to support soil where a sloping site requires excavation and either there is insufficient room or it is impractical to batter the soil.

A batter is an embankment where the ground is cut at an angle to make the surface stable. Rock can be cut at a much steeper angle than sandy soil.

Retaining walls over one metre high must be designed by a qualified structural engineer. The engineer designs the retaining wall so that it is able to resist soil pressures and is a stable structure.

Failure of retaining walls

The diagrams show three ways in which failure of retaining walls is likely to occur.

1. In the first diagram the retaining wall is shown tipping over to the left.
2. In the second diagram the wall is shown as being moved to the left (while still remaining vertical).
3. In the third diagram the wall is shown as being pushed further down into the ground.

**Types of retaining walls**

**Inclined retaining wall**

An inclined retaining wall leans into the excavated soil and is constructed at an angle between 45 and 80 degrees. It may be constructed from brickwork or pre-cast interlocking concrete units.

![Inclined retaining wall diagram](image)

A diagram shows an inclined retaining wall left of a slope with soil between the slope and the wall.

**Gravity retaining wall**

A gravity retaining wall relies on its own weight to resist overturning forces from the soil. It is typically constructed of heavy materials such as stone, brickwork or concrete.

![Gravity retaining wall diagram](image)

A diagram shows a retaining wall left of a slope. The retained wall is positioned at the bottom of the slope. At the bottom of the slope there is a horizontal section of the wall that extends into the slope.

**Cantilever retaining wall**
A cantilever retaining wall is the most complex of the three types and must be carefully
designed by an engineer. It relies upon the correct placement of steel reinforcement and
varying thickness of concrete to resist the compressive and tensile forces exerted on the wall
by soil pressures.

A diagram shows a cantilever retaining wall with a concrete base at the bottom of a slope. It
is withholding the pressures from the soil.

**Construction requirements**

All types of retaining walls require a system to minimise the build up of water pressure
exerted upon the retaining wall by the water contained within the soil. This pressure is
called 'hydrostatic pressure'.

Minimising hydrostatic pressure can be achieved by carefully controlling the backfill that
is placed behind the retaining wall. It must be a coarse, well draining material such as
scoria (Scoria is a type of volcanic rock. It is relatively light rock because of its many
holes and is usually a reddish brown colour).

Scoria is a type of volcanic rock. It is relatively light rock because of its many holes and is
usually a reddish brown colour.
An agricultural drain placed behind the wall within the free draining backfill will help drain the water away to the stormwater drainage system. A series of weep holes in the base of the wall will also minimise the effects of hydrostatic pressure exerted upon the wall.

In some cases retaining walls form the external wall of a building and therefore must be adequately sealed to prevent moisture entering the building. This is achieved by applying 'tanking' which is a waterproofing system that incorporates waterproof membranes.

**Concrete slabs**

**Ground slabs - Introduction**

Concrete slabs are similar to beams in the way they span horizontally between supports and may be simply supported, continuously supported or cantilevered.

Unlike beams, slabs are relatively thin structural members which are normally used as floors and occasionally as roof systems in multi-storey buildings.

Slabs are constructed of reinforced concrete poured into formwork on-site or into trenches excavated into the ground. Concrete slabs are usually 150 to 300 mm deep.

Slabs transmit the applied floor or roof loads to their supports. Slabs may be classified into two main groups depending on whether they are supported on the ground or suspended in a building.

**Ground slabs**

Ground slabs are those slabs that are poured directly into excavated trenches in the ground. They rely entirely on the existing ground for support. The ground (more correctly known in the industry as the foundation) must be strong enough to support the concrete slab. In a residential situation the BCA prescribes a minimum bearing capacity of 50 kPa for slab sites.

In most cases, the foundation easily meets this minimum bearing requirement. However, where clays and silts are present in the soil, the slab may experience stresses. These soils tend to be on reactive sites which are those areas where the volume of soil changes
because of its moisture content. This results in the foundation expanding or contracting depending on how much moisture the soil contains.

Foundation movements can be significant enough to damage a slab and any other components it supports, such as the brickwork shown in the photo.

**Ground slabs - Foundation movement**

It is important to understand the effects of foundation movement on the slab. The slab must be designed and constructed to make sure that it is strong and stiff enough to oppose stresses. It is necessary to have a method of regulating the moisture content of the foundation soils so that the overall stress is minimised. Some of the ways in which this can be done are:

- appropriate drainage
- by sloping the ground away from the building
- paving
- careful tree planting
- minimal watering of garden beds.
The amount of water and its distribution throughout the soil have a direct influence on soil movement. Seasonal changes in the weather may cause overall expansion or shrinkage of the soil. Localised soil movement at a corner or along one side of a building may be caused by many factors.

Any of the following may cause localised variation in soil moisture:

- soil depressions, dams, bores
- natural water courses or springs, tidal areas
- leakage from water supply or drainage pipes
- pavements and driveways which drain water away from buildings
- septic tank drainage trenches
- excavation of soil which is subsequently replaced by another material with different soil characteristics
- heavily watered lawn and garden beds
- dense vegetation and trees.

**Ground slabs - Slab bending**

When there is foundation movement because of reactive soils, the slab will bend. The resulting movement is classified as either dishing or doming. The type of bending will determine where steel reinforcement needs to be placed in the concrete slab.

A ground slab may experience dishing in very wet conditions. The soil expands with the extra moisture which exerts stress on the slab.

A ground slab is most likely to experience doming. As the sun dries the soil, moisture moves under the slab and creates an area of soil expansion.
Doming of a slab results in tensile stress in the upper surface of the slab. This means that the steel reinforcement should be placed in the upper area of the slab.

Stresses are reversed for the dishing slab, but as this is not a typical industry case it is not covered here.

**Ground slabs - Stiffening beams**

The design of the arrangement of stiffening beams is influenced by the reactivity of the foundation soils.

Ground slabs are typically constructed with stiffening beams which are placed along the perimeter of the slab.

Alternatively ground slabs form a grid pattern which is spaced along the entire length and width of the concrete slab.
Suspended slabs

Suspended slabs are slabs that are not in direct contact with the ground. They form roofs or floors above ground level.

**Suspended slabs** are grouped into two types:

- one way slabs which are supported on two sides
- two way slabs which are supported on all four sides.

The way a slab spans its supports has a direct impact on the way in which the slab will bend.

**One way slab**

One way slabs are usually rectangular where the length is two or more times the width. These slabs are considered to be supported along the two long sides only even if there is a small amount of support on the narrow ends.
A diagram of a concrete slab with two supporting sides is shown. The width of the slab is also the short span.

**One bend slab**

It is assumed that one way slabs bend only in the direction of the short span, so the main steel reinforcement runs in this direction across the slab.

A diagram of a concrete slab with two supporting sides is shown. Compression on the slab pushes towards the middle of the slab which causes the slab to bend inwards. Tension is distributed across the supporting sides.

**One reo slab**

Secondary steel reinforcement (which has a smaller bar diameter) is used in the direction of the long span. This reinforcement is placed in the bottom region of the suspended slab to reduce shrinkage cracks.
A diagram of a concrete slab with two supporting sides is shown. In the slab is steel reinforcement in the direction of the long span.

**Two way slab**

Two way slabs are approximately square where the length is less than double the width and the slab is supported equally on all four sides.

A diagram of a concrete slab with four supporting sides is shown. The pressure spans equally across the width and length of the concrete slab.

**Two bend slab**

These slabs are assumed to bend in both directions, so main steel reinforcement of equal size and spacing is run in both directions.

A diagram of the compression that occurs in a two bend slab is shown. The pressure runs to the middle of the slab which causes all four sides to bend equally.

**Two reo slab**
Steel reinforcing is usually placed in the slab at both top and bottom edges. However, it is the bottom reinforcement that is doing all the work as the top layer is primarily used to control concrete shrinkage cracks.

A diagram of steel reinforcing placed evenly down the width and across the length is shown.

**Main steps in slab formation**
There are four steps in this process:

1. Assemble the formwork which has been accurately built.
2. Steel reinforcing is positioned.
3. Concrete is poured into the formwork.
4. Formwork is removed when the concrete has set (cured).
Structural principles - Demolition

It is important that any demolition work of existing structures is done in accordance with legislative and planning requirements. Safe work practices are a vital part of the demolition process.

Introduction

The Australian Building Codes Board (ABCB) oversees a national framework for building legislation, including the Building Act 1993 which details the procedure for demolition.

A demolition permit must be granted before demolition can commence. Once the documentation for a permit is prepared by the builder or the demolisher, the main work in the application process is done by the building surveyor (Building surveyors advise on and interpret laws and regulations controlling building construction and safety).

In some circumstances a planning permit will be required prior to a demolition permit being issued. The building may be within a heritage overlay, which triggers the requirement for a planning permit.

(A heritage overlay is part of a planning map which defines the nature of particular areas, eg residential, retail, rural. It may specify the design features or particular aspects of a structure such as the façade)
Demolition permit procedure

The application process for a demolition permit is summarised in the following flowchart. Take note of the four different paths possible once the regulatory authority has checked the permit application.
Demolition permit

An application for a permit to demolish or remove a building must include the following information:

- a description of the building
- a site plan showing the building in relation to boundaries, other buildings on the site and adjacent sites, streets, footpaths and crossings
- structural computations demonstrating the structural adequacy of the building if it is only to be partially demolished
- details of protection, hoardings, barricades and protective awnings
- a written description of the demolition procedure
• evidence that the demolisher has the necessary knowledge, experience, equipment and facilities to properly conduct the demolition operations.

Refusal of a demolition permit is mandatory (It is a legal obligation that the demolition permit is refused), where a planning permit is required and has not been issued.

**Safe work practices**

All demolition operations are to be in accordance with Australian standards and codes of practices. These are:

• AS 2601: The demolition of structures
• code of practice - Demolition 1991

Related websites for further information are:

Australian Safety and Compensation Council  
[www.ascc.gov.au](http://www.ascc.gov.au)

National Occupational Health and Safety Commission  

**Safety authorities around Australia**

Each state and territory has its own WorkCover or WorkSafe authorities.

WorkCover ACT  

WorkCover New South Wales  

Queensland WorkCover Authority  

WorkSafe Western Australia  

WorkCover Corporation of South Australia  
[www.workcover.com](http://www.workcover.com)
Demolition Licences

A licence is required in Western Australia for certain types of demolition works. Only a licence holder or an employee of a licence holder may carry out this type of work.

In the regulations ‘demolition' means the complete or partial demolition of a building or structure by pre-planned and controlled methods or procedures.

Demolition work in mines is covered by the Mines Safety and Inspection Act and regulations made under that Act.

There are three types of licence (Class 1, 2 and 3) Each licence is valid for a period of two years and is endorsed with a number of conditions that relate to the way demolition work is carried out:

Class 1: in relation to demolition work, means demolition work of any of the following kinds

1. work comprising the total demolition of a building or structure that is 10 metres or more in height when measured from the lowest ground level of the building or structure to the highest part of the building or structure;

2. work —
   o comprising the partial demolition of a building or structure that is 10 metres or more in height when measured from the lowest ground level of the building or structure to the highest part of the building or structure; and
   o affecting the structural integrity of the building or structure;

3. work —
   o comprising the total or partial demolition of a building or structure; and
   o involving the use of load shifting equipment on a suspended floor;

4. work comprising the total or partial demolition of pre tensioned or post tensioned structural components of a building or structure;

5. work comprising the total or partial demolition of a building or structure containing precast concrete elements erected by the tilt up method of construction;
6. work involving the removal of key structural members of a building or structure so that the whole or a part of the building or structure collapses;
7. work done to a building or structure involving explosives;
8. work comprising the demolition or partial demolition of a building or structure that involves the use of a tower crane or any crane with a safe working load greater than 100 tonnes;
9. work involving the removal of an area of brittle or fragile roofing material in excess of 200 m² from a building or structure if any part of the area to be removed is 10 metres or more above the lowest ground level of the building or structure;

Class 2: in relation to demolition work, means demolition work comprising the total or partial demolition of a building or structure that is less than 10 metres in height when measured from the lowest ground level of the building or structure to the highest part of the building or structure but does not include —

1. the total or partial demolition of a single storey dwelling; or
2. work of a kind referred to in paragraphs (3), (4), (5), (6), (7), or (8) of the definition of class 1;

Class 3: in relation to demolition work, means work comprising the removal of more than 200 m² of brittle or fragile roofing material from a building or structure;

Single story dwellings can be demolished without holding a demolition licence. Although a licence is not required to demolish a single story dwelling, all demolition work must be carried out properly using safe work procedures and systems of work. There is a duty of care that all demolition is carried out in accordance with the *Occupational Safety and Health Act 1984*, the Occupational Safety and Health Regulations 1996 and *Australian Standard 2601 – The Demolition of Structures*.

Each licence is valid for a period of two years and is endorsed with a number of conditions that relate to the way demolition work is carried out.
**Footing systems**

Footings are the construction that transfers the load from the building to the foundation. There are many things to consider such as the type of the foundation soil and the choice of an appropriate footing system.

**The bearing pressure of foundation soils**

Soils are measured for their allowable bearing pressure. The allowable bearing pressure is the soil's ability to carry the load of a building and its contents without excessive settlement.

For one and two-storey buildings, the Building Code of Australia (BCA) requires a minimum bearing pressure of only:

- 100 kPa for under strip and pad footing systems
- 50 kPa for under slab footings.

Few building failures are caused by insufficient soil bearing capacity even when footings are unevenly loaded. This is because the loads imposed on foundations soils by houses, even those with solid masonry walls, are small compared to the bearing potential of natural firm soil.

Critically low soil bearing pressure is only found in alluvial soil (mud or silt), wet sand or poorly compacted fill. There are also rare cases of soils that have adequate bearing potential in dry weather, but which change to low bearing potential in wet weather.

**Volume changes in soil**

Unsaturated soil consists of individual soil particles held together by water and air pockets between the particles. The air and water combination pulls the soil particles together by surface tension. This results in a force called 'soil suction'.
Wetting the soil reduces this soil suction force. This causes the soil particles to separate and the soil volume to increase. Drying the soil revives the suction force which pulls particles together causing the soil volume to decrease.

**The effects of volume changes in soil**

Volume changes result in possible serious damage to the footings or to the building they support. The footing system must be selected to suit the anticipated volume change of the foundation soil.

Footings laid on clay soil are liable to subside or lift as the clay's volume decreases with drying and increases with wetting. The pressure of a building on that soil can limit this volume change. However, small buildings of three or less storeys do not exert the necessary pressure to prevent expansion of the foundation material. Therefore, small buildings, like houses, are the most often damaged by soil volume changes.

**Soil types**
There are four basic types of soil:

**Rock sites**

Building houses on solid rock foundations is the best structural solution. Rock is the most stable foundation. However, these sites cause cost difficulties with excavations for footings, water pipes, sewer pipes, underground power, gas and stormwater drainage. So, generally, rock sites are not viewed favourably.

**Sand sites**

Housing sites located on sand are the best sites. Sand is capable of supporting up to four-storey houses. It is generally easy to excavate with a hand shovel.

**Clay sites**

Clay sites are among the most common in Australia. They are the main type of site around our capital cities. Clay surface movements range from relatively small to extremely large.

Clay soil is measured by its ability to expand or contract with the addition or subtraction of water. The measure is referred to as its 'reactivity'. These reactive soils change according to seasonal changes in the moisture content.

Swelling soils will lift footings and their buildings and can cause significant structural damage. Shrinking during dry periods causes buildings to sink and crack.

**Problem sites**

Poor supporting soils include soft clays, wet sand, dump sites containing uncontrolled fill or rubbish, loose soil and unknown or unclassifiable material. These sites are unpredictable and cause the biggest problem for footing designers. Such sites require an engineer to design appropriate foundations.

**Site classification**

Soils are classified according to their stability. Soil samples are taken on the site to determine soil class. A geotechnical engineer's report will clearly state the likely soil conditions and recommend a suitable footing system.
### Table 1: General Definition of Site Classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Foundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Most sand and rock sites with little or no ground movement from moisture changes</td>
</tr>
<tr>
<td>S</td>
<td>Slight reactive clay sites with only slight ground movement from moisture changes</td>
</tr>
<tr>
<td>M</td>
<td>Moderately reactive clay or silt sites which can experience moderate ground movement from moisture changes</td>
</tr>
<tr>
<td>H</td>
<td>Highly reactive clay sites which can experience high ground movement from moisture changes</td>
</tr>
<tr>
<td>E</td>
<td>Extremely reactive clay sites which can experience extreme ground movement from moisture changes</td>
</tr>
<tr>
<td>A to P</td>
<td>Filled sites – see AS 2870</td>
</tr>
<tr>
<td>P</td>
<td>Sites which include soft soils, such as soft clay or silt or loose sands; landslip; mine subsidence; collapsing soils; soils subject to erosion; reactive sites subject to abnormal moisture conditions or sites which cannot be classified otherwise</td>
</tr>
</tbody>
</table>

Note: For classes M, H and E further division based on the depth of the expected movement is required. For deep-seated movements, characteristics of dry climates and corresponding to a design depth of suction change $H_s$, equal to or greater than 3m, the classification shall be M-D, H-D or E-D as appropriate. For example, H-D represents a highly reactive site with shallow moisture changes.
Footings

The selection of the size and type of footings depends on:

- the weight and type of house construction
- the site class.

<table>
<thead>
<tr>
<th>Construction type</th>
<th>Weight</th>
<th>Loading</th>
<th>Minimum bearing capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladding</td>
<td>Light</td>
<td>1 kN/m = 1 kPa</td>
<td>50 kPa/slab 100 kPa/strip footing</td>
</tr>
<tr>
<td>Brick veneer</td>
<td>Medium</td>
<td>6 kN/m = 6 kPa</td>
<td>50 kPa/slab 100 kPa/strip footing</td>
</tr>
<tr>
<td>Solid brick</td>
<td>Heavy</td>
<td>10 kN/m = 10 kPa</td>
<td>50 kPa/slab 100 kPa/strip footing</td>
</tr>
</tbody>
</table>

Table 1: Footing selection

Footings requiring engineering design

The common footing types - stump pads, strip, slabs - can be used for most housing construction. They can be selected from AS 2870 by appropriately qualified practitioners. However, two soil classifications require a qualified professional engineer to assess the footing requirements. These are Class E and Class P.

Class E - extremely reactive clays

Class E sites are predominant in the Adelaide area but are also found in other arid and small regional pockets. Class E sites contain extremely reactive clays that have reactive depths down to 4 meters below the natural ground level. Class E sites invariably require stiffened raft slab footings with deep edge beams and substantial Y bar steel reinforcement cages.

AS 2870 sets out requirements for stiffened raft and waffle slab construction for Class E sites. However, footings on Class E sites should always be designed and supervised by a structural engineer experienced in domestic construction.

Class P - problem soils

Problems soils can be found at any site and can consist of any of the following:

- rubbish dumps and uncontrolled fill
• soil with low bearing pressures (<50 kPa)
• loose sand
• soft clay
• landslip zones
• mine subsidence areas
• swampy areas
• erosion plains and gullies
• alluvial waterways (rivers, streams, creeks).

Class P includes any site that cannot be classified. Experienced geotechnical or civil engineers should identify and classify Class P sites in accordance with AS 1726 - 1993 - ‘Geotechnical site investigations’. Observation of building damage on surrounding properties may also indicate potential and sub-surface soil problems.

Footings – Stump pad Footings

The stump is the simplest and most familiar footing used for the vertical support and the transfer of building loads to the foundation. Stumps are used to support timber-framed houses for which they are currently the most cost effective.

Three types of materials are commonly used for stumps:

- timber
- concrete
- steel.

Stumps must have a concrete or timber footing placed underneath the base of the stump. This is to spread the load transferred to the stump from the building. This support beneath the stump is called a 'pad' or 'soleplate'. Usually concrete stumps are provided with
concrete pads poured in situ on the site. Timber stumps are provided with timber soleplates.

Selecting the size

The depth of the stump pad footing must be selected from AS 2870-1996 'Residential slabs and footings - construction'. The distance between each stump pad footing must also be considered.

<table>
<thead>
<tr>
<th>Site Class</th>
<th>Depth of pad footing (Ds) mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>400</td>
</tr>
<tr>
<td>S</td>
<td>400</td>
</tr>
<tr>
<td>M</td>
<td>500</td>
</tr>
<tr>
<td>H</td>
<td>1,000</td>
</tr>
</tbody>
</table>

Table 1: Footing depths

To select the appropriate size you can use the Australian Standard AS 1684 ‘Residential timber framed construction’ or AS 2870-1996 ‘Residential slabs and footings - construction’.

Footings - Strip footings

Substantial footing supports of reinforced concrete are needed for buildings that have external or internal masonry walls - solid brick, cavity wall, brick veneer, or concrete blocks and earthwall or stonewall. Reinforced concrete footings are commonly called ‘strip footings’ and are usually continuous around the entire perimeter of the building.

Strip footings require a minimum specified depth of concrete to ensure that the footings have adequate strength. This depth is called the 'overall depth' of strip footing. It has the symbol Df.
Dimensions and reinforcement

Strip footings are designed to engineer's specifications and installed to manufacturer's specifications. Refer to the BCA, Section 3.2.4.5 for further information on strip footing dimensions and reinforcement.

Note: It is not necessary to have articulation joints. However, buildings that do not have articulation joints require stronger footing systems than those that do. TN 61, published by the Cement and Concrete Association of Australia, discusses articulation joints and their requirements fully.

Gridded

If there is to be full masonry on strip footings, the strip footings must be gridded on a maximum spacing of 6 metres in both directions.

Gridded strip footings ensure that the deep strip footings of the perimeter of the buildings cannot be pushed or tilted sideways by soil movement or soil pressures. This is a serious problem in high and extremely reactive clays.
Vapour barriers

A moisture barrier is required in all strip footing excavations on Class H sites that exceed 700 mm in depth. The barrier must be double layer polythene and 0.2 mm thick.

The polythene barrier provides a separation between the concrete strip footing and the ground. It prevents 'down drag' (or upheaval) from the ground to the footing.

Soil suction at depth in cohesive reactive clay can adversely affect the footings. In turn, this affects the building being supported by the footings. The polythene allows sideslip between the footing and the soil along the vertical sides of the footing.

Footings - Stepped footings

Stepped footings

On flat building sites (or sites without slopes) a footing excavation can be made at a constant depth from the natural ground surface. Flat sites allow easy access and generally are simpler to excavate than sloping sites.

The base of the excavation is always horizontal and parallel to the natural ground surface.

Obtaining horizontal excavation bases on sloping sites presents problems. If the slope of the ground exceeds 1:10 fall (a 1 in 10 or 10% fall) it is unacceptable to excavate parallel to the natural ground surface.

Sloping footings can slide down an allotment due to gravity. For this reason the base of strip footings should be excavated horizontally, where possible.
Footings - Concrete slabs

Stiffened raft slabs

Slab footings consist of concrete beams and floors across the entire floor plan. Slabs are also referred to as slab floors, slab on ground or raft slabs. Slab is the general term used to refer to any of the available types of slabs.

The stiffened raft slab is the simplest and most common slab construction available. The stiffened raft configuration can be used on all classes of sites (except problem sites - Class P).

Stiffened raft slabs consist of:

- 100 mm thick concrete slab
- edge beams
- internal beams (except Class A and Class S sites)
- steel reinforcement.

The concrete is poured in one operation.
More about stiffened raft slabs

AS 2870 provides the required minimum dimensions and specifications for the depth, width and spacing of beams in a stiffened raft slab footing.

The excavation depth depends on:

- depth of adequate bearing soil below the surface
- depth of vegetation
- slab height.

The height of the finished concrete slab floor level must be specified or calculated before construction. This ensures that the completed floor level finishes above the surrounding ground level. Raising the slab level above the ground level makes sure that floodwater or stormwater cannot readily flow into the house and cause water damage.

The minimum recommended distance from the top of the slab to the finished ground level (FGL) is 150 mm. Note NGL on the diagram which refers to natural ground level.

<table>
<thead>
<tr>
<th>Table 7.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF = 500 - 150 = 350 mm</td>
</tr>
<tr>
<td>Excavation depth = 350 mm from the FGL</td>
</tr>
<tr>
<td>Note: Often the FGL is the NGL reinstated</td>
</tr>
</tbody>
</table>
Strip footings

This slab is supported by strip footings. Strip footings are also called ‘edge beams’. A footing slab requires two separate concrete pours. It can only be used on Class A and Class S sites.

Advantages of footing slabs are that they:

- adapt to sloping sites
- require simple formwork (no edge rebates)
- require simple excavation that is exposed for minimal time
- do not require internal beams.

The fill material is usually restrained at the external walls. Therefore these walls need to be strong enough to support the fill.
More about slab footings

The following diagram shows details for constructing slab footings on Class A and Class S sites and on sloping sites.
Alternate edge treatment using untied strip footings

For footing sizes see table below

Note:
1. The proportions for the tied edge beam only apply where there is a structural connection between the slab concrete and the footing concrete using reinforcement fittings.
2. Slab reinforcement reduces one size when footings are not tied to the slab, i.e., F62 for slab ≤ 16 m long and F72 for slab > 16 m long.

<table>
<thead>
<tr>
<th>Footing sizes for untied strip footings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall type</td>
</tr>
<tr>
<td>Clad frame and masonry veneer</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Full masonry</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Footing slab
Site class A and S
Wall types: CLAD FRAME, MASONRY VENEER and FULL MASONRY

Alternate construction for sloping sites

1. Single width wall with engaged piers
   H < 450
   200 mm block wall filled with 20 MPa concrete

2. Double width masonry wall
   H = 450-750
   75 mm cavity filled with 20 MPa concrete

3. Reinforced block wall
   H < 1500

4. Reinforced cavity masonry wall
   H = 750-1500
Waffle raft slabs

Waffle raft slab construction is quite different from stiffened raft and footing slab structures. The slab ribs are formed on top of the ground using a grid of polystyrene void forms which are laid out on a levelled area. It is ideally suited to very reactive clay sites and does not have the problems associated with stiffened raft slabs that have their beams embedded in the reactive clays.

Features of waffle raft slabs

The features of waffle raft slabs include the following:

- they are used on flat sites
- they are wholly above ground
- no beam excavation is required
- no controlled or rolled fill is used
- cardboard slab panel/void formers are used
- slab panels are on 1 metre grids (approximately)
- trench mesh or individual bars can be used
- slab thickness is 85 mm
- internal beams are 110 mm wide
- there is minimal concrete volume
- no beam down drag from clay (above ground slab) occurs
- shrinkage of slab is lower than stiffened rafts and footing slabs
- they use 30% less concrete than a stiffened raft
- they use 20% less steel than a stiffened raft.
This construction is rarely used on Class A and Class S sites.

**Footings - Pier and beam**

**Their purpose**

Class P sites are problematic. The low allowable bearing pressures of such sites cannot support the loads imposed by a house structure via the footings. The building would suffer damage.

Blinding concrete is used to transfer the loads from the house to the good bearing. This avoids the need to increase the total footing depth to reach the underlying good bearing soil.

Most problem sites contain a problem area on the top layers of soil only. Often, good bearing soil is located at a specific depth below the natural ground level. The depth at which this good bearing soil is located will determine the structural footing design and the cost of the footing construction.

When good bearing soil or strata cannot be located within 1.5 metres of the NGL or surface, pier and beam construction is usually considered. Pier and beam footings are only considered for low bearing soil sites. They require engineering design.

![Footings - Pier and beam](image)

**Timber piles with concrete beams**

As with all the previous pier and beam systems, a qualified engineer must design these footings.

Power driven timber piles are slightly different to the previous pier and beam systems - a building inspector cannot inspect the foundation. This is because there is no excavation with power driven timber piles.
The vibration transferred to the ground by the pile driving rig may also shake and move buildings in the immediate vicinity. The building surveyor, design engineer, checking engineer and supervising site engineer must gauge and assess the amount of vibration before and during construction.

Where piling of any kind is required, the sub-surface soil in the vicinity is likely to be poor. So, the existing buildings may not be founded on piles and may be perched on the soft/fill soil with minimum support. Pile driving vibration could easily disturb these buildings, resulting in cracking or failure and collapse.

The last 10 blows on the piles are recorded. This, in effect, is a measure of the resistance of the soil and determines when a pile is 'set'.

Steel screw in columns

Power driven galvanised steel columns are an alternative pier system to copper chrome arsenate (CCA) treated pine piles. The columns have a fluted flange (helix) on the ends. This enables the column to drill itself into the ground.

The system is an engineered system. It requires an accreditation certificate to ensure acceptance by building authorities.

These columns have a potential corrosion problem, which is difficult to assess timewise. Aggressive (heavy, reactive polluting) chemicals in the soil could attack the columns. The galvanised coating can also be removed from the column if coarse boulders, gravel or sand are hit during the drilling process. Removal of the galvanised protection coating can accelerate its corrosion.
Damp proof coursing

Damp proof course in brickwork

Damp proof course (DPC) is a barrier of impervious material built into a wall or pier to prevent moisture from moving to any part of the building.

The DPC is built into base wall brickwork. It bridges brick skins and/or the brick and pier.

The DPC is laid into the brick wall approximately two courses (two bricks) below the lowest timber member, typically the bearer.
**Damp proof course in slab construction**

Damp proof courses are also installed to residential buildings constructed on concrete slabs.

The DPC, commonly called the ‘flashing’, is run around the perimeter of the building attached to the wall frame just above the top plate. It is angled down to the brickwork where it is embedded just below the weep hole.

**Damp proof course - Materials**

Damp proof course materials are specified in the Australian Standard AS/NZS 2904:1995 'Damp-proof courses and flashings'. Various water resistant materials may be used as damp proof coursing, including corrosion resistant metal, such as aluminium, copper or zinc, and impact resistant plastics like polyethylene.

These photos show different types of damp proof or waterproof membranes.
Termites

Termites are commonly referred to as white ants. They eat timber.

Before starting a new building the builder contact the local municipality to check whether the house is in a declared termite zone.


All new buildings must have their primary building elements (structural elements) built with termite resistant materials or be protected against termite attack.

**Termite resistant materials**

Termite resistant materials include:

- steel, aluminium or other metals
- concrete
- masonry
- fibre-reinforced cement
- naturally termite resistant timbers
- treated termite resistant timbers.
The use of termite resistant materials must be backed up by regular inspections and a maintenance program. Therefore provision must be made during construction to allow space for inspection under the floor of the house. This will include the use of ant caps which aid in the detection of termites.

**Termite protection**

Physical barriers or chemical barriers must be used where:

- the building is a termite risk area
- some or all of the primary building elements are not of a termite resistant material.

**Flow chart for identifying if a termite barrier is required**

```
Is the building in a termite risk area?

Yes
Are the primary building elements subject to termite attack?

Yes
Install appropriate termite barrier

No
termite barrier required

No

No
```

**Concrete slabs - A termite barrier**

Concrete slabs form part of the termite barrier. However, termites may be able to access timber framing at the edges of the slab, around service pipes and box-outs for plumbing fixtures or through naturally occurring cracks in the concrete.

The majority of termite infestations occur at the perimeter of the building. Leaving an exposed edge to the perimeter of a concrete slab allows easy detection of the presence of termites.
Concrete slabs - Preventing termite entry with graded stone

Graded stone may be used to prevent termite entry. The stone is finely crushed granite of a size difficult for termites to tunnel through. The graded stone is placed at likely entry points for termites, such as service penetrations and the perimeter.

Concrete slabs - Preventing termite entry with steel mesh

Stainless steel mesh finely woven to a size that does not allow termites to pass through can also be used to secure locations, such as the perimeter or service pipes.
Concrete slabs - Preventing termite infestation with pesticides

Chemical pesticides can be sprayed under the slab area and to the external perimeter of the building. A network of supply pipes may be placed under the slab so that the pesticide can be replenished.
Suspended timber floors - Protection from termites

Timber floors can be protected from termites by providing metal shields that force the termites out into the open for easy detection. Adequate space must be provided under the floor to allow for inspection.

Alternatively, the systems using graded stone, stainless steel mesh or chemical treatments can be considered.
Floor systems

When constructing the floor system it is important to take into consideration the type of flooring, the laying of pipes and reinforcement. The type of flooring in a house must be adequately supported by the flooring structure below.

Concrete slab - General

Concrete slabs are floor systems of concrete and steel reinforcing. They are constructed on the ground. Various types of slabs are available.

Slab on ground

Concrete floor supported on the ground and incorporating integral edge beams.

Stiffened raft slab

Concrete floor supported on the ground with a separately poured edge strip footing.

Footing slab

Concrete floor supported on the ground with a separately poured edge strip footing.

Waffle raft slab

Stiffened raft with closely spaced ribs constructed on ground and with slab panels suspended between ribs.
Infill slab

Slab cast on the ground between walls and with no stiffening beams.

Specifications

Generally, AS 2870 is used to obtain the required minimum dimensions and specifications for the depth, width and spacing of beams' slab thickness. The minimum strength of concrete used in slabs is N20 grade (20 MPa). It contains 20 mm aggregate and a slump of, typically, 80 mm.

The excavation depth of beams depends on:

- depth of adequate bearing soil below the surface
- depth of vegetation
- height of slab.

However, before the excavation of the slab begins, the entire area for the slab must be scraped. This removes grass and other organic matter which can decompose or shrink after a slab has been laid over it.

Typically a layer of approximately 100 - 150 mm is removed.

Finished concrete slab floor level

The height of the finished concrete slab floor level must be specified or calculated before construction. This is to ensure that the finished floor level finishes above the surrounding ground level. Raising the slab level above the ground level ensures floodwater or stormwater cannot readily flow into the house and cause water damage.

The minimum recommended distance from the top of the slab to the finished ground level (FGL) is 150 mm.
Edge rebates - Purpose

Where external walls are to be masonry veneer or full masonry, edge rebates must be provided in the edge-stiffening beam. A check out from the edge beam will create a ledge for the brick to rest on lower than the top of the slab. This is an added precaution to prevent surface run-off water from entering the building.

The rebate must be flashed and weep holes provided in the masonry. The weep holes must be spaced at a minimum distance of 1.2 metres to allow water to drain out and away from the wall and the slab.

Edge rebates - Types

Minimum edge rebate
Deep edge rebate

Bedding sand

A layer of packing sand is placed between the stiffening beam locations. This allows a firm level base for the slab and takes up any irregularities in the level of the site. Also, sand is far cheaper than concrete.

The sand is screeded level and provides a good base for the plastic membrane. It is typically laid to a minimum thickness of 50 mm.
Vapour barrier

A vapour barrier is a plastic membrane laid under the slab to improve its performance against rising damp. It is also called a ‘moisture barrier’ because it stops the moisture from the soil migrating into the concrete slab. This must be placed under the slab for all areas where there are to be habitable rooms.

Care should be taken not to tear or puncture the vapour barrier. Any tears that occur, and joints, must be adequately taped.

Concrete slab - Laying pipes

Service pipes such as sewer and water are often required for plumbing fixtures that are not located directly adjacent to the external walls. These pipes must be run through or under the slab.

Stormwater pipes may also need to pass through the slab. These service pipes may be installed using the following techniques:

- slab recesses
- penetration through beams
- run under beams
- run under slabs
- run through slabs.

Slab recesses

Recesses cast into the slabs allow for easier access for maintenance than trying to locate pipes under a slab.
Through beams

The technique of pipe penetrations through the edge beam should be avoided unless there is no alternative. Pipes must pass through the middle third of beams to ensure that the strength of the beam is maintained. Where pipes penetrate the beams, additional strengthening of the edge beam with steel reinforcement or depth of concrete can be used.

Below beams

Service pipes may run under stiffening beams. When pipes are laid and beams are excavated the finished depth of all beams must be considered to ensure sufficient clearance of services pipes.
Under slab

If pipes are laid under the slab they should be located wholly under the slab where possible. Extra bottom mesh should be placed over the pipe to avoid any weakening of the slab.

Box-outs for bath, shower bases and similar plumbing fixtures should be placed carefully to minimise weakening of the slab.

Note: Electric heating cables may be embedded in the slab without any increase in thickness or reinforcement.

Through slab

It is best to avoid running plumbing pipes through the slab. However, this may occur when the pipe discharge level is critical and there is no other means to maintain sufficient height.
Hot water heating pipes may be embedded in the slab. However, the slab thickness must be increased by 25 mm and the mesh increased to the next size up.

Note: Electric heating cables may be embedded in the slab without any increase in thickness or reinforcement.
Lagging the pipes

All plumbing pipes that penetrate the slab or beams must be lagged to isolate them from the concrete. Closed-cell polyethylene lagging of 20 mm thickness must be used around all stormwater and sewer pipe penetrations. The lagging allows pipework and concrete to move independently. This minimises the stress placed on pipework.

Concrete slab – Reinforcement

In most cases slabs require steel reinforcement to improve their ability to resist tensile stresses. Protection from corrosion in the reinforcement is achieved by providing minimum covering of concrete. Cover for the reinforcement must be:

- 40 mm from unprotected ground
- 40 mm from external exposure
- 30 mm from a membrane in contact with the ground
- 20 mm to an internal surface.

Supporting the reinforcement

Various types of bar-chairs are used to support the reinforcement. In turn, these provide the minimum amount of concrete edge cover.

Slab on ground plastic bar chairs

This type of bar chair is used for reinforcing slabs that are:

- cast against the ground
- on plastic sheeting.
Trench mesh support

This type of plastic bar chair is used in strip footings.

Trench mesh

This is designated as x-L8TM, x-L11TM or x-L12TM. The x is the number of main bars.

For example:

- 3-L8TM has three bars, which are 8 mm in diameter.
- 4-L11TM has four bars, which are 11 mm in diameter.

Square mesh

This is designated SL62, SL72, SL82, SL92 or SL102. The first digit refers to the diameter of the bars. The last digit refers to the spacing of the bars.

For example, SL72 has diameter 7 mm bars, which are on a grid of 200 mm apart.
Reinforcing bars

This is designated x-N12, x-N16 or x-N20. The x is the number of individual bars placed together. The digits refer to the nominal diameter of the bar.

For example, N16 has a diameter of 16 mm.

Lapping reinforcement

All forms of steel reinforcement must be lapped in accordance with AS 2870 requirements. The overlaps should be held together with tie wire.

Trench mesh laps
Where trench maps are joined end to end, they need to be overlapped by at least 500 mm. Where they overlap at T or L intersections the overlap should be the width of the trench mesh.

Square mesh lap

Square mesh lap has to be overlapped by at least 225 mm.

Reinforcing bar lap

Reinforcing bar laps need to be overlapped by at least 500 mm.
Re-entrant reinforcement

Weak points occur where the concrete slab forms an internal corner because of the overall shape of the building. This internal corner is referred to as a re-entrant corner. It must have additional reinforcement as cracks are likely to develop from this point.

It is sufficient to use additional layers of trench mesh:

- a minimum of 2 metres long
- laid diagonally across the re-entrant corner.

Curing

The concrete must be kept moist immediately after finishing. This ensures that the chemical bonding between the cement, aggregate and sand occurs. Curing produces much stronger concrete and minimises surface cracks.

Methods of curing the concrete slab include:

- soaking in water
- spraying with water mist
- covering with plastic or hessian
- spraying with chemical compounds.

Pouring concrete during extremely hot windy days should be avoided as these conditions cause water loss.

Thickening

Slab thickening may be incorporated into the slab where:

- load bearing internal walls occur
- the wall is more than 1 metre away from the nearest internal stiffening beam.

This is done to strengthen this part of the slab. The slab thickness is increased to 150 mm for a width of 500 mm.
Slabs on fill

Concrete slabs may be constructed on filled sites only where the placement of the fill has been strictly controlled. This is referred to as 'controlled fill'. This means the fill material has been carefully selected and compacted in accordance with the procedure set out in AS 2870.

Typically, coarse clean sandy soils are used for this purpose. They are compacted by mechanical rollers. Appropriate amounts of moisture aid the compaction process. The fill is laid down in layers not exceeding 150 mm in thickness. Before the slab is constructed the minimum bearing pressure of the fill must be tested.

Under no circumstances are slabs to be constructed on uncontrolled fill. Uncontrolled fill consists of material that has not been compacted or has been poorly compacted and contains a high portion of expansive clays. This will result in excessive footing movement.
Concrete slab - Types of construction

There are several types of concrete slab constructions. These include:

- stiffened raft slabs
- slabs on the ground
- footing slabs
- waffle raft slabs
- infill slabs.

Stiffened raft slab

The stiffened raft slab is the simplest and most common slab construction. The stiffened raft configuration can be used on all classes of sites (except problem sites - Class P).

Refer to Figure 3.2.5.3 (b) of the Building Code of Australia.

Slab on the ground

The slab on the ground is constructed similar to the stiffened raft, however, it does not require internal stiffening beams and can only be constructed on Class A or Class S sites.
Refer to Figure 3.2.5.3 (a) of the Building Code of Australia.

Footing slab with no connection between slab and footing

Footing slabs are supported by strip footings. They require two separate concrete pours and can only be used on Class A and Class S sites.

One configuration is the footing slab with no connection between the slab and the footing. This is the preferred option because it is simple to construct and relatively economic. It is ideal for flat sites.

The soil must have a minimum bearing capacity of 100 kPa. No reinforcement is required in the edge beam.
No connection between slab and footing

Footing slab with connection between slab and footing

The slab is connected to the footing with R10 round steel starter bars at 600 mm centres.

It can only be constructed on Class A and Class S sites. The soil must have a minimum bearing capacity of 50 kPa. It is a suitable method for mildly sloping sites.

Connection between slab and footing

Footing remote from slab

This is the most complex of the three footing slab options. It is best suited to sloping sites. It can only be constructed on Class A and Class S sites. The soil must have a minimum bearing capacity of 50 kPa.

The concrete slab is supported by controlled fill. The controlled fill is, in turn, restrained by the external walls which must be strong enough to contain the fill.
Waffle raft construction

Waffle raft slab construction is quite different from stiffened raft and footing slab structures. The slab ribs are formed on top of the ground using a grid of polystyrene void forms. These are laid out on a levelled area. The construction is ideally suited to very reactive clay sites. It does not have the problems associated with stiffened raft slabs, which have their beams embedded in the reactive clays.

The slab would be designed to the engineer’s specifications and installed to manufacturer’s specifications.
Polystyrene void forms below reinforcement

Infill slab

Infill slabs are simply poured between existing walls, so no formwork is required.

They require no external or internal stiffening beams and are typically used in garage floors where the walls are masonry.

The masonry wall and concrete slab must be separated from one another because they shrink or expand at different rates. If they are not separated the risk that the slab may develop unsightly cracks along the wall edge is increased.

A compressible filler strip, nominally 12 mm thick, is used as an impervious separation strip. Saw cuts may be required after 24 hours to control the shrinkage and cracking that is likely to occur.
Expansion joints in the surface of the concrete slab

Concrete slab joining with brick wall

Engineer designed footings

It is mandatory that a qualified professional engineer design the footing systems for Class E and Class P soils.

**Class E sites:** Class E sites contain extremely reactive clays, which have reactive depths down to four metres below the natural ground level. Footing requirements for Class E sites invariably result in stiffened raft slab construction with deep edge beams and substantial steel reinforcement cages.

**Class P sites:** These are problem sites, with problem soils due to the following:

- previous use as a rubbish dump
- uncontrolled fill
- loose sand
- proximity to large trees
- soft clay
- landslip potential
- previous land use
- mine subsidence
- swampy areas
- proximity to sewer mains
- potential erosion.
Sites with inherent low allowable bearing pressures will be unable to support the loads imposed by a house structure via the footings. The building will suffer damage if constructed on low bearing soils.

**Pier and beam footings**

Pier and beam method of construction is usually considered when good bearing soil or strata is not located within 1.5 metres below the existing surface.

Most problem sites contain a problem area in the top layers of soil only. Often, good bearing soil is located at a specific depth below the natural ground level. The depth at which this good bearing soil is located will determine:

- the structural footing design
- the cost of the footing construction.

Pier and beam footings can be constructed in a variety of configurations. Two are:

- bulk pier and beam
- bored pier and beam.

**Bulk pier and beam**

Bulk pier and beam systems are satisfactory where good bearing soil is located between 800 and 1,200 mm below the natural ground level.

Bulk piers are excavated using a backhoe. The excavation is usually 1 metre x 1 metre in area and extends to the founding depth (800 - 1,200 mm). Piers are normally located at 3 to 5 metre centres. When the piers have been poured, the beam is excavated. The beam is similar to a strip footing and runs over the bulk piers.
Bored pier and beam

The primary difference between the bulk pier and beam and the bored pier and beam is the size of the piers. The bored piers are much smaller than the bulk piers. The diameter of the piers is usually 450 mm or 600 mm.

A minimum of four vertical reinforcement bars are placed in the pier with N6 ligatures at 300 mm centres. The drilling rig can penetrate to depths of 3 metres with minimal disturbance to adjoining structures. The bases of the piers are founded on good bearing soil at the appropriate depth.

Timber piles with concrete beams

Power driven timber piles are slightly different to the previous pier and beam systems. The vibration transferred to the ground by the pile driving rig may also shake and move buildings in the immediate vicinity. The building surveyor and design engineer must gauge and assess the amount of vibration before and during construction.

A building inspector cannot inspect the foundation because no excavation is done with power driven timber piles. The last 10 blows on the piles are recorded. This is a measure of the resistance of the soil and determines when a pile is ‘set’.

The timber used for the piles is copper chrome arsenate (CCA) treated pine.
Driven timber piles and beam

**Power driven steel screw in columns**

Power driven galvanised steel columns are an alternative pier system to timber piles.

The piles have a helix auger on the ends, which enables the pile to drill itself into the ground.

This engineered system requires an accreditation certificate to ensure acceptance by building authorities.

**Sub-floor framing - General**

Sub-floor framing includes the framework that eventually supports the flooring. A number of systems can be used to construct a sub-floor frame. These include:
Conventional timber bearers and floor joists

Long span engineered timber products

Mild steel and cold-formed steel members

The basic principles of these sub-floor framing members are similar

Sub-floor framing – Bearers

Bearers are the first of the sub-floor frame members to be installed. They are positioned over stumps, piers or other supports. In most cases they are timber, however, a wide variety of engineered timber products are available. As well, mild steel and cold-formed steel sections may be used to achieve greater spans.
Span

Bearers span across sub-floor supports with a single span or continuous spans.

Notching

Where the bearers do not sit flat or are irregular in shape they may be notched, packed or planed to ensure they lay flat and true.

Packing of minor deficiencies in depth is permitted if the packing material is durable.
Support

Bearers must be attached to supports to provide resistance against uplift and lateral movement. Where bearers have to be joined, this should be done over a support. However, this is not necessary for some engineered products.

Ventilation

It is necessary to allow adequate ventilation and ensure durability of the timber bearer. To do this a minimum ground clearance from underside of bearer to finished ground level of 150 mm should be maintained. This clearance must be increased to 200 mm where access space for termite inspection is required. When particleboard flooring is installed a clearance of 400 mm below the actual flooring is required.
Spacing

Span does not refer to the length of a member. It refers to the maximum distance allowed between its supports.

Bearer spacing is the centre-to-centre distance between consecutive bearers.

Position

Bearers are typically:

- run in the long direction of a building
- located under the side perimeter walls
- equally spaced across the width of the building.
Size and grade

The selection of a bearer size and stress grade depends on:

- whether the bearer is under a load bearing wall
- whether the bearer only supports floor loads
- the span of the bearer
- the spacing of the bearer.

AS 1684 'Residential timber framed construction' provides an appropriate span table. The required wind classification for the intended site of the building must also be known. The span tables relate to:

- bearers supporting load bearing walls
- or
- bearers supporting floor loads only.

Both tables provide options for selecting:

- single span bearers
- continuous span bearers
- cantilever bearers.

Floor loads

Whether the bearers are supporting load bearing walls or only floor loads, the area of the floor supported by an individual bearer must be determined. This is referred to as the floor load width (FLW).

Where the bearer supports load-bearing walls the type of roof covering also needs to be determined. Tile roofs impart a heavier dead load on the bearers than sheet roofs.
Refer to Figure 3.4.4.1, Table a of the Building Code of Australia.

**Sub-floor framing - Floor joists**

Floor joists are the next series of members for the sub-floor frame. They are supported by the bearers.

Typically the floor joists run over the tops of bearers, however, they may be attached to the sides of bearers. Like bearers, floor joists may be single span or continuous span. They can be made of timber or steel.

**Position**

Floor joists run perpendicular to the bearers and are spaced closer together.
Spacing

The spacing of the floor joists depends on the spanning capacity of flooring being supported.

The maximum allowable spacing of joists supporting tongue and groove strip and sheet flooring relates to the species of wood, grade and thickness.

An example of this would be: South-eastern Australian hardwood, AS 2796, standard grade, 19 mm thickness, maximum spacing of joists 620/680 mm, butt joists, 470/520 mm end matched.

Span

Floor joists span across bearers by a single span or continuous spans.
AS 1684.2 ‘Residential timber framed construction’ provides a span table for selecting floor joists.

**Notching**

Floor joists must be laid with their top surface level to receive flooring.

Floor joists may be notched similar to bearers.

The depth of all the floor joists are the same. The maximum depth of the notch which is cut out of the joist is $\frac{d}{4}$.

**Joints**

Floor joists are firmly connected to the bearers. Where joins are required these must be over a bearer.
Supporting fitted floorboards

Floor joists supporting fitted floorboards must ensure that the floor in every room can be adequately fixed and supported. This will require additional floor joists at the walls, which run parallel to the floor joists.

A pair of floor joists is typically placed at the beginning and end of a run of floor joists.

Supporting platform floors

Floor joists supporting platform floors only require additional floor joists under parallel internal load bearing walls.

As with fitted floors, a pair of floor joists is typically placed at the beginning and end of a run of floor joists.
Deep floor joists are those where the joist height exceeds four times its width.

Deep floor joists must be restrained from rolling over. They require blocking between the joist spacings. This can be achieved by:

- providing a continuous trimming joist to the ends of the joists immediately over the external bearer
- or
- solid blocking between the outer pairs of joists and between intermediate pairs at not more than 1.8 metre centres. Where span exceeds 3 metres additional mid-span blocking at 1.8 metre spacings may also be required.
Size and grade

The selection of a floor joist size and stress grade depends on:

- the span of the floor joist
- the spacing of the floor joist.

The required wind classification for the intended site of the building must be known.

The roof load width (RLW) is similar to the floor load width (FLW), however, how much of the roof load is distributed to the floor joists must be determined. So, the type of roof covering must also be known.

Engineered beams

Engineered beams may be used as bearers or floor joists. The manufacturer's design specification should always be referred to during construction.

The various types of engineered beams include:
- beams with metal connectors
- plywood beams in solid sections
- plywood I-beams
- truss floor joists.

These types of engineering beams are shown in the following photographs and diagrams.

**Beams with metal connectors**

*Joining pieces end to end to make a longer beam*

*Joining two pieces to make a wider beam*
Joining timber top and bottom for continuous beam

Plywood beams in solid sections

Plywood beams are suitable as webs in manufactured beams because of the material's high shear strength.
A detail of sub-floor framing using plywood beams.

Plywood I-beams

Close up of plywood and beams showing panel and timber edges
Truss floor joists

I beams as joists for second storey construction

Truss floor joists are engineered beams

A cut away view of truss floor joists for the second storey of a building
Flooring - Introduction

Flooring performance must satisfy the two usual criteria relating to strength and deflection. Strength is straightforward - design loads must not impose stresses in excess of allowable working stresses. The selection of appropriate deflection limits requires some judgement based on safe loads.

This section covers the requirements for installing:

- fitted floors - tongued and grooved
- platform floors - plywood flooring and particleboard sheet flooring.

Flooring materials

Any timber species may be used for floor framing, provided it is kept dry. It must:

- be well ventilated
- not be exposed to weather
- not be in contact with or close to the ground.

Some timber species commonly used for flooring are:

- Tasmanian Oak
- Blackbutt
Source: Boral Timber Flooring

**Flooring - Fitted floors (cut-in floors)**

Fitted floors (cut-in floors) are installed after walls have been erected and after roofing, wall cladding, doors and windows have been installed.

Where boards are laid parallel with walls, a minimum 10 mm gap shall be provided between the board adjacent to the bottom plate and the bottom plate.

**Flooring expansion joints**
For continuous floor widths over 6 metres, measured at right angles to flooring, intermediate expansion joints are required. This is in addition to the perimeter gaps.

This joint can be:

- a single 10 mm wide gap, under a wall or across a hallway and the like
- smaller gaps with closer spacings to give an equivalent space, for example, 1 mm gaps at 1 metre spacing or loose cramping.

Laying floors - End-matched flooring

Fitted flooring must be kept 10 mm clear of walls or wall plates that are parallel to the length of the boards. End-matched flooring may be laid with end joints between joists provided that:

- end joints are well distributed
- end-matched joints in adjoining boards do not fall within the same joist spacing.

Board lengths have to be at least the equivalent of two joist spacings. Finger-jointed hardwood flooring manufactured in accordance with AS 2796 is equivalent to continuous strip flooring.

Tongues are fitted into grooves. Boards are cramped together ensuring that the boards are bedded firmly on floor joists. Boards must be in contact with the joists at the time of nailing.

Laying floors - Butt joints
Butt joints are cut square and butt-joined tightly together over floor joists. Joints in adjoining boards are staggered.

Again, the tongues are fitted into grooves. Boards are cramped together ensuring they are bedded firmly on floor joists. Boards must be in contact with the joists at the time of nailing.

Floor nailing

Boards up to 85 mm cover width need to be fixed by face-nailing with one or two nails or be secret-nailed with one nail at each joist.

Boards over 85 mm cover width must be fixed with two nails at each joist.

Alternate nails in double-nailed boards are to be skewed slightly to the vertical, in opposing directions. The minimum edge distance for nailing at butt joints or board ends is 12 mm.

All nails, including machine-driven nails, should be punched a minimum of 3 mm below the top surface. Nail punching should allow for sanding and finishing and for drawing boards tightly onto joists.
Pre-drilling boards for fixings at butt ends helps reduce splitting.

Flooring - Platform floors

A platform floor provides a working platform for the builder as the floor is laid before erecting the wall and roof framing. However, this method is not recommended for feature floors because the flooring is exposed to the weather during construction.

The platform floor should be protected from getting wet by rain and/or wet trades, however, as it is difficult to provide adequate protection, degradation due to the effects of sunlight, wetting or work practices may occur.

Plywood panels are laid with the face grain of the plies at right angles to the line of the supporting joists. They must be continuous over at least two spans. Ends of sheets are butted over joists.

Edges of sheets, unless tongued and grooved, are to be joined over noggings between joists. Noggings are timber of not less than 70 x 35 mm sections. They are set flush with the top of the joists.

Fixing plywood platform floors

Nails used for fixing plywood have to be of a length not less than 2.5 times the thickness of the panel and be:

- 2.8 mm diameter flathead or bullet-head hand-driven nails
- 2.5 mm diameter machine-driven nails.

Nails shall be spaced at:

- 150 mm centres at panel ends
- 300 mm centres at intermediate joists and along noggings.

Nails must not be less than 10 mm from the edge of sheets.

Deformed shank nails have to be used where a resilient floor covering is fixed directly to the plywood. Structural adhesive or deformed shank nails are to be used where plywood is fixed to unseasoned floor joists of depths greater than 150 mm.

Other plywood flooring details

Other details about installing plywood floors include the following:

- Where possible, panel ends should be staggered.
- Structural plywood flooring must not be cramped during installation.
- Structural elastomeric adhesive should be used in a designated wet area.
Fixing particleboard platform floors

Particleboard flooring is laid and fixed in accordance with AS 1860.

Sheets must be securely glued and nailed to the top edge of the joists. The nails are to be:

- 10 mm from all edges
- at 150 mm centres at ends and butt joints for square edge sheets
- at 300 mm centres maximum at intermediate joists or noggings.

Flooring in wet areas

Timber floors in wet areas such as bathroom and laundries, must be protected from moisture in accordance with the Building Code of Australia.

A wet area in a home is any space that is supplied by water - that means bathrooms, laundries and kitchens. How much waterproofing each of these areas requires depends on how much risk they are at from water damage, and generally, they are divided into two areas - showers which are most susceptible and more general wet areas like the floors and walls next to fixtures such as baths, basins and laundry tubs.

When lining floors in kitchens, bathrooms, laundries, and other 'wet areas', compressed sheeting needs to be used. In both domestic and commercial applications, this cement sheet is immune to water damage and will not rot. Compressed sheet is a fast, economical and versatile flooring panel which is ideal for tiling.
There are many products on the market. Check to ensure they conform to the requirements of AS 2908.2 – 1992, ‘Cellulose-cement products Part 2: Flat sheets’.
Wall systems

- Provide structural support to roof systems
- Allow for installation of services
- Provide a means to apply external and internal linings

The most common wall frame system in Australia is the timber stud wall frame. Its members are:

- top plate
- lintel
- common stud
- jamb stud
- jack stud
- nogging
- bottom plate
- timber or metal bracing
- sheet bracing.

The following diagram shows all these parts of the frame.

**Top plate**

Top plates are built along the full length of all walls, including over openings.

Where roof trusses or rafters land on top plates directly above a stud, the top plate may be the same section as the stud. Where roof trusses or rafters do not land directly over a stud, the top plate needs to...
be reinforced with blocking. Alternatively an additional top plate may be installed.

**Lintels**

Lintels are beams that span the openings for windows and external doors. The size of the lintel depends on:

- the width of the opening
- the combination of loads being supported.

Look at Figure 3.4.4.3 in the BCA for details about lintel requirements.

**Common studs**

Common studs are vertical members which transfer loads vertically to bottom plates.

They are usually evenly spaced to suit loads, lining and cladding fixing. Spacings are generally 450 or 600 mm, depending on the roof cladding. Roof tiles require studs at 450 mm spacing. Metal roofing may require studs at 600 mm.

Common studs should be reinforced at points of concentrated loads. This is done by nail laminating additional studs together.

All junctions must have sufficient studs. They must be located so as to allow linings to be fixed.

*Source: Timber Framing Manual (revised February 1994), Timber Promotion Council*
Common studs - Holes and bracing

Holes in studs must be located within the middle half of the depth of the member and holes in plates must be located within the middle half of the breadth of the member. AS 1684.2-2006 provides a table with all the details set out similar to the following example:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Notched</td>
</tr>
<tr>
<td>A</td>
<td>Distance between holes and/or notches in stud breadth</td>
<td>Min 3D</td>
</tr>
</tbody>
</table>

*Table 1: Hole distance in studs*

Where studs have to be braced, the bracing is notched into the stud as shown in the diagram below.

*Source: Timber Framing Manual (revised February 1994), Timber Promotion Council*
Jamb studs

A jamb stud is a stud immediately adjacent to an opening, so it supports a greater share of load than a common stud. Jamb studs can be large single ones or two or more stud nails laminated together.

Jamb studs in external walls and other load bearing walls must not be:

- notched within the middle half of their height
- within the height of the opening.

Jack studs

A jack stud is a stud that has been cut down to be placed above and/or below an opening. The jack stud provides support to the lintel trimmer and sill trimmer.
Noggings

A nogging is a horizontal member that runs between studs. It provides lateral support to studs.

The maximum spacing for noggings is 1,350 mm. This means that there is usually one nogging for walls up to 2,700 mm height. Walls in excess of this may require multiple rows of noggings.

![Diagram of wall construction with noggings, top plate, bottom plate, and stud]

Noggings are not required to be stress graded. Nogging thickness must be:

- a minimum of 25 mm
- suitable for fixing cladding and linings.

Noggings have to be installed either centrally in the depth of the studs or flush with one face of the stud. This is to provide fixing or support to cladding or linings. Stagger in the row of noggings must not be greater than twice the nogging breadth.

Bottom plates

Bottom plates are provided along the full length of all walls except at door openings. The bottom plate is the lowest member of the wall frame and is attached directly to the floor system.

Where a stud lands immediately over a floor joist, the bottom plate may be the same section as the common stud.
Where a stud does not land immediately over a floor joist, the bottom plate needs to be blocked between the floor joists. Alternatively, an additional bottom plate may be installed.

**Designing wall framing member**

AS 1684.2-2006 provides tables for selecting wall framing members. This includes tables for selecting common studs (Table 7) and for the size of lintels in load bearing walls - for single or upper storey and for sheet or tile roofs (Table 17).

**Bracing**

Bracing is attached to studs to provide lateral support to wall framing. Metal straps, timber or sheet bracing can be used for bracing.
Load resistance

Bracing enables the roof, wall and floor framework to resist horizontal forces (racking forces) applied to the building. These forces include:

- live loads - people, furniture etc
- dead loads - structural elements
- wind loads.

Wind classifications

The wind classification needs to be known when designing a bracing system.

Winds are classified according to:

- building height
- geographical region
- terrain category
- shielding classification
- topographical classification.

The following are the classifications for non-cyclonic regions:

- N1 - W28N for 100 km/h gust
- N2 - W33N for 120 km/h gust
- N3 - W41N for 150 km/h gust
- N4 - W50N for 180 km/h gust.

**The effect of forces**

These forces (live loads, dead loads and wind loads) acting on buildings can cause walls to deform (known as 'racking') and/or increase the tendency to slide.

**Bracing systems**

The horizontal loads that winds produce on buildings must be transmitted through the structure to the foundation. In a conventionally constructed house these loads are transmitted to the ground by the complex interaction of the walls, ceiling/roof structure and floor structure.

The ceiling and floor form large horizontal **diaphragms**. A diaphragm is a wall running up to the roof-ridge. Most walls rely on support from this ceiling or floor diaphragm to prevent them from...
The wind forces are transmitted to the ceiling diaphragm from the walls and also the roof. They are then transferred through the ceiling diaphragm to the bracing walls. These transmit them to the floor structure, foundations and then into the ground.

The bracing action

To resist the racking (horizontal) forces, appropriate bracing units must be installed at 90 degrees to the surfaces facing the wind.

For example, take a single-storey house with a gable at one end and a hip at the other. The gable end facing the wind results in a greater load at right angles to the width of the house than the hip end facing the wind.

Permanent bracing

Permanent bracing must be provided to enable the roof, wall and floor framework to resist the horizontal forces.

An appropriate connection is needed to transfer these forces through the framework and sub-floor structure to the building's foundation. When required, bracing within the building is to be constructed into walls or sub-floor supports and distributed evenly throughout. This bracing is normally in vertical planes.

Where buildings are more than one storey in height, wall bracing has to be designed for each storey.

Temporary bracing

During construction, temporary bracing is necessary to support wind and construction loads on the building.
Temporary bracing must be equivalent to at least 60% of permanent bracing required. Temporary bracing may form part of the installed permanent bracing.

Note: The wind forces on unclad frames (under construction) may be equal to or even greater than those on a completed clad or veneered house.

**Nominal wall bracing**

Nominal (minimum) wall bracing is wall framing lined with sheet materials such as plywood, plasterboard, fibre cement or hardboard, or similar. The wall frames are nominally fixed to the floor and the roof or ceiling frame.

The maximum amount that can be resisted by nominal wall bracing is 50% of the total racking forces.

Nominal wall bracing has to be evenly distributed throughout the building. If it is not, the contribution of nominal bracing is ignored because it has little effect.

The minimum length of nominal bracing walls must be 450 mm.

**A bracing example**

The example takes a residential building with the following characteristics:

This example shows the procedure for designing a simple wall bracing.

- single storey
- rectangular home (16.2 m x 7.2 m)
- gable roof.

Fixings and tie-downs

Fixings are necessary to ensure the structural adequacy of the interconnection of the various framing members in a house. AS 1684.2-2006 gives details about design solutions for fixings, for a range of wind classifications, and for various connection options.

All internal brace walls must be fixed at the top and bottom. Details about these fixings are covered in Table 8.22 of AS 1684.2.
Fixings

All fixings, such as straps, bolts, screws, coach screws and framing anchors must match the requirements of the relevant Australian Standards.

All fixings used for framing anchors and straps must be corrosion protected. The level of corrosion protection relates to:

- weather exposure
- timber treatment
- moisture
- presence of salt
- other types of corrosion protection required by relevant authorities.

Where corrosion protection of steel is required it must accord with AS/NZS 4791, AS/NZS 4534, AS 1397 and AS 1214.
Tie-down fixings

Tie-down fixings provide for structural connections to resist uplift and shear forces (lateral loads) in floor framing, wall framing and roof framing.

Where specific tie-down fixings provide equal or better resistance to gravity or shear loads, nominal nailing is not required.

Continuity of tie-down must be provided from the roof sheeting to the foundations.

Where necessary, allowance might need to be made for the counterbalancing effects of gravity loads. If the gravity loads equal or exceed the uplift loads, only nominal (minimum) fixings are required. That is unless otherwise noted for shear or racking loads.

Quality procedures

Checklist

The following is a checklist for ensuring the quality of the frame members and the frame as a whole. Check each of the items listed below:

- walls for plumb, square, straight and level
- top and bottom plates have a tight fit on studs
- bracing and tie-downs in accordance with plan
- noggings at correct centres and support for fixtures
- corner blocking
- walls tied together
- room sizes and ceiling heights with plan
- window and door clearances and openings
- jamb studs to all openings
- concentrated load bearing studs
- lintels for adequate bearing
- block under studs if timber floor
- any excessive notching
- provisions for plumbing services and fixtures
- safety of frame
- adequacy of temporary bracing.

Moisture prevention

Sarking

Sarking is a waterproof, vapour-permeable, flexible sheet material. It is fixed directly behind timber cladding or under flooring material.

The purpose of sarking is to direct any water that may have penetrated the cladding back to the outside of the structure. It also provides a draughtproof barrier to keep wind-driven rain or dust out of the wall cavity.

Sarking is not a substitute for well-chosen and properly installed cladding. It should never be regarded as the principal means of weatherproofing.

Sarking - Materials

Only vapour permeable building paper should be used. Sarking must be impermeable to moisture yet still allow the free flow of water vapour from the back surface of the cladding. If sarking restricts the flow of vapour, timber cladding that has taken up moisture in wet weather may tend to cup as the outside face dries.

Never use non-permeable materials, such as polyethylene film or
foil as sarking immediately behind timber cladding. Perforated foil insulation should not be used as sarking immediately behind timber cladding.

Where board cladding is used it is good practice to use a vapour permeable sarking on the outside of studs and directly under the timber cladding.

**Flashings**

Flashings are used at corners and vertical joints and around openings. The purpose is to ensure that water is prevented from penetrating the wall frame cavity. Because the flashing does not extend fully behind the cladding, non-permeable materials may be used.

**Vapour barriers**

If water vapour is allowed to cross the cavity of a wall when outside temperatures are low, moisture will condense on the back of cold outer cladding or sarking. Under some conditions timber frames and cladding will take up this moisture. This could lead to decay in non-durable, untreated timber. The correct placement of a vapour barrier alleviates this problem.

A separate vapour barrier may be used as well as sarking, depending on:

- the type of construction
- the intended use of the building
- the climate at its location.

Large temperature differences between indoor and outdoor environments have the potential for condensation of water vapour within a frame. As well, people, wet areas and activities (cooking, showers, etc) generate large amounts of moisture vapour within a building. Some of this vapour moves outwards through plaster, wood and other permeable materials until it:

- disperses into the atmosphere
- reaches an impermeable barrier
  or
- meets a surface cold enough for it to condense into liquid.
Vapour barriers should be positioned on the warm side of all infill insulation materials. In climates where day and night are extremely different, expert advice should be sought. Vapour barrier installation must comply with AS 1904.

**Services**

**Plumbing rough-in**

All plumbers must be registered with the appropriate water and sewerage authority. All their work has to be inspected, approved and issued with a compliance certificate guaranteeing their work.

All internal water and gas pipes run through the building to their designated locations. Ensure that plumbers do not cut excessively deep notches into studs or other load bearing members when running pipe work. Excessively notched members should be replaced or repaired with additional back blocking.

All pipes should be properly clipped to the frame to avoid water hammer and pipe vibration. All plumbing fixtures should be adequately attached to the frame.

Check for leaks before installing internal linings.

**Electrical rough-in**

All electricians must be fully registered with the governing electricity authority. All their work must be inspected, approved and issued with a compliance certificate guaranteeing their work prior to connection to the electricity supply.

The electrician will run cables throughout the building to all power points, switches, light fittings and appliances. The building may also be wired for phone services, intercom, computer cabling, home theatre and home security systems. These may be installed by the electrician or by other specialised tradespeople.

Ensure that electricians do not cut excessively deep notches into studs or other load bearing members when running electrical cables. Excessively notched members should be replaced or repaired with additional back blocking.

The electrician should be provided with suitably marked working drawings indicating the precise location of all installations, power points, light fittings and switches internally and externally. All appliances that require electrical power must be readily identified, for example, wall ovens, rangehoods, hot water units. The manufacturers' specifications for these appliances should be given to the electrician to ensure they are connected to suitable wiring.
After the electrical rough-in

All cabling must be satisfactorily clipped to the frame and be adequately protected from mechanical damage. The protection is simply done by installing with the frame, and then covering with internal lining such as plasterboard. Where wires are on the outside of a wall, which is common in garages with brick walls, the cables must be run in a protective conduit.

Prior to installing internal wall linings ensure all electrical cabling is installed. To ensure their easy location once internal lining is complete the location of power points, lights and switches should be clearly marked on the floor of the building.

Non-permanent marking should be used where the existing floor is the final finished surface.

Cladding systems

Cladding systems are the building envelope. They enclose the building and provide protection from the weather.

External cladding contributes to the comfort, structural adequacy and aesthetics of a building.
Buildings clad with timber have many natural advantages on sites that are subject to high winds, extreme climate, highly reactive soils and subsidence or earth tremors. Timber’s natural resilience and high strength-to-weight ratio enables it to withstand far greater stresses and movement than masonry or other rigid materials.

Timber cladding performs best with wide eaves and verandahs. This provides weather protection to walls.

Cladding must be watertight with adequate flashing and sarking in accordance with best industry practice. Special care has to be taken with detailing and protection at ground level and north facing walls.

**Timber species**

Sawn timber weatherboards are generally available in a wide range of timber species, sizes and profiles.

Solid timber external cladding is manufactured from various imported and local timber species. If buildings are exposed to moderate to severe weather, cladding from the highest available grade of timber should be used.

**Hardwood**

AS 2796 ‘Seasoned hardwood - Milled products’ sets out the grades and tolerances for hardwood but does not specify profile details or overall dimensions. These vary between individual manufacturers. AS 082 and AS 083 set out the grades for unseasoned sawn weatherboards.

Naturally durable species are best. However, less durable
Eucalypts can be satisfactory in less severe weather conditions and with good fixing, finishing and maintenance.

**Cypress pine**

AS 093 'Unseasoned cypress pine - Milled weatherboards (Chamferboard)' sets out grades and tolerances for cypress pine. Manufacturers' literature can also be referred to.

**Preserved treated pine**

AS 1784 'Preservative treated cladding milled from Australian grown conifers' sets out grades and tolerances for treated pine (except radiata pine and cypress pine). AS 1495 sets out grades and tolerances for preservative treated radiata pine cladding.

Radiata pine, slash pine and hoop pine are the most common species used. They require preservative treatment because of their low natural durability.

**Imported timbers**

The most commonly used imported cladding timber is western red cedar. Other imported timbers include redwood and Baltic pine. There is no Australian Standard to govern the grades and tolerances of imported timbers. The imported timber shown is Merranti which is imported from Malaysia.

**Profiles and seasoning**

**Profiles**

Timber cladding is generally produced from 150 - 200 mm wide boards. Wider boards are more likely to cup or split. Various profiles are available from manufacturers.

- Sawn weatherboard
- Splayed checked and chamfered
- Double teardrop
- Tongue and groove (T&G) chamfer
- Rusticated
- Double log cabin
- Ship-lap or channel
- Board and batten
Seasoning

Timber will take up and lose moisture and expand and contract accordingly. Timber cladding is usually supplied as 'dry', 'kiln dried' or 'seasoned', with a moisture range of 10 - 15%. Exceptions include western red cedar, cypress pine and hardwood weatherboards, which may be supplied unseasoned.

Unseasoned cladding will shrink as it dries. So, allowance must be made for shrinkage by increasing the overlap of boards. Wider unseasoned boards may also develop slight cupping across the face unless they are restrained. Unseasoned hardwood boards should be fixed as soon as possible after delivery.

Tolerances

Under Australian Standards there are certain millimetre amounts to which board size can differ, yet still be considered acceptable – this is called ‘Tolerance’.

a) Size Tolerance

Visual grading (F – Grades)

- Dressed products (gauged): + 2mm, - 0mm with variation in size within a piece or a parcel not exceeding 2mm.
- Cypress pine products: + 3mm, - 0mm with variation in size within a piece or a parcel not exceeding 2mm.
- Sawn Products: + 5mm, - 0mm with variation in size within a piece not exceeding 2mm.

Machine grading: (MGP – Grade) + 2mm, - 0mm.

Engineered Wood Products: Refer Manufacturer’s Information.

b) Length Tolerance – not less than the specified dimension.

Installation - Nailing

Note: Cladding should be kept dry and clean before installation.

When machined profiles are produced from seasoned timber the design of the edge-joint will allow for movement. Such movement is due to seasonal changes in equilibrium moisture content. (Equilibrium moisture content is the percentage of water content in a solid material.)

Good quality of work is sufficient to compensate for slight expansion and contraction in use. Nails should be placed so that movement of boards caused by changes in moisture content does not create sufficient stress to cause timbers to split. Individual boards must not be nailed together at the lap.
Installation - Flashings and fixings

All vertical joins, windowsills, heads and other openings should be adequately flashed. They should be fixed at least 25 mm under the cladding when covered by it.

Sarking

Sarking is a reflective foil laminate that is installed inside roofs. It has many benefits including weatherproofing, insulation and reduction of dust and sound. It should also be fixed directly under timber cladding.

Fixings should be in accordance with manufacturers' recommendations and to best industry practice. Boards fixed horizontally must have each end protected.

If a painted finish is to be used, end joints should be sealed with a compatible mastic. Alternatively, a timber paint primer should be applied to the ends of boards before fixing.

Where cladding abuts masonry, clearance should be left or ends sealed. This is to prevent moisture from being taken up by the boards.
Installation - Positioning of flashings and sarking

The following diagrams illustrate correct positioning of flashings and sarking on timber cladding. Note that in each case the flashing or sarking on timber cladding is positioned between the external cladding and the corner studs.

Weatherboard stops

Each corner join has the cladding butting up to a weatherboard stop, a narrow piece of timber which is used at corners.

Corner boards

The corner join may be covered by corner boards to protect the cladding join underneath.
Corners without weatherboard stops or boards

The corner joins show the cladding being cut to match exactly in the corners without additional timber required. The mitred corner is used for an external corner and the scribed joint is used for an internal corner.

Sarking and vapour barriers

On the exterior side is the cladding and brick piers, then the sarking, on the other side of which are the stud framework and internal lining.
Plywood cladding

Exterior plywood cladding is available in various veneer grades and profiles. Plywood should comply with AS 2271 ‘Plywood and Blockboard for Exterior Use’. If a plywood cladding is structural, the manufacturer will indicate the stress grade. Plywood cladding can also provide structural bracing and roof hold-down resistance.

Plywood has standard tolerances on length, width, squareness, thickness and edge straightness. Type A bond is required for all exposed use of plywood. Type B bonds are considered only semi-durable. They may give satisfactory performance in semi-exposed situations such as under verandahs.

Plywood can be treated for protection against insect and fungal attacks.

Installation - Preparation

**Note:** Plywood cladding should be kept dry and clean before installation.

Flashing material should be fixed to the frame before plywood cladding is fixed. This must be done in accordance with best industry practice. Some manufacturers produce special pre-formed metal flashings.

Installation - Fixings

All sheet edges and edges in openings should be sealed before sheets are fixed. All joints must be made on a stud or fixing batten. Care must be taken with edge detailing.

Simple butt joints that rely on flexible mastic for sealing may break down prematurely. This means they will allow water into the edge of the sheet or the frame of the structure. A more reliable butt joint can be made using a
cover batten over the sheet joints with the interspace filled with mastic. An alternative method is to use a pre-formed metal or plastic joint cover section with a mastic sealant.

Horizontal joints between sheets should be flashed or rebated.

Fixings should be in accordance with manufacturers' recommendations and to best industry practice.

**Bracing properties**

Plywood exterior cladding can be used to provide structural bracing and hold-down resistance to roofs. If it is used in this way, careful attention must be given to design and construction details.

To provide tie-down, external walls must be clad so that plywood sheets acting in tension connect the top and bottom plates. The connection between the floor joist and the bottom plate, and the top plate and the rafter or truss must also be designed to complete the tie-down 'chain'.

When plywood cladding is used to provide structural bracing on external walls, additional bracing may still be required for the internal walls.

**Hardboard cladding**

Exterior hardboard that is manufactured for use as an exterior cladding must comply with AS 2858. The manufacturers' guidelines should be consulted when using hardboard sheet cladding as structural bracing or for diagonal or vertical applications.

**Installation**

**Note:** Hardboard cladding should be kept dry and clean before installation.

Flashing material should be fixed to the frame before the hardboard cladding is fixed. This should be done in accordance with best industry practice.

Sheet hardboard is fixed in the same manner as plywood cladding. Internal corners can be detailed using a timber stop, or the planks can be cut and scribed to match the splay of the plank on the adjacent wall. External corners can be detailed using either a timber stop or a manufacturer's pre-formed metal corner.

Fixings should be in accordance with manufacturers' recommendations and to best industry practice.
Masonry cladding

This is usually called 'brick veneer'. A single skin of brickwork is laid on the outside of a building to form a barrier against the weather. This single skin of brickwork is not load bearing, that is, it does not support any roof loads. However, it must be strong enough to resist lateral loads from wind.

Installation - Ties and cavities

The brick veneer is attached to the timber frame using a series of brick ties. These provide sufficient support against wind loads.

A gap, referred to as a 'cavity', is maintained between the brickwork and the timber frame. The cavity is necessary as bricks are extremely porous and absorb a lot of water. This water has the potential to cause serious damage to the timber wall frame. The cavity prevents migration of moisture through to the timber frame.

Installation - Flashings

Brick veneer clad buildings must also be adequately flashed so that any water absorbed by the brickwork is directed out and away from the wall.
Brickwork over openings

Where brickwork runs over openings for windows and external doors, lintels are required to support the brickwork. Lintels are made of hot dipped galvanised mild steel. They are usually in the form of angles, flats or T-sections.

Adequate support must be provided where the lintels land on the brickwork. The following table gives minimum end bearings.

<table>
<thead>
<tr>
<th>Span</th>
<th>Conventional sections</th>
<th>Proprietary lintels</th>
<th>Minimum end support (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1 m</td>
<td>75 x 10 flat bar</td>
<td>85 flat</td>
<td>90</td>
</tr>
<tr>
<td>Over 1 m to 2.1 m</td>
<td>100 x 100 x 8 angle</td>
<td>100 x 100 angle</td>
<td>100</td>
</tr>
<tr>
<td>Over 2.1 m to 3.6 m</td>
<td>150 x 100 x 8 angle</td>
<td>150 x 100 angle</td>
<td>150</td>
</tr>
</tbody>
</table>

*Table 1: Table of minimum end bearings*

Articulation joints
Brick veneer construction is very brittle and susceptible to cracking due to movement. Movement occurs for many different reasons, including variations in climate or temperature, movement in the frame and movement in the foundations. Articulation joints accommodate these movements in a building.

Vertical articulation must be installed in all un-reinforced masonry walls unless the soil has been classed as A or S.

Articulation joints are tied at specific intervals and sealed with filler. In straight walls that do not have openings, the articulation joints must be at no more than six metre centres. They must not be closer than the height of the wall away from the corners. Where articulation joints are adjacent to a door or window a gap of 10 mm must be left between the edge of the frame and the brickwork.

**Articulation joints - Positioning**

Here is a plan showing where articulation joints are marked.

The following three diagrams are the elevated views of the house plan. The articulation joints are marked on the plans.
Articulation joints and openings

Articulation joints and changes in wall height

Articulation joints between openings

Here is an example of the construction of an articulation joint.
Installing windows

The frame members

The following diagram shows the parts of a window frame.
Window frame types

Window frames may be made of timber, aluminium or plastic. The most common opening methods are awning, sliding, double hung, side hung and louvre.

Awning
- Usually timber - western red cedar or seasoned hardwood
- Usually purpose made, though some standard sizes are produced
- Stay-openers may be used
- Insect screens fitted on the inside

Sliding
- Generally aluminium
- Produced in standard sizes, with wide range of price and quality
- Range of colours in anodised acrylic
- Insect screens fitted on the outside

Double hung
- Traditionally timber - western red cedar or hardwood, but also available in aluminium
- Usually purpose made
- Counterbalancing systems, including lead weights and spiral friction balances
- Insect screens fitted on the outside
- Some roll-up screens fitted inside

Side hung
- Generally timber - western red cedar or seasoned hardwood
- Stay-openers may be used
- Insect screens fitted on the inside
Louvres

- Aluminium, steel or timber
- Usually purpose made
- Not common as difficult to get 100% watertightness
- Insect screens fitted on the outside

Window frame glazing and accessories

Window frames are delivered fully glazed. The window glazing should be in accordance with AS 1288. This specifies the requirements for human impact areas (for safety of the occupants) and the anticipated wind loads.

The latches or winders are already fitted. Additional requirements, such as locks or architectural furniture, can be fitted off-site or on-site.

Installation - Flashings

Timber window frames require flashings under the sill to stop water migrating to the inside wall linings. Side flashing is also necessary to prevent water migrating to the back of the stiles. Some manufacturers provide a groove in the stile in which to tuck the flashing.
When the head of a window may be exposed to weather, such as a window in a gable wall, the head of the window needs to be flashed to stop any water getting in.

**Installation - Checking the jamb studs**

Jambs and heads must be plumb and level. The edges should be adjusted to ensure they are flush with the interior wall lining. When allowing for 10 mm plasterboard internal lining, a good quality folding rule can be used. Most are 10 mm thick and so are ideal to use as a gauge when setting a frame in position.

**Installation - Aluminium frames**

Timber reveals are fitted to aluminium frames. The width of the reveal suits brick veneer or cladding. No additional flashings need to be fitted to aluminium window frames. The opening is packed ready for the window frame, then the frame is fixed in place. Fixing through the reveals into the studs is the usual fixing method.
Surfaces must be protected from mortar splashes. Some aluminium window manufacturers supply their windows with protective tape fitted.
Installation - Timber frames and weatherboards

Timber window frames should be fully primed or treated to prevent water damage. Any surfaces that are likely to be splashed with mortar should be masked or taped.

The width of the reveal timber is particularly critical for weatherboard construction. In these the reveal size is usually the stud depth plus the thickness of the interior lining.

Window schedules

Window frame manufacturers produce a range of readily available frames. Their sizes are detailed on a schedule. A typical schedule details the appearance of the window frame when viewed from the outside. It also shows the finished height and width of the frame. The height is usually shown to the left of the page and the width is shown across the top. Most schedules also show the stud opening size required. When specifying the dimensions of a window frame, the height is always written first.

The height and width opening sizes are checked to determine an appropriate window.
Schedules for aluminium window frames

Aluminium window schedules differ from those for timber window frames. The timber reveals fitted to the windows for brick veneer and weatherboard construction are an additional size over the window size. This appears as an extra row of figures on a schedule.
Roof systems

A roof system is the structure that forms the roof of a building. In Australia, the roof system may be made up of:

- a timber frame roof built on-site or
- a prefabricated truss roof in which major components are constructed in a factory and then assembled on-site

Different types of roof may be built for a low rise construction such as:

- Box gable
- Dual pitch roof
- Dutch gable
- Dutch hip
- Gable end
- Hip and valley
- North light
- Skillion

A roof may consist of a combination of various styles.

**Gable roof**

This type of roof has a triangle on the side or front of the facade, which is formed by the straight slope declining from the ridge to eave.

**Hipped roof**

This type of roof has an even roof to wall junction for the whole house and eaves on all sides.

**Hip and valley roof**

This type of roof is used for an L or U shaped buildings. The valley is formed at the internal junction of the two roofs for L or U shaped buildings.
Hipped roof with Dutch gables

This is a combination of a hipped roof and a gable ended roof.

Skillion roof

This is a single pitched roof with rafters running from one wall to another.

Conventional roof framing

'Coupled' roof is a conventional roof that is constructed on-site. It uses ceiling joists, hanging beams, strutting beams, struts, underpurlins, collar ties, rafters and ridgeboards.
Ceiling joists

The ceiling joists have a double function:

- they provide the structure onto which the ceiling is fixed
- they are the member that connects or ties the lower ends of rafter couples (pairs). Therefore, they prevent the rafters spreading and causing the roof to sag or collapse.

Ceiling joists are normally horizontal members, however, under special circumstances they can be fixed on a slope. They are spaced according to the material they support. Typically the material is plasterboard which can span 450 mm.

For coupled roofs, ceiling joists have to be in single lengths or spliced. They must be at the same spacing and in the same direction as the main rafters so they can be fixed to, and act as ties between the feet of opposing rafter pairs. Where there is no internal wall to support the ceiling joist a hanging beam must be installed.

Any opening, manhole, skylight and similar must be trimmed to provide full support for ceiling linings.

Refer to the Table 21 of AS 1684.2 for details about the required spans for ceiling joists.
Hanging beams

A 'hanging beam' is generally a deep timber beam located perpendicular (at right angles or 90º) to ceiling joists and directly above them. The function of a hanging beam is to reduce the span of the ceiling joists. This allows for a more economic joist size and consistent section. Hanging beams must only support ceiling joists and the attached ceiling materials.

The hanging beam has to be adequately supported on its ends over load bearing walls. This is done using blocking pieces of the same timber as the ceiling joists. The ceiling joists are fixed to the hanging beam with:

- hoop iron straps
- timber battens
- or
- purpose made metal joist hanger brackets.

Hanging beams are held in a vertical position at both ends. They can be nailed or bolted to an available rafter, gable end strut or held by means of angle strutting from internal walls.

The sizes for hanging beams are determined using Table 23 of AS 1684.
Strutting beams

'Strutting' beams are used in many ways and locations in a conventionally framed roof. Their function is always to support roof members, generally below the underpurlins, where there are no conveniently located load-bearing walls. Strutting beams only support roof loads. The strutting beam transfers the roof load directly to load bearing walls. It must never rest on, or transfer load to, a ceiling joist.

Strutting beams cannot double as hanging beams. This is because they are likely to sag and will cause the ceilings to sag. Also, they transfer roof loads that are often dynamic because of wind pressure acting on the roof. This means they may move up and down or from side to side, causing the ceiling to move and possibly crack.

The ends of strutting beams must bear on the full width of wall plates. Blocking should be provided between strutting beams and wall plates to provide an initial clearance of 25 mm at mid-span. This clearance is between the underside of the beams and the tops of ceiling joists, ceiling lining or ceiling battens, as appropriate.

Strutting beams may extend in any direction in the roof space. They bear directly above studs supporting concentrated loads or distributed over two or more studs by means of top plate stiffening. Where strutting beams occur over openings, the lintels have to be designed for a concentrated load.

Strutting beams continued

The ends of strutting beams may be chamfered to avoid interference with the roof claddings. Where the end dimension is less than 100 mm or one-third of the beam depth, whichever is greater, an alternative support method must be provided. This support is similar to that shown for hanging beams.

Table 27 of AS 1684 provides details
for maximum strutting beam support.

Roof struts

The struts are needed in the roof frame to transfer the loads from underpurlins and other beams to the load bearing walls. Struts should be adequately supported over studs in timber walls. They should have anti-slip blocks, where necessary, to prevent them sliding horizontally.

Struts are generally more efficient the closer they are to the vertical. Struts must be either vertical, perpendicular to the rafters or at an angle to the vertical which does not exceed 35°. They are 'birdsmouthed' or halved to fit underpurlins as shown below. (Birdsmouthing is so called because the cut looks like a bird's open beak.)
If they are not vertical, struts must be restrained with blocks or chocks.

Struts may be perpendicular to the rafters.

**Underpurlins**

Underpurlins are so called because they are fixed under the rafters. They are fixed horizontally and perpendicular to the direction of the roof slope. In a conventional roof frame the underpurlins support the underside of the rafters. This allows for the most economic rafter size and prevents the roof from sagging and collapsing.
Underpurlins must be in single lengths where possible. They must be in straight runs at right angles to the direction of rafters. Where underpurlins are joined in their length, the joint needs to be made over a point of support, with the joint halved, lapped and nailed.

Collar ties must be provided in all coupled roof construction. They supplement the ceiling joists and prevent the rafter couples spreading.

Where the rafter span is such that it requires support from underpurlins, collar ties are fitted to opposing common rafters at a point immediately above the underpurlins.

Collar ties must be fitted to every second pair of common rafters.
Rafters

Maximum overhang is 30% single span value of rafter except where overhang for a birdsmouthed rafter permits a greater overhang.

In a conventionally framed roof, the rafters are fixed on a slope and run in the same direction as the roof slope. Rafters are generally erected in opposing pairs or couples. They meet each other directly at their apex on the ridge of the roof. The rafters give the roof its required slope and provide the structure onto which the roof covering is fixed.

Where a rafter meets its supporting top plate it is cut so that it rests directly on the top plate. The cut is a ‘birdsmouth’ cut. Rafters may be birdsmouthed to a depth not exceeding one third of the rafter depth. Rafters must be single length members or joined over supports.

Table 29 of AS 1684.2 provides details for rafters and purlins.
Ridgeboards

The ridgeboard in a conventional framed roof is not so much a structural member as a setout member. It makes sure that rafter couples meet at a consistent height giving a horizontal ridgeline free from sags. Ridgeboards locate and stabilise rafter ends. Opposing pairs of rafters must not be staggered by more than their own thickness at either side of their ridge junction.

Full-length ridgeboards should be used wherever possible, however, ridgeboards may be joined using a scarf joint at the abutment of a rafter pair. Or, preferably, they should be nail-spliced using full depth fishplates on both sides of the ridgeboard.

Quality procedures for conventional roof framing

Checklist

This checklist will help ensure the quality of the roof frame.

Check each of the following items:

- rise and pitch of roof against plan
- correct propping of ridge, hips, valleys, rafters and underpurlins at correct centres
- adequate collar ties
- line of rafter, hips and valleys
- support to strutting beams
- fascia and barge boards
- all tie-downs and fixings
- ceiling joist and alignment with rafters
- hanging beams
- trimmers for location
- trimming to manhole.
Roof trusses – General

Manufactured timber roof trusses provide a structurally efficient alternative to timber beams. They place greater emphasis on axial loading of members and less on bending.

The advantages of trusses include the following:

- They are strong, but light to erect.
- They can be made to suit most roof shapes.
- There is less on-site fabrication, therefore less site labour is required.
- They are less affected by bad weather.
- Factory production allows automated production.
- Better quality control is possible.
- Trusses make maximum structural use of the timber.
- Trusses are capable of long spans.
- Internal walls are usually non-load bearing, therefore lighter weight internal walls are possible.

Design requirements for roof trusses

The design of a timber roof truss must accord with engineering principles and with AS 1720.1. This includes the wind design. AS 4440-1997 'Installation of nail plated timber roof trusses' provides details for correct practices when installing roof trusses.

Trusses are usually spaced at regular intervals, typically 600 mm, 900 mm or 1,200 mm apart. The spacing depends on the mass of the roofing material and local practice. A range of truss types can be configured to attain different shapes.

Terms for roof truss members

The following diagram shows the terms used for general roof truss members.
The following diagram shows the terms applying to gable end roofs.

**Truss types for hip roofs - The basic concept**

Hip end trusses include various types required to shape a hip end. The following diagram shows the basic concept.
The various trusses for hip roof systems

**Truncated standard truss**
This takes a standard truss shape but cuts off the top to suit the slope at the top of a hip end.

**Truncated girder truss**
This is the main truss in a hip end. It occurs below the standard truncated trusses. It takes the load of the outer hip trusses including the hip, jack and creeper trusses. It is made stronger than the standard truncated trusses to take these loads.

**Hip truss**
This forms the hip line of the roof. It is similar to a half truss but has an extended top chord. This extends over the truncated girder truss and finishes as the top of the hip. Some jack and all creeper trusses butt into the hip truss.

**Jack truss**
This runs into the hip truss. It is similar to a half truss but with an extended top chord. This extends over the truncated girder and meets the hip truss.

**Creeper truss**
This runs into the hip truss with no extension of the top chord. That is, it stops short of the truncated girder.

**Scissor truss**

There is a modified standard truss to suit a sloping ceiling. Most scissor trusses have an equal pitch ceiling each side of the apex. Other ceiling lines are also possible.

**Bell truss**

This is a common roof shape for Federation and homestead style houses. The top chord has two pitches. The lower pitch is usually over a verandah or patio area.

**Bowstring truss**

This truss is mostly used as a commercial truss, however, it is becoming more common in the domestic sector. The top chords are designed to allow a curved roof.

**Cantilever truss**

This can actually be any type of truss but the support point on one or both sides is located inside the span, not at the heel. An extra web is required at the inner support location(s).

**Cut off truss**

This can be any type of truss but does not have a heel. This truss shape is determined by the location and comparative height of the pitching lines on either side of the roof area.

**Half truss**

A half truss is a full truss, cut off at the apex.
The camber in trusses

During production, trusses improve on traditional rafter design by forcing an upward bend into the chords of trusses. This is referred to as a ‘camber’.

A camber helps to resist loads. For example, the amount of bend is calculated to help resist the load of tiles and ceiling lining. The calculations are designed to ensure the truss eventually flattens out to provide straight chords once it is fully loaded.

Roof trusses – Bracing

Downward loads on the roof cause compression in the top chords. Long slender members tend to buckle sideways in compression. Top chords are long slender members and, therefore, they tend to buckle sideways.

Trusses need to be prevented from buckling because this causes them to move outside their plane of strength (ie plane of vertical strength). Fixing roof battens to the top chords at regular intervals restrains the sideways movement in the top chords. Battens should be fixed to every truss, including each ply of double and triple ply trusses.
Diagonal bracing to stabilise roof planes

Diagonal bracing is required to address top chord distortion. It is used in other parts of the roof as well, for example, the bottom chords and webs. Bracing is often provided by a steelbrace. A steelbrace is made from metal strapping and has a slight bend along the centre line. A typical specification for steelbrace is shown below.

Diagonal steelbraces that cross over the top chords act as tension ties. If the ties are only fixed at the ends, the mid regions of the top chords can still move sideways. If the steelbrace is fixed to every element it crosses, the forces arising from wind or lateral buckling can be transferred to the supporting structure. Consequently, the whole assembly can be kept square.

The steelbrace must also be attached to elements such as walls that transfer loads to the structure.
The steelbrace only works in tension, therefore it is applied in X or V patterns across the roof planes. The steelbrace is nailed through its holes to the members it passes over. This ties and assists the restraint provided by roof battens.
Diagonal bracing for hip and Dutch gable roofs

**Hip and Dutch gable roofs** A hip roof is a roof where ends and sides are all pitched (sloping). A Dutch gable is a hip roof that has a gable projecting from a hip and is approximately two thirds up the roof slope. They tend to self-brace because of the sloping ends. Even so, the same concepts of span and length determine the nature and frequency of bracing. Two spans lengths need attention - spans up to 13 m and spans which are 13 to 16 m.

For spans up to 13 m, diagonal bracing is only required in the gable section between hip or Dutch gable ends. That is, between the apex of opposing ends. Specific bracing requirements depend on whether the roof length (L) is longer or shorter than the half truss span (h). The shorter scenario is shown in the diagram below.
Lateral restraint for bottom chords

Bottom chords also need to be braced against lateral buckling and distortion. The treatment of the ceiling and its type of attachment to the bottom chords affect the need for restraint.

Ceilings fixed directly to the bottom chord require minimal bottom chord ties, for example, ties not exceeding 4,000 mm apart. Ceiling battens nailed or screwed to trusses provide lateral restraint similar to roof battens so no additional restraint is needed.

Suspended ceilings or battens that do not provide lateral restraint need bottom ties, eg clip on battens. These must comply with an approved specification.

Ties must be attached to building elements capable of taking bracing loads. Steelbraces should be used to prevent ceiling plane distortion.

Lateral bracing of web ties

If the truss is heavily loaded and has deep slender web elements, the designer may specify that the webs be laterally braced. The timber web tie links the centre of all webs together (just as battens do for the top chords).
The steelbrace stabilises the rectangular shape of the plane formed by the webs.

Roof trusses – Connections

**Common truss connections**

The main connections in trusses are factory fixed nail plates. Nevertheless, many elements in the roof assembly still require fixing on-site.

AS 4440 determines methods for common connections. However, if skew nails, nail plates or metal strapping are used, wind load classifications must determine the connection. In high wind areas (N4, C2, C3) the connections tend to be upgraded from nails to nail plates, and from nail plates to straps.
**Girder bracket connections**

Truss boots are often in situations where one end of a number of trusses is supported on the bottom chord of a girder truss.

Girder brackets (or truss boots) transfer loads from standard trusses to girder trusses. The load involved makes this connection important. The bracket option used will depend on the load requirements.

**Framing bracket**

Add a framing bracket at the bottom chord junction. As a general rule, use two or three nails where each chord butts against another member.

![Framing bracket diagram](image)

**Anti-twist truss boots**

Anti-twist truss boots support standard trusses, truncated standard trusses and small girder trusses.

![Anti-twist truss boots diagram](image)
High load truss boots

High load truss boots are usually made from welded brackets. They support large standard and truncated standard trusses as well as girder and truncated girder trusses.

For connection details, refer to manufacturer's specifications.

Roof trusses – Application

Setout

Roof truss setout is about the process of correctly applying truss technology to roof shapes in the building design. The process is as follows:

- Use roof lines on the drawings to convert roof shapes into separate truss areas known as 'blocks'.
- Set the positions of key trusses in each block.
- Set the positions of remaining trusses.
- Determine where valley in-fills are required.
Figure 3.4.4.2
STRUTTING BEAM SUPPORTING A ROOF AND CEILING

Strutting beam application

<table>
<thead>
<tr>
<th>Steel section</th>
<th>STEEL SHEET ROOF</th>
<th>TILED ROOF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strutting beam spacing (m)</td>
<td>Strutting beam spacing (m)</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>2.4</td>
</tr>
<tr>
<td>125TFS</td>
<td>5.7</td>
<td>5.4</td>
</tr>
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<td>150UB14.0</td>
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<td>200UB18.2</td>
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<td>250UB31.4</td>
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<tr>
<td>310UB48.2</td>
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<td>11.3</td>
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</table>

*Replace 0.5 with 0.6 if hanging beams are continuous over strutting beams.

Maximunum span of strutting beam (m)
Figure 3.4.4.2
STRUTTING BEAM SUPPORTING A ROOF AND CEILING

<table>
<thead>
<tr>
<th>100TFC</th>
<th>4.6</th>
<th>4.4</th>
<th>4.2</th>
<th>3.9</th>
<th>3.7</th>
<th>4.0</th>
<th>3.7</th>
<th>3.6</th>
<th>3.4</th>
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<tbody>
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<td>9.3</td>
<td>8.8</td>
<td>8.4</td>
<td>8.2</td>
</tr>
</tbody>
</table>

Notes:
1. If point load applied, then it should be located within the middle third of the strutting beam span.
2. Top and bottom flanges of strutting beam must be laterally restrained at the loading point.
3. Strutting beam must be tied down at the support points, in the case of steel sheet roofs.
4. Steel is base grade.

Figure 3.4.4.3
LINTELS SUPPORTING ROOF, FRAMES AND TIMBER FLOORS

Lintels supporting roof and floors

(a) Floor and truss roof

(b) Floor and conventional roof

(c) Floor - example A

(d) Floor - example B
Table 3.5.1.1b SARKING REQUIREMENTS FOR TILED ROOFS

<table>
<thead>
<tr>
<th>Roof—degrees of pitch</th>
<th>Maximum rafter length without sarking (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 18 &lt; 20</td>
<td>4500</td>
</tr>
<tr>
<td>≥ 20 &lt; 22</td>
<td>5500</td>
</tr>
<tr>
<td>≥ 22</td>
<td>6000</td>
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</table>

**Note:** The maximum rafter length is measured from the topmost point of the rafter downwards. Where the maximum rafter length is exceeded, sarking must be installed over the remainder of the rafter length.
Roof trusses - On-site cautions

Lifting

When lifting, it is important to sling the trusses carefully so that damage is avoided.

Trusses should only be lifted by attaching slings to the panel points.

When the truss span is greater than 9,000 mm, use a spreader bar or strong-back.
No modifications!

Under no circumstances are roof trusses to be modified on-site. If trusses are forced to work in ways they were not designed for, problems will develop.

Cutting the bottom chord will cause the other parts to work more in bending than axial loading. The truss will sag and break.

Cutting a web will cause the truss to be no longer a pattern of rigid triangles. The truss will become unstable and distort out of shape.

The bottom chord is designed to work mainly in tension. If the middle is wrongly supported by a wall, the chord will be put into bending. The truss may break.

Load bearing
Most roof trusses are only designed to be supported on external load bearing walls.

Quality procedure for roof trusses

Checklist

This checklist will help ensure the quality of the roof trusses.

Check each of the following items:

- truss layout plan
- manufacturer's specifications for tie-downs, bracings and lateral stability
- roof truss certification
- adequacy of supporting structure
- dimension, overall width and length of wall for fit
- support to girder trusses
- plumb and spacings
- all tie-downs and fixings
- location of specialised trusses
- trusses have not been modified on-site
- eave overhangs
- trimming to manhole.

Roof cladding – Tiles

Tile materials

Roof cladding is the material used to protect the building from the extremes of the weather. The two most common options are roof tiles and metal roof sheeting.

Roof tiles are particularly suited to the Australian climate, which generally does not have high winds or snow loads. These elements are most likely to reduce the life of roof tiles. Roof tiles can generally be used on roofs of 15° or greater pitch, however, some materials and methods of manufacture require 25° or greater pitch.

Roof tiles come in many different materials.
**Terracotta tiles**

The tile is formed in wet clay and then fired to give a hard, long-life roofing product. They come in a number of profiles. Terracotta tiles have a roof life greater than 50 years in most environments, however, salt atmospheres sometimes cause premature fretting.

**Concrete tiles**

Concrete roof tiles are generally modelled on terracotta tiles. Modern concrete tiles have roof lives approaching those of terracotta. They are stable, warp-free and have the same basic profiles as terracotta tiles. The colour on the concrete tiles is an applied coating. Although some colours fade quickly (within five years), most of the popular red/brown/charcoal colours have long colour retention.

**Slate tiles**

These are a naturally occurring rock.

**Shingles**

Fibre cement shingles are slate-like products manufactured from fibre-reinforced cement.

**Shingles/shakes**

Timber shingles/shakes are made of sawn or split timber boards.

**Aluminium or steel pressed tiles**

These are metal that is shaped to imitate a tile. They are often covered with coloured sand glued to the metal.
Tile styles

As well as being made of many different materials, tiles come in various profiles.

Fixing terracotta and cement tiles

Both terracotta and cement tiles are fixed to timber battens with wire clips, nails or screw fixings. Manufacturers provide fixing specifications. Specialised capping tiles are laid along ridges and hips. These must be pointed with mortar to ensure adequate fixing and waterproofing.
Fixing cement and timber shingles

The fixings for tiles, the edging details and the fibre cement shingles and timber shingles are shown in the diagrams below.

**Fibre cement shingles**

- Crampon
- Multi notch fibrous cement shingle sheet
- Laying of sheets from eave to ridge

**Timber shingles**
Sarking

Most manufacturers of roof tile products indicate a minimum pitch for their product without sarking and a different minimum pitch for roofs with sarking. However, sarking is advisable under any roof, particularly if the sarking can perform two roles, that is:

- acts as a secondary protection against moisture penetration due to wind-blown spray, broken tiles, condensation, etc
- acts as a reflective foil surface to reflect the radiant heat of the sun.

Roof cladding - Metal roof sheeting

Profiles and materials

Roof sheeting is available in various profiles and materials. Generally, roof sheets can be used on any roof type, but each particular profile has a particular range of roof pitches in which it is most efficient. The standard corrugated profile has the widest range of applications and it is the only profile that lends itself to curving.

Corrugated profile is available in several materials such as aluminium, galvanised steel, pre-painted steel and vinyl-coated sheet, copper, fibreglass and in vinyl or acrylic plastic sheet. Zincalume coated steel roof sheets are also produced in many different profiles.

Roofing profiles

Watertight properties and fixing

Most sheet roof products remain adequately watertight down to a pitch of 5°. Some, particularly the decking profiles, remain watertight on pitches that are nearly flat at 1°. Generally speaking, all sheet roofs should have a waterproof sarking immediately under the roof sheets.
The manufacturers of roof sheets generally produce good quality technical information for their products. They also give extensive information on fixings for high wind areas. In some instances special profiles are produced for use in extreme climatic conditions.

The manufacturers’ details include:

- how many fasteners to use per sheet
- the location of the fasteners
- the minimum length of fasteners for steel or timber supports
- the side lap fastener spacing.

For example, the ‘normal’ type of corrugation requires three fasteners per sheet at the internal supports and five fasteners per sheet at the end lap supports.

Cautions with metal roof sheeting

For personal safety, sheets should be handled wearing clean, dry gloves. Sheets taken freshly from packs have an oily surface and care must be taken when walking over newly laid sheets until the oil has had time to evaporate. This applies particularly to steeply pitched roofs.

Wearing gloves helps to preserve the surface finish. Do not slide sheets over rough surfaces or over each other and do not drag tools, etc over sheets.

If it is necessary to saw cut sheets, on-site care should be taken to avoid cutting over other sheeting when using power saws which produce hot metal particles, particularly in the case of Colorbond steel. If such cutting is necessary, a protective covering should be placed over the lower sheets. When saw-cutting Colorbond, use padded supports and cut sheets with the face side downwards. Also, it is preferable to use metal cutting steel blades in power saws (minimum 4,000 RPM). These produce fewer fine metal particles and leave less burred edges than carborundum discs.

To provide temporary protection during production, handling and transport, some Colorbond steel roof and wall claddings and accessories are coated with a plastic film before rolls are formed. This plastic material has a relatively short life under exterior exposure conditions. It should be removed either immediately before or immediately after installation.

Electrolytic (galvanic) corrosion has a detrimental effect on the durability of any metal roof covering. Precautions should be taken to avoid this type of corrosion.

Avoid the use of different metals together, whenever possible, for example:
• rainwater should not be permitted to drain from copper onto galvanised sheet or aluminium
• new galvanised steel will rapidly corrode if it is in contact with rust from an earlier corrosion.

Installing metal roof sheeting

When lifting sheets to the roof frame ready to start laying and fastening, care should be taken to make sure all sheets are the correct way up. Have the overlapping side towards the edge of the roof from which installation will start, otherwise sheets will have to be turned over and/or turned end to end.

One and a half corrugations is the generally accepted sidelap for roofing. It is used also for wall cladding in areas subject to extreme conditions of driving rain.

Side lapping

Installation procedures for roofing and flashing using self-drilling screws, drills, hacksaws, power saws or files usually deposit metallic particles on or near the roof sheeting and roof area. These metallic particles and all other debris including blind riven shanks, nails, screws, nuts, cuttings, swarf, etc should be swept from the roof sheeting, flashings and gutters as soon as possible.

Screw positioning

Flashings

Appropriate flashings must be used to provide a watertight seal where roof sheeting ends.

End apron flashing and steel decking
Ridge capping and steel decking

End capping, galvanised steel or aluminium sheet

Stepped apron flashing

Fasten at 600 mm centres
Sheet laying procedure
Completed roof with all sheets laid

Order in which sheets are laid

References

National VET Content, Structural Principles – Properties, ToolBox 10.01 BuildRight