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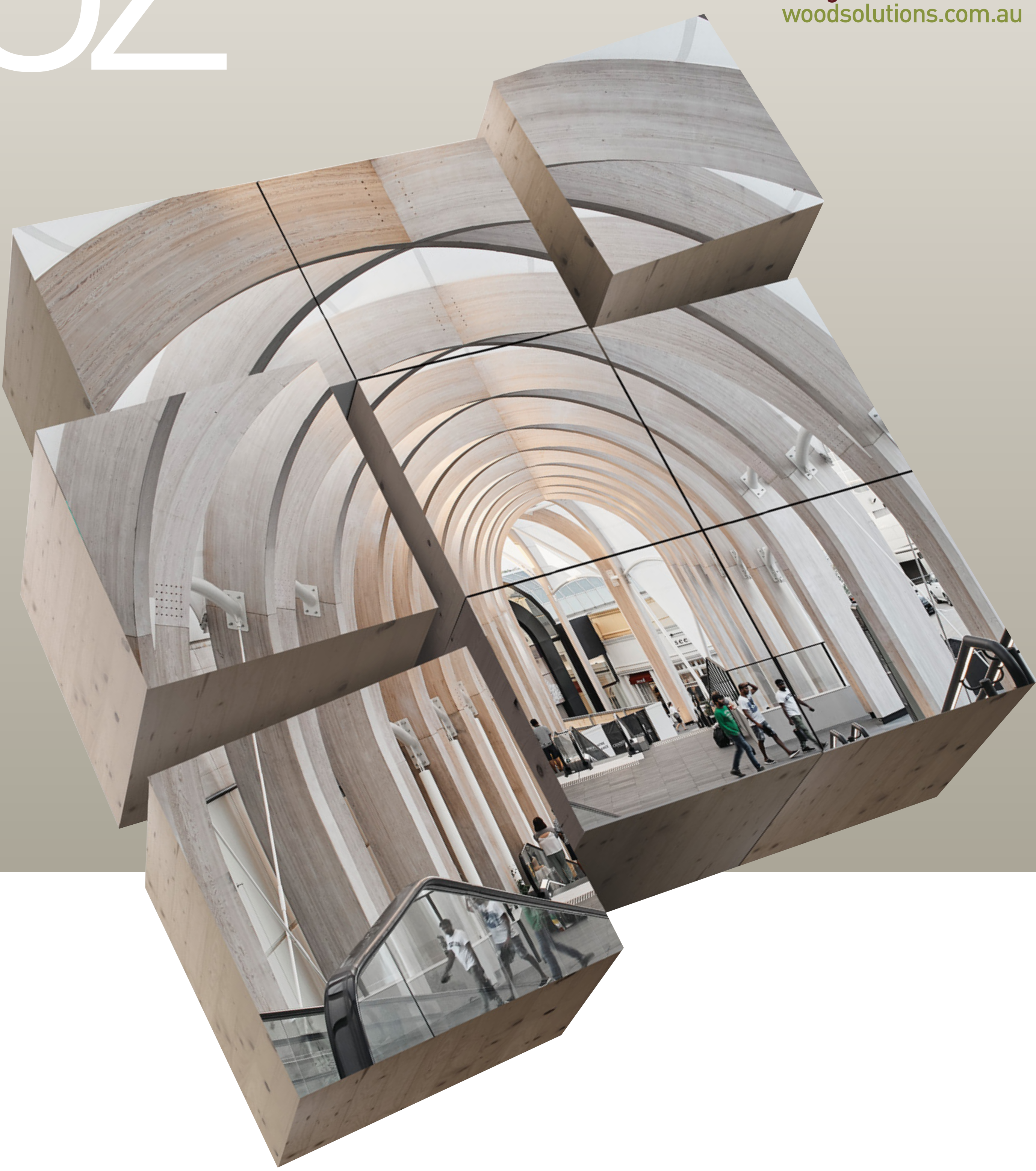

Timber Connectors

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Author
Timber Development Association
Unit 6/281 Pacific Highway
North Sydney NSW 2060

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1 Introduction and scope

Many of the advances in mass timber construction in recent years are due to the availability of modern wood fasteners and connectors.

Where timber can be used somewhat depends on the ability to join the timber elements together. For designers, a connection is one of the critical elements to consider as it has a significant impact on the structure and the cost. As with most engineering structures, joint design substantially affects the building's economics (Milner [23]). It can account for between 5 and 50% of the un-jointed timber members' cost and consume up to 70% of design effort (Batchelar [8]). Connector costs in large spanning structures may have a higher cost – up to 100% of the element's cost – so their appropriateness affects the affordability of the structure.

Each connector has specific behaviour and requirements for detailing and unique capacity often depend on the timber elements it connects. Also, timber may be connected to other materials, which adds to the design decisions.

There are various methods to connect timber elements, and the use and choice of the connection are dependent on several variables. This guide aims to help designers choose the most appropriate connection for the intended purpose.

1.1 Audience and scope

This guide is aimed at construction industry practitioners and presents the state-of-the-art information at the time of writing. It aims to inform designers, users and specifiers, such as engineers, architects, fabricators, construction and joiners. Where the readers are looking for a more detailed explanation or direction to other information sources this information, where available, is provided.

The guide will help designers make informed choices in designing timber connectors by understanding what factors influence the capacity or degradation of the connection. It focuses on mechanical joints; however, adhesive connections are mentioned for context. It is not intended to provide information to carry out a timber connection design.

This guide covers lightweight timber-framing applications and mass timber construction, and the discussion is divided into these timber construction types. There is no reason that a concept from one construction type can't be used within the other.

1.2 Guide structure

This guide is divided into the following seven sections:

Section 1 – Introduction and scope

Section 2 – Ready reckoner to select a connector or fastener

Section 3 – Common fastener types

Section 4 – Lightweight timber-frame connectors

Section 5 – Mass timber connectors

Section 6 – Timber joint design to AS 1720.1

Section 7 – Detailing timber connection

1.3 Terminology convention

It is important to understand the terminology associated with connectors. A connector is a solitary fastener, while a connection is referred to as several connectors or fasteners. A fastener is a device that closes or secures something; in timber construction these are nails, screws, bolts and dowels, often referred to as dowel-type fasteners.

A connection is an assembly used to join a piece of timber with another piece of timber, steel, concrete, or other material to transfer loads. Connections are typically created using a combination of fasteners, plates and bearing.

1.4 Development of timber connectors

Timber has been used in construction for many thousands of years. The earlier versions of a timber joint relied on the wood itself; usually, a fork in a tree provided a bearing surface for timber elements. The first use of mortise and tenon joints to join timber dates back more than 7,000 years and was found in a well near Leipzig, accredited as the world's oldest intact wooden architecture (*University of Freiburg*). It has also been found joining the 'Khufu ship' wooden planks, a 43.6 m long vessel sealed into a pit in the Giza pyramid complex around 2,500 BC.

The next significant development in timber connectors came about with timber framing or 'post-and-beam' construction, traditional methods of building with heavy timbers, creating structures using squared-off and carefully fitted and joined timbers with joints secured by large wooden pegs. If the structural frame of load-bearing timber is left exposed on the exterior of the building, it may be referred to as half-timbered. In many cases, the infill between timbers is used for decorative effect (see Figure 1).

Figure 1: Half-timber six-storey timber building circa 1561. (Image credit: TDA)

The subsequent significant development was the inclusion of non-wood materials to form the joints. Here metal plates combined with fasteners such as bolts and nails, and screws form the joints (see Figure 2).

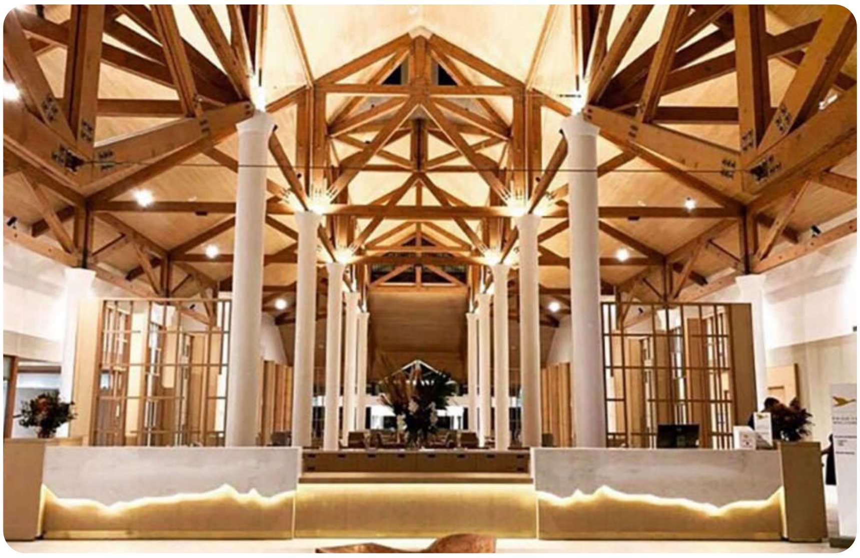

Figure 2: Metal fin plates and bolted connections – Twin Waters Resort. (Image Credit: Novotel)

The next significant development, in the mid-1950s, was the nail plate connection. This development revolutionised lightweight timber framing and is still how timber framing is used in roof construction (see Figure 3).

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Figure 3: Timber nail plate truss. (Image credit: MiTek)

The final significant development of timber connection began in the 1990s when bolts and plates made way for modern screws and hook types of connectors (see Figure 4). These modern connectors have changed how timber buildings are constructed and assisted in the current use of mass timber construction.

Figure 4: Modern timber truss, air craft hanger roof, Switzerland. (Image credit: TDA)

2 Ready reckoner to selecting a connector or fasteners

Table 1 is a quick reference to the type of timber connector or fastener appropriate to various timber products and situations.

Table 1: Ready reckoner to selecting a connector or fasteners

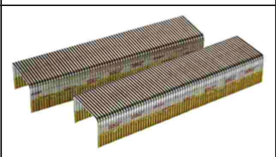
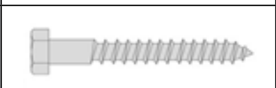
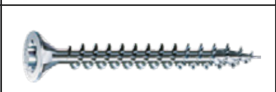
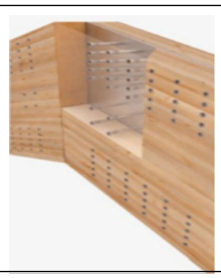
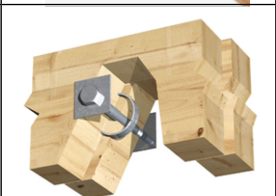
#	Image	Light -Timber Frame[1]	Heavy Timber[2]	Panel	Truss	Portal	Mass Timber	Fire Resistance	Archi-tectural Expression	Design	Cost	Off-site Fabrication Potential
Nails		Yes	Yes	Frame	No	Ply-wood Gusset	Potential	Low	Low	AS 1684 AS 1720.1	Low	High
Spikes		No	Yes	No	No	No	(Ex-posed)	Low	Low	AS 1684 AS 1720.1	Low	Low
Corrugated Fastener		Yes	No	No	No	No	No	Low	Medium	Performance Solution	Low	High
Staples		No	No	Yes	No	No	No	Low	Low	Performance Solution	Low	High
Traditional Wood Screws		Yes	No	Yes	No	No	No	Low	Low	AS 1684 AS 1720.1	Low	Low
Coach Screw		Yes	Yes	No	No	No	Yes	Low	Low	AS 1684 AS 1720	Low	Low
Modern Screws		Yes	Yes	No	No	Yes	Yes	High	Medium	AS 1720.1 or Performance Solution	Low	High
Dowels		No	Yes	No	Yes	Yes	Yes	Medium	High	AS 1720.1 or Performance Solution	Medi-um	High
Split–Ring Connector		No	No	No	No	No	No	Low	High	AS 1720.1	Medi-um	Medium
Shear-Plate Connector		No	No	No	No	No	Yes	Low	High	AS 1720.1	Medi-um	Medium

Table 1 (Continued): Ready reckoner to selecting a connector or fasteners

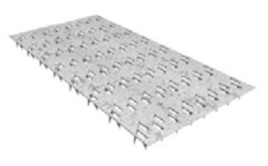
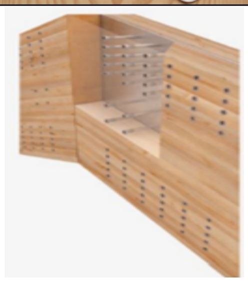
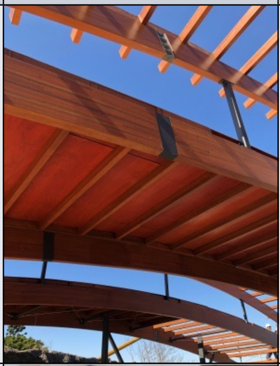
#	Image	Light -Timber Frame[1]	Heavy Timber[2]	Panel	Truss	Portal	Mass Timber	Fire Resistance	Archi-tectural Expression	Design	Cost	Off-site Fabrication Potential
Nail Plate		Yes	Yes	No	Yes	No	No	Low	Low	AS 1720.5 [37] or Manufacturer	Low	High
Thin Gauged Metal Plate Connectors		Yes	Yes	No	Yes	No	No	Low	Low	AS 1684 or Manufacturer	Low	High
Pin Hook Connector		No	Yes	No	No	No	Yes	High	High	Performance Solution	Medi-um to High	High
Dove Tail Hook Connector		No	Yes	No	No	No	Yes	High	High	Performance Solution	Medi-um to High	High
Fin Plate Connector		No	Yes	No	Yes	Yes	Yes	Medium	High	AS 1720.1 or Performance Solution	Medi-um	High
Quick Connect		No	No	No	No	Yes	No	Low	Medium	Performance Solution	Medi-um	High
Timber Rivet		No	No	No	Yes	Yes	Yes	Low	High	Performance Solution	Medi-um	Low

Table 1 (Continued): Ready reckoner to selecting a connector or fasteners

#	Image	Light -Timber Frame[1]	Heavy Timber[2]	Panel	Truss	Portal	Mass Timber	Fire Resistance	Archi-tectural Expression	Design	Cost	Off-site Fabrication Potential
Adhesive		No	No	No	Yes	Yes	Yes	Low	High	Performance Solution	Medi-um	High
Timber		No	No	No	Yes	Yes	Yes	High	High	Performance Solution	High	High

Note:

1. *Light-timber frame is stud size material.*
2. *Heavy timber is a significant sized timber element; typical applications include wharves, boardwalks, pedestrian bridges, etc.*
3. *Panel systems are based on sheet materials.*

3 Common fasteners types

Many types of fasteners can be used in timber or in combination with other materials to make a connection. The following describes these common fasteners.

3.1 Nails

There are many types, sizes and forms of nails and their use dates back to Egypt in 3,400 BC1. Figure 5 shows the most common fasteners used in timber construction. Smooth, uncoated steel wire nails – often called bright or common nails – are the most frequently used.

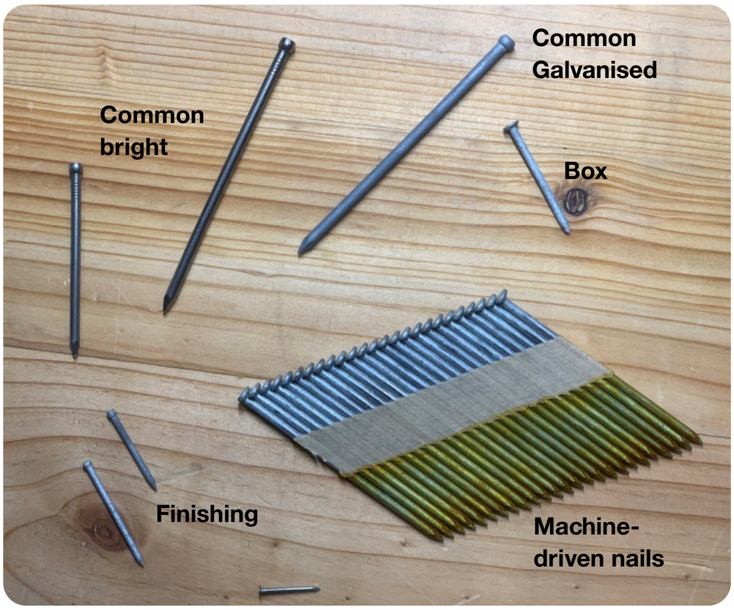


Figure 5: A range of nails. (Image credit: TDA)

When nails are driven into wood the nail's point pushes apart the wood fibres. The nail's holding power is from the friction of the displaced fibres gripping the nail's shaft. Nails driven across the wood grain have better holding power than nails driven into the end grain.

Nails are made from various metals, including steel, stainless steel, brass, copper or aluminium. If left without a coating, they are referred to as bright nails. Coatings are often added to the nail to improve the gripping behaviour, which increases the service life or help its penetration (see Section 7 for more information). Nails that are galvanised or made from another metal may increase the potential service life of the connection. They are essential when used with copper-based, pressure-treated timber to prevent the corrosion caused by the chemicals. Modern nails may also be made from timber itself.

3.1.1 Nail types

There are many types of nails that are used for various applications.
The following describes a few common types.

Common nails

Common nails are used for general construction and specifically for framing and other structural work. In comparison to most other nails, common nails have a thick shank and a wide head, often called a bullet head or a diamond-shaped point (see Figure 6). The increased thickness of the shank makes this nail a stronger fastener; however, they are more likely to split the wood when compared to thinner nails.

They are used predominately in lightweight timber framing where the default nominal connection is two 3.33 mm diameter nails that are skewed (angled) into the connecting timber. The length of the nail varies and depends on the timber thickness it is nailing through. Ideally, the nail should have at least 10 times its diameter penetrating the receiving member.

Figure 6: Common nail.

Box nails

Box nails (see Figure 7) are similar to common nails but have a thinner shank and are better suited to thinner wood materials because the smaller shank of the nail is less likely to split the timber. As the name suggests, these nails are used for boxes and crates. They should not be used for any structural purpose as they don't have the strength or holding power of common nails.

Figure 7: Box nails.

Duplex head (double-headed)

Duplex head nails are specialty nails that are used when they are to be extracted at a later date. The nail has two heads where the lower head is driven, so it is flush with the wood, leaving a second head to aid extraction (see Figure 8). They are generally used for temporary construction, such as formwork used for pouring concrete or attaching temporary cleats for coverings.

Figure 8: Duplex head or double head nails.

Annular ring or ring shank nails

Annular ring nails, also called ring shank nails, have rings on their shanks for extra grip and additional resistance to pulling out of the wood (see Figure 9). They are commonly used for softwood timber, where extra holding power is required. Other nails that may have rings include plasterboard nails or deck board nails, also intended for improved holding power.

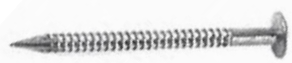


Figure 9: Annular or ring shank nail.

Finishing nails

Finishing nails are similar to box nails but differing primarily in the shapes of their heads. A finishing nail has a small, slightly rounded head that is slightly bigger than the nail's shank (see Figure 10). The head is designed to accept the pointed tip of a nail punch, making it easier to be countersunk, driven flush or below the wood surface without leaving a large hole. These nails are used mainly for fixing wood architraves or trims.

Figure 10: Finishing nails.

Brad nails

Brad nails are essentially smaller finishing nails often used in woodworking. Because of the small shank diameter, length and small head, these nails significantly reduce the possibility of splitting when used in hardwood (see Figure 11). Brads are ideal for general joinery and are usually countersunk below the surface of the wood using a nail punch. The holes are then filled with putty for a finished appearance.

Figure 11: Brad nails.

Clout nails

Clout nails have a short shank and a wide, flat, thin head (see Figure 12). They can be used to fasten sheet materials to timber studs. They should not be used with framing brackets, where specialised nails are required.

Figure 12: Clout nail.

Framing bracket nails

Framing bracket nails are specialist nails used with framing brackets. They generally have a short shank and a flat head and are coloured (see Figure 13). They look like clouts but have a wider shank and head and must be used with the framing bracket. The colouring identifies that framing bracket nails have been used. They are also a part of the framing bracket system, and their load capacity and compliance are dependent on the right nail being used.

Figure 13: Framing bracket nail.

3.1.2 Nail heads

Nails come in a variety of head types for different applications and features. The following briefly describes the options and applications.

Bullet heads: They have a rounded head that is not much wider than the nail's shank. The head's top is flat with a textured top surface to reduce hammer slipping (see Figure 6). They are predominately used in timber frame construction.

Counter-sunk heads: These have a conical shape, tapered and are designed to be pushed through the surface of the wood and be covered with putty if they need to be concealed (see Figure 14).

Flat heads: The nail has a broad flat head (see Figure 12). It has strong holding power and is used to hold cladding and linings.

Cupped heads: Have a concave shape head (see Figure 15). These nails are used to hold the lining board and conceal where necessary, such as plasterboard walls.

Figure 14: Counter-sunk headed nail.

Figure 15: Cup head nails.

3.1.3 Nail point

In addition to the type of nail based on the head shape, there are different nail points. The typical nail point is a diamond shape with a point angle of 35° (see Figures 6, 7, 8, 10, 11, 12 and 13).

Chisel blunt or shear point nails are used for sheet, hardwood and cypress. Common diamond head nails tend to fracture brittle sheet material or split hardwood and cypress. In these situations, a blunt head is used. Nails with dull points are less likely to prevent the wood from splitting, but they require more effort to drive into the timber.

3.1.4 Nail coating

Nails are often coated to increase the service life, the holding strength or aid in the driving of the nail. Vinyl coated nails enable them to be driven more efficiently and offer a superior grip, but it does not protect against corrosion. Nails can also be coated with cement or adhesive to improve their holding power. Most construction nails are steel, often with some kind of surface coating.

Corrosion and staining

In the presence of moisture, metals used for nails may corrode when in contact with wood treated with copper-based preservative or fire-retardant treatments. Timber treated with ammoniacal copper arsenate or chromate copper arsenate performed well with nails made from copper, silicon bronze and 300 series stainless steel. However, timber treated with copper azole or alkaline copper quaternary requires 300 series stainless steel nails. See Section 7 for more information.

3.1.5 Avoidance of splitting

The design capacities of nails found in the design Standard AS 1720.1 have been derived on the assumption that timber splitting does not occur to any significant extent. In unseasoned timber that shows a marked tendency to split, the use of pre-bored holes that are 80% of the nail diameter is recommended and adhering to edge, end and spacing requirements, which are discussed later.

3.1.6 Nails for power-actuated tools

Power-driven nail devices have taken over from hand-driven hammers as they are generally quicker and require less effort. They are available in a similar range of nail types as discussed above; however, they often vary slightly, particularly the nail's head, to allow the nails to be supplied in magazines or coils (see Figure 16). Nailheads for machine-driven nails are often D or T shaped to allow for continuous feeding of the nail.

The nail diameter, and therefore their nail holding capacity, often varies from common nail sizes. When hand-driven nails are specified, such as within the residential framing Standard AS 1684 series, machine-driven nails may substitute for hand-driven nails. However, the supplier of the machine-driven nail is responsible for verifying that the nails have comparable or better properties than the replaced hand-driven nails. These nails are also generally not suitable for use with framing brackets as framing brackets have specialist nails that are a part of a system.

Figure 16: Magazine of power-driven nails. (Image credit: TDA)

Care is required in power-driven nails, as overdriving does not give the nail the total design capacity. They also come in a variety of surface coatings and have different corrosion resistance classes. Refer to Section 7 for a description of the durability of fasteners.

3.1.7 Other nail materials

Modern nails may be made from other materials such as plastic and even wood itself (see Figure 17). Wood nails are commercially available in beech. The nail is hardened by compressing the cell structure and infusing it with resin.

The wooden nail is pneumatically driven. During the process of being driven, a large amount of heat is generated by friction, causing the lignin of the wooden nail to weld with the surrounding wood to form a substance-to-substance bond. The benefits of wooden nails include minor wear on machining tools used after installation of the nail, no pre-drilling required, no metal reaction to the wood, and the timber element is easier to recycle post-consumer use.

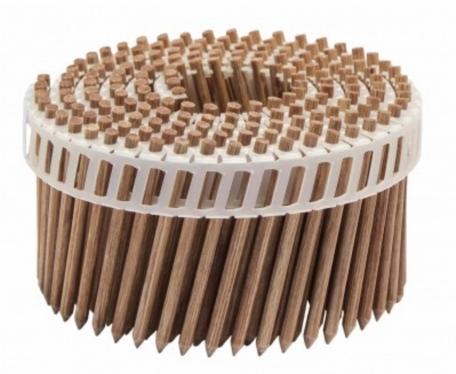


Figure 17: Wooden nails. (Image credit: LignoLoc)

3.2 Nails used in residential timber frame construction – AS 1684 requirements

The National Construction Code (NCC) prescriptive solution for lightweight timber-frame construction for houses refers to the Australian Standard AS 1684 [2]. This Standard has minimum requirements for nails, including the smallest diameter of the nails, sizes found in Table 2.

Table 2: Minimum nail sizes.

	Hardwood and Cypress	Softwood
Machine-driven nails	3.05 mm	3.33 mm
Hand Driven Nails	3.15 mm	3.75 mm

Note: Requirements are from AS 1684.2

Machine-driven nails must also be a plastic polymer (glue) coated or annular or helical deformed shank nails.

The nail length is not specified. However, the minimum penetration depth into the final receiving member must be 10 times the nail diameter when driven into the side grain or 15 times the nail diameter in the weaker direction when driven into the end grain. Also, as a minimum, two nails are required at each joint of the timber element.

Nails used in continuously damp joints or exposed to the weather must be hot-dip galvanised, stainless steel or Monel metal. See Section 7 for further discussion on the durability of fasteners.

3.2.1 Nail end, edge and spacing

The nail's end, edge and spacing are detailed in the engineering design Standard AS 1720.1 and discussed in more detail in Section 7. These requirements aim to minimise the likelihood of the nail splitting the timber, resulting in a reduction of strength.

Nails that are spaced too close together are likely to act as a wedge and split the timber. Figure 18 demonstrates two situations with the spacing, i.e. nails close together along the grain and nails spaced close together across the grain. The nails spaced close together along the grain have split the timber; however, the nails that are spaced across the grain have not. There are generally different spacing requirements for fasteners spaced along the grain than across the grain.

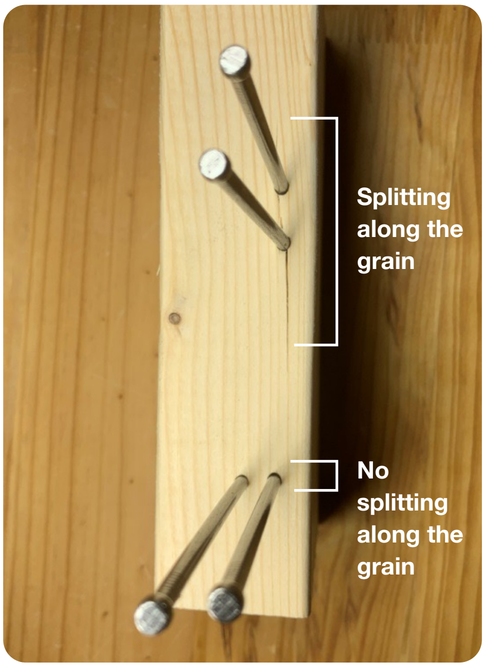


Figure 18: Nails spaced closely along the grain and across the grain. (Image credit: TDA)

To avoid splitting along the grain, a slight stagger to the placement of the nails reduces splitting; however, minor splitting adjacent to the nail may still occur (see Figure 19).

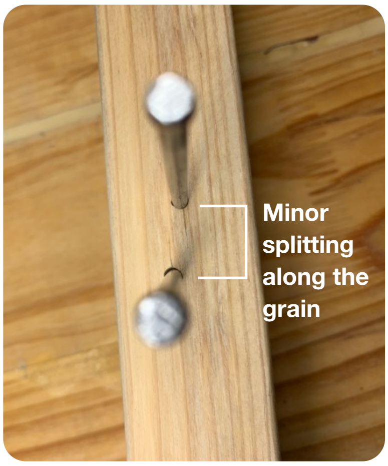


Figure 19: Nails slightly staggered along the grain. (Image credit: TDA)

A common mistake is fixing the nails to a sheet braced wall at the butt joining of the sheets, where two rows of nails are present. The staggering of the nails does not mean any nails in pairs are offset to each other (see Figure 20), it means the nails are slightly staggered along the grain.

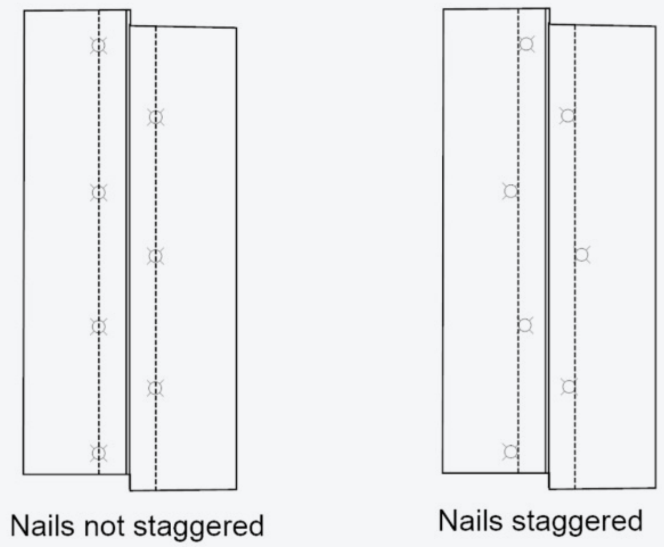


Figure 20: Correct way to stagger nails along the grain. (Image credit: TDA)

3.2.2 Straight and skew nails into the end grain of the timber

The nail withdrawal capacity from side grain is given within the engineering Standard AS 1720.1 [3]; however, if the withdrawal is from the end grain using straight-driven nails, the capacity of the fastener is only 25% of the withdrawal capacity from the side grain. This difference in the fastener's capacity is due to the fibres in timber not being separated in the same way as when the nail is driven into side grain, reducing the holding power of the wood fibre onto the nails' shank.

However, if the fastener is skewed at an angle, the strength reduction is only 60% for withdrawal from the side grain. This skewing of the nail into the end grain means the nail also has side grain fibre encasing the shank, increasing its holding power onto the shank.

3.3 Spikes

Spikes are common nails manufactured in the same manner, except they are much larger in size, diameter and length. They often have either a chisel point or a diamond point and are made in 75 to 300 mm lengths (see Figure 21). Typical applications include heavy timber construction such as thick decking boards for wharves or boardwalks.

Figure 21: Spike nail.

3.4 Corrugated fastener

A corrugated fastener, sometimes referred to as a corrugated nail, is a small corrugated strip of steel sharp on one of the long edges (see Figure 22). The fastener is hammered or pneumatically driven across wood joints in rough carpentry. Used predominately in binding crate elements together, particularly in the mitre joints, they can also be used in construction. They are often used as a substitute for nails, mainly where nails may split the timber.

Figure 22: Corrugated fastener.

3.5 Staples

Staples are pieces of thin wire with two short right-angled end legs in a U shape (see Figure 23). Like nails, there are many different staples with various modifications in points, shank treatment and coatings, gauge, crown width and length, having a similar effect on the staples withdrawal and lateral load capacity. These fasteners are generally only available in clips or magazines for use in power-driven staplers.

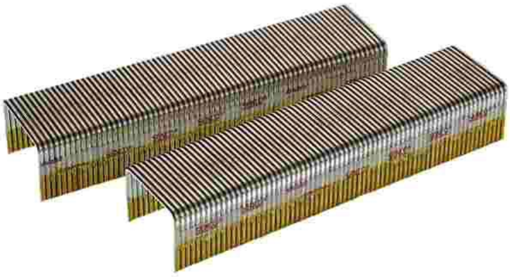


Figure 23: Construction staples. (Image credit: TDA)

They are often used to fix sheeting to timber framing, such as bracing or flooring, with the aid of power-driven installation that installs many fasteners rapidly. They are often used in panelised construction due to the ease of automated stapling equipment (see Figure 24). However, they are not recognised within the NCC's DTS documents AS 1684 [2] or AS 1720.1 [3] and require supporting information or a performance solution for compliance.

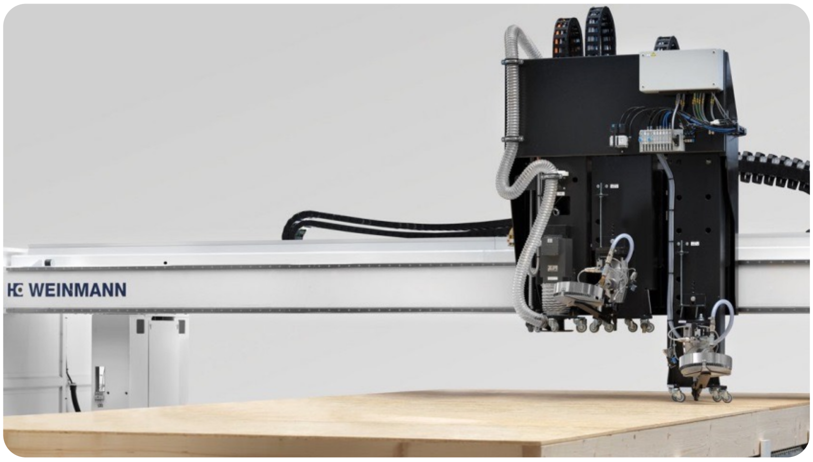


Figure 24: Staple bridge used in panel fabrication. (Image credit: Weinmann)

3.6 Wood screws

This section is discussed in two parts, traditional and modern wood screws. Wood screws have changed considerably over the years, and there are many differences between the two.

3.6.1 Traditional wood screws

Wood screws are typically made of metal and characterised by an external thread that tapers into a point at the end. The traditional wood screw has a flat or dome head. The flathead screw is most commonly used if a flush surface is required. Dome head screws are used for appearance and when countersinking is not acceptable. The difference between a screw and a nail is that a screw cuts into the wood fibre, where the thread bears onto the cut timber fibre. Nails push apart the wood fibre and rely on the nail shank's friction on the wood fibre. A bolt differs from a screw as it passes through a substrate and takes a nut on the other side; a screw takes no nut because it threads directly into the timber substrate. Bolts are discussed in more detail later.

Traditional screws are installed into a pre-drilled hole and often are self-threading or self-tapping. The thread cuts into the timber when the screw is turned, creating an internal thread that mechanically inter-locks between the fastener and the timber fibre – this helps prevent pull-out of the fastener, which increases the strength. Wood screws are usually made of steel, brass, other metals, or alloys and may have specific finishes such as nickel, chromium or cadmium.

Screw terminology

The principal parts of a screw are the head, shank, thread, and core (see Figure 25). The root diameter, a standard reference to the size of the screw, is the thickness of the metal the thread is attached to and is generally about two-thirds of the shank diameter. There are many aspects to specifying a wood screw: head type, drive type, shank width, thread length, location and point or tip. They are classified according to material, type, finish, the shape of the head and diameter or shank's gauge. Gauge is an imperial measurement of the shank, discussed later.

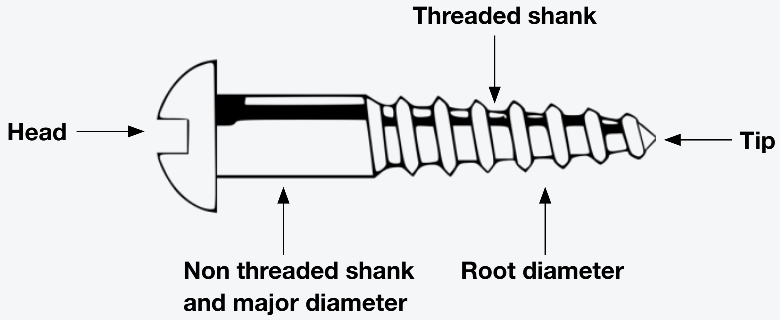


Figure 25: Screw terminology.

Some screws are self-drilling, as they have a drill-shaped tip that cuts through the wood, eliminating the need for pre-drilling (refer to the section on modern screws). Sometimes the self-drilling head can cut through thin steel material (discussed later in the modern screws section).

Screw head type

There are seven standard head types: pan-head, dome head, round head, mushroom, countersunk, hex or raised head (see Figure 26).

Figure 26: Screw head types. Left to right: pan, dome, round, mushroom, countersunk, raised, hex. (Image credit: TDA)

Pan, dome, round, mushroom and hex head screws are used to clamp another element to a substrate. A countersunk screw is designed to rest flush with the surface of the element into which it is inserted. The raised head version of the countersunk is a version between pan head and countersunk. Another head type is a bugle head, similar to a countersunk head, except the head is shaped like a trumpet's bell.

Screw drive

More than 40 types of screw heads are matched to a screw drive, i.e. a system used to turn a screw. At a basic level, shaped cavities or protrusions on the screw head allow torque to be applied. Common screw heads are slot drive, Phillips, square, hex or Torx (see Figure 27).

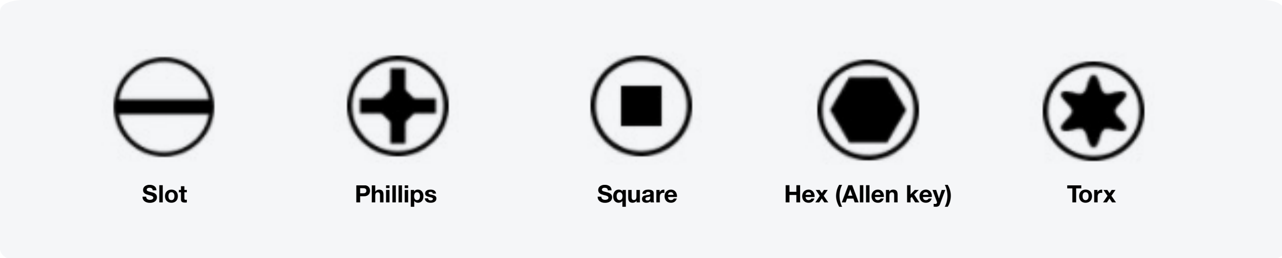


Figure 27: Common drive types. (Image credit: TDA).

Point shape

Point shape can be categorised into the following product groups, with each group having several different screw points available.

Tapping screws – a thread-forming screw that creates its own hole as it is driven into a material.

Thread cutting screws – have cutting edges and chip cavities that cut into the material, removing the material from the part they are driven into. They do not actually remove any material but, instead, displace it or push it aside so that the material flows around the screw's thread.

Self-drilling and self-piercing screws –have a tapering shaft with a continuous thread running from the point toward the screw head. The term 'self-drilling' signifies that the screw is capable of drilling itself into a material; however, a pilot hole may be necessary to get the screw started. Self-drilling screws are not always designated as such; the term encompasses ordinary screws, machine screws and even specialty screws like drywall or wood screws.

There are many types of screw points depending on the various application the screws are used. Type A, Type AB, Type B, Type 25, Type F and Type 23 are for metal applications and not discussed in this guide.

Type 17 Screw point

Type 17 in screw terminology describes the tip shape, as it has a cutting thread, specially made for wood, with a coarse tapping screw thread and a unique long sharp point fluted to capture chips (see Figure 28). Often, structural wood screws are referred to as Type 17, which can be misleading as modern screws have improved tips to aid in drilling or increasing the speed and are technically not Type 17. However, the term has developed to generally describe structural screws but may have a different screw point. Refer to the section on modern screw specification for more information.

Figure 28: Type 17 point. (Image credit: TDA)

Screw gauge

The gauge of a screw is an imperial (old) way to describe the screw's shank diameter, i.e. the thickness (diameter) of the un-threaded part of the screw. Table 3 describes the various screw gauges and the equivalent metric shank diameter.

Table 3: Screw gauge shank diameter (mm)

Screw Gauge	Shank Diameter (mm)
4	2.74
6	3.45
8	4.17
10	4.88
12	5.59
14	6.3
18	7.72

Based on AS 1720.1 Table 4.5 (A) and (B)

Pre-boring pilot or clearance holes

Traditional wood screws require a hole to be bored into the timber before screwing it to the substrate. Two diameters are required: one for the material being fixed to the substrate and the other in the substrate. The diameter of the hole in the element being fixed to the substrate should be the diameter of the unthreaded part of the shank. The diameter of the hole in the substrate should not be greater than the root diameter of the screw, allowing the thread of the screw to cut into the timber. This assumption is used in determining the capacities of screws found in the engineering Standard AS 1720.1 [3]. Deviations away from these dimensions of pilot holes result in the fastener having less structural capacity.

Countersunk screws may also need the 'V' shaped hole formed at the surface to allow the screw head to finish flush with the timber's surface.

3.6.2 The capacity of traditional screws to nails

According to Handbook 108 [12] for shear application (Type 1 connection, refer to Section 6 of this guide for a description), for the same shank diameter, the capacity of the screw is 10% greater than for a nail. For withdrawal application (Type 2 connection), screws have three times the capacity of a nail.

3.6.3 Specifying traditional screws

Generally, the screw length, gauge or shank diameter, and pilot holes are required in the specification. The screws must be long enough to hold the element that is being fixed and to have adequate depth in the receiving member. AS 1720.1 [3] has screw capacities, and the Standard requires the thickness of the element being fixed to a timber substrate to be at least 10 times the shank diameter of the screw. In addition, the screw must penetrate the receiving element at least seven times the shank diameter. Lower values are possible, but the capacity reduces in proportion to the decrease in-depth or penetration until it is considered non-load bearing at four shank diameters.

Shank diameter (gauge): Wood screws must be thick enough to grab onto the two boards. If the screw is too thin, it may pull out of the wood. If the screw is too thick, it may split the wood, rendering it useless.

Pilot holes: Again, the size of the pilot hole being the root diameter of the screw is the assumption used in AS 1720.1 [3]. Any deviation from this could either split the timber or not have adequate timber for the thread to fix. It is recommended to specify the pilot hole as a general note on structural drawings.

The information required to obtain the correct screw contains the shank diameter or gauge, head type, drive type, tip type, thread length, coating or metal type if durability is a concern.

3.6.4 Coach screws

A coach screw is sometimes known as a carriage or lag screw (see Figure 29). They are heavy-duty screws that have square or hexagonal heads. The coach screw shaft is cylindrical and tapers to a point at the tip with a coarse thread. They are primarily used for holding together heavy timber or fixing metal to timber. They are used when it is not possible to have a bolt through the entire width of the timber. Coach screws are often confused with coach bolts, a large bolt with a round head; refer to the bolt section of this guide.

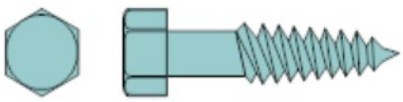


Figure 29: Coach screw. (Image credit: TDA)

3.7 Modern structural screws

Traditional wood screws have been around for a long time; however, they must be installed in pilot and clearance holes. This requirement is further complicated for large structural screws where drilling requires two steps, one size drill hole for the threaded part of the screw shank, called a pilot hole, and another for the unthreaded parts of the shank, called clearance hole. They are also slow to install by hand because larger diameter screws require high torque or power-drive; they are prone to overdriving, compromising the screw's structural capacity.

The features of traditional screws have resulted in them often not being employed in mass timber buildings, in favour of heavy metal plates and bolt connections. However, these metal plates and bolt connections were expensive, slow to install, and had inefficient connector capacity, meaning mass timber buildings were expensive. In the late 1990s, high-performance structural screws were developed by researchers and manufacturers in Europe. The main difference to traditional screws was that they were self-tapping and made from high strength steel. They also had different screw geometry, such as thread shapes, for strength and ease of installation. The extent of threading along the screw's shank, either partially or fully threaded heads, are used for different applications, such as clamping or reinforcing. Furthermore, drilling tips are designed for increased speed and have features to remove the swarf or clear a hole. The drive mechanisms are also different, allowing greater torque to be applied to the screw.

This redesign of the screw has resulted in effortless and faster installation, reducing wood splitting and eliminating the need for drilling pilot holes in softwood timber and increasing connection strength. The high-strength steel also makes it possible to drive long screws under high torque without breaking (see Figure 30). This revolution in screw technology has assisted the rapid growth of mass timber buildings, but it applies to all timber construction, including lightweight timber-framing.

Figure 30: Long screws used in construction. (Image credit: TDA)

3.7.1 Modern screw sizing

One key difference between modern screws and traditional screws is the relationship between thread diameter and shank diameter. The thread on modern screws protrudes above the shank providing a more effective thread diameter than the shank diameter. For traditional screws, the thread diameter is the same as the shank diameter (see Figure 31). Modern screws designate their size according to the outer thread diameter, not the shank diameter as in traditional screws.

Figure 31: Traditional screw thread diameter compared to modern screw.

3.7.2 New applications

Modern, fully threaded self-tapping screws can transfer load in tension or compression. However, traditional failure mechanisms for screws result from splitting and shearing, causing a brittle failure mode. A different superior failure mode is reached when these failure modes are prevented an overall connection capacity occurs. For more information, refer to HB108 [12] and the report, 'Development of Limit States Design Method for Joints with Dowel Type Fasteners' [11].

New applications for screws are possible, for example:

- reinforcement to reduce wood splitting, such as reinforcing openings or notches in beams (see Figure 32) or reinforce curved glulam beams (see Figure 33)
- increasing the fasteners capacity for bolted connections or other connections that are dependent on perpendicular to grain capacity (see Figure 34)
- increasing the perpendicular to grain bearings capacity by increasing the surface area supporting the bearing load (see Figure 35).

All these new uses result from the increase in perpendicular to grain performance.

Figure 32: Modern screw reinforcing a notched beam. (Image credit: Spax)

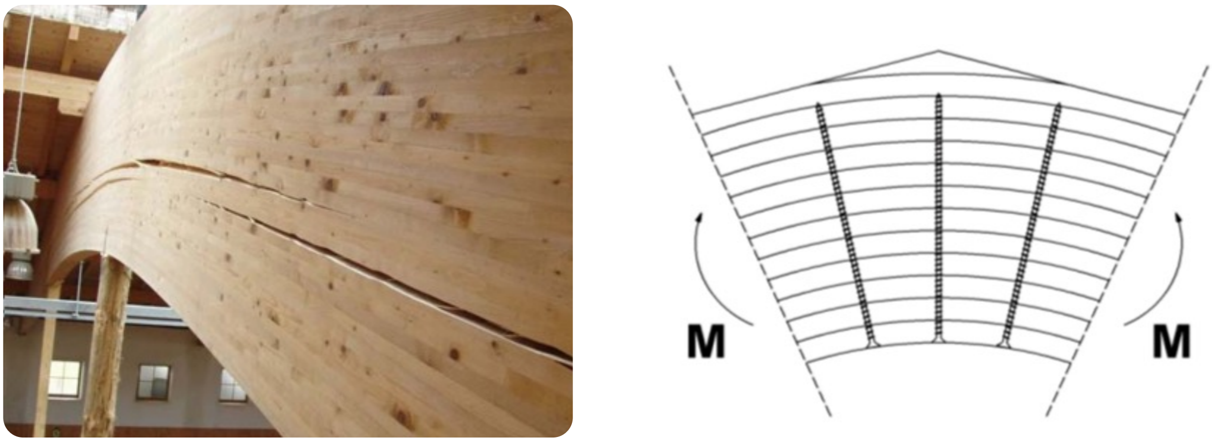


Figure 33: Reinforcement of curved glulam. (Image credit: Spax)

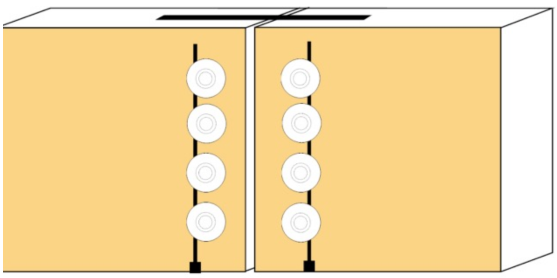


Figure 34: Screw reinforcement to a bolted or dowelled connection. (Image credit: TDA)

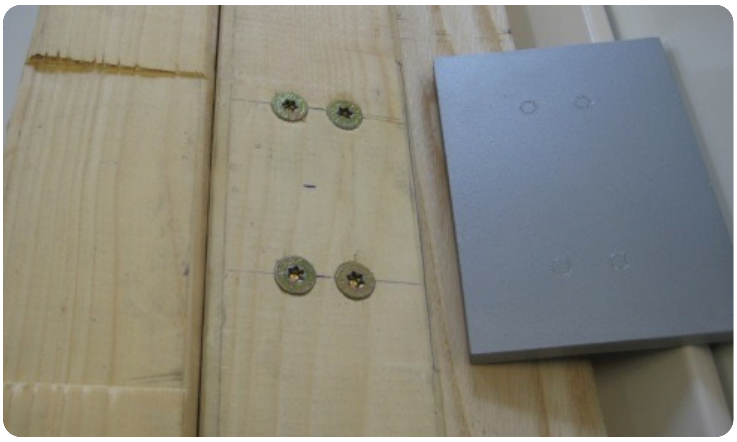


Figure 35: Screw and plate to increase bearing capacity. (Image credit: Spax)

Another benefit of fully threaded screws is the high withdrawal capacity when comparing screws that only rely on the screw head. In this situation, the thread surface area is greater than the screw's head surface area, reducing the head-pull-through failures.

3.7.3 Increased fastener capacity

Traditional screws are installed perpendicular to the face of wood members to transfer shear forces and are limited due to the withdrawal or the tensile capacity of the screw. However, the ability of modern screws to resist tension and compression loads (up to three times higher than traditional screws) can be used to increase the joint's capacity. Furthermore, when a modern screw is placed at an angle to the wood's surface, it results in a combined shear and withdrawal resistance. This combined shear and withdrawal resistance increases the capacity of the fastener tremendously; for example, a single self-tapping screw installed at 45° to the grain can be equivalent to multiple traditional screws installed perpendicular to the face [27] (see Figure 36).

Figure 36: Comparison of perpendicular to face screws versus inclined screw.

Another advantage is that the connector's overall stiffness increases, being many times more than a traditional screw arrangement.

By inclining modern screws, they can also be used as a connection, joining a beam to beam or beam to column (see Figure 37).

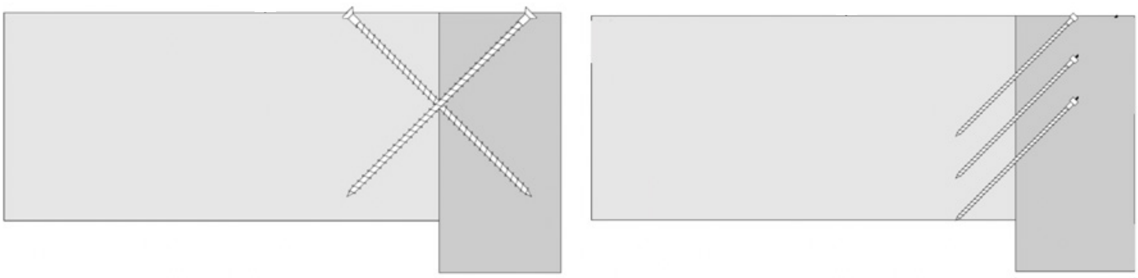


Figure 37: Screw fixed be am to beam connection. (Image credit: Spax)

3.7.4 Types of modern screws

Thread types

Screws are available in full threaded or partially threaded.

Fully threaded

Fully threaded screws have a thread along the entire shank of the screw. Consequently, there can be no clamping effect when joining two elements together, i.e. drawing the two members together (see Figure 38). Fully threaded screws can also be placed into tension and compression applications, and are available in lengths up to 600 mm (see Figure 30).

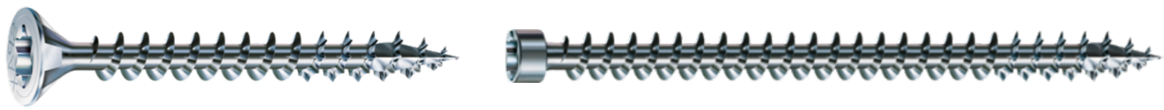


Figure 38: Fully threaded screws. (Image credit: Spax)

Partial thread

Partially threads screws are designed explicitly for wood use and have an unthreaded section below the screws head. The screw is designed to pull together elements, called the clamping effect. The clamping effect is dependent on head shape and size, a larger head having significant more capacity. The screw is intended to fix an element to another, such as fixing panels or decking. The unthreaded portion of the screws is usually the thickness of the material being installed (see Figure 39).

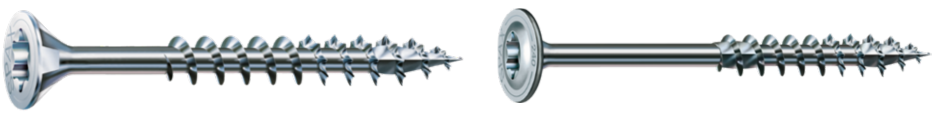


Figure 39: Partial threaded screws. (image credit: Spax)

Partially reverse thread screws

Sometimes screws have a reverse thread where the unthreaded portion of the screw would be (see Figure 40). This reverse thread is for applications where the screw head is drawn below the surface of the wood, such as decking boards' to joists. In this situation, the screw's head cannot provide any significant clamping effect, so the reverse thread portion of the screw cuts a new path into the timber element being clamped to the substrates, providing a degree of fixing to it.

Figure 40: Partially reverse thread screws – decking screw.

Ribbed portion of shank

Sometimes, partially threaded screws have a ribbed portion above the thread (see Figure 41). The purpose of the ribs on the screw's shank is to clear the hole formed by the screw in the timber element that is being fixed to the substrate. This clearing of the hole allows the element to be drawn fully to the substrate without being caught by the shank of the screw.

Figure 41: Ribbed portion of a partially threaded screw. (Image credit place holder)

Head Shapes

The following section discusses the various head shapes available for modern screws and their application.

Countersunk

A conical shaped head is used for flush fixing to a surface (see Figure 42). Uses include fastening steel or timber to a timber substrate. Sometimes ribs are on the conical portion of the head used to assist in cutting the timber to allow the head to be recessed.

Figure 42: Countersunk head.

Washer head:

An enlarged flat head shape (see Figure 43), used to provide increased clamping force or high pull-through resistance.

Figure 43: Washer head.

Cylinder head

A thin diameter head, usually a little larger than the shank of the screw (see Figure 44). Applications are for recessing the head below the timber surface for anesthetic or fire resistance reasons.

Figure 44: Cylinder head.

Load capacity of modern screws

AS 1720.1 [3] does not allow for the total design capacity of modern screws, as it does not provide information on the head effect or tension capacity of inclined screws. Where the total capacity of the screw is required, it is recommended that the design be carried out to the product manufacturer's specification or the Eurocode EC5 [11].

Table 4 compares the differences between the Australian Timber engineering Standard and the Eurocode. A performance solution design is required to utilise this increased capacity of modern screws, as the product manufacturers specification or Eurocode EC5 [11] is not a DTS solution within the NCC.

Table 4: AS 1720.1 vs Eurocode Comparison

AS1720.1	EC 5 [11]
Joint strength groups based on design densities (radiata pine = 550 kg/m^3)	Based on characteristic densities (radiata pine = 400 kg/m^3)
Considers shank diameter	Considers thread diameter
Shear – tables specify characteristic capacities	Shear – based on Johansen's Yield Theory with 6 possible failure modes plus rope effect
Withdrawal – considers 2 failure modes. Head pull-through not considered.	Withdrawal – considers 3 failure modes, including head pull-through.
Simplified minimum edge, end and spacing distances	Complicated minimum distances but more logical, e.g. consider load direction
All values applied to pre-drilled holes only	Pre-drilling is not necessary. Values calculated for both non-pre-drilled and pre-drilled holes
No design criteria for inclined screws	Design methods for larger numbers of configurations

Specifying structural screws

To specify screws requires the consideration of the following:

- shank diameter
- screw length, noting the requirements of depth in receiving member and any thickness of the clamping element
- the material the screw is made from (where there is no mention of material used, it is usually assumed to be steel)
- coating for durability
- head type: countersunk, washer head, cylinder head
- thread length: fully threaded or partially threaded
- tip type: Type 17
- drive type: torq drive
- spacing, edge and end distances.

Specification example: 8 mm Ø, 150 mm long, partially threaded galvanised countersunk screw.

3.8 Bolts

Bolts are widely used in traditional timber construction and often used in wood-to-wood, wood-to-steel and wood-to-concrete connections. Bolts are commonly used to fix heavy (large) timber members together or timber to steel and resist moderately heavy loads. They function by transferring the force between members through a combination of bolt bearing and bending of the bolt. In addition, washers at the bolt head or under the nut must be large enough to prevent timber fibres from crushing when exposed to pull-out loads.

3.8.1 Bolt head

There are only two-bolt head types commonly available: hexagon and cup. The latter is sometimes called a coach bolt (see Figure 45). Squarehead and countersunk heads may also be available but are not readily accessible. The timber engineering Standard AS 1720.1 [3] provides capacity data only for bolts fitted with a washer under both the bolt head and the nut, and therefore it does not apply to cup-head bolts.

For practical purposes, hexagon head bolts are more straightforward than cup head bolts as the washers under the cup head bolt and the nut need to be of different diameters. However, it is possible to use cup head bolts without a head washer for non-structural applications. Where long bolts are required, a threaded rod with nuts and washers at each end provide unlimited bolt lengths.

Type	Application	Illustration
Hexagon Head Bolts	General structural purpose	
Cup Head Bolt (Coach Bolt)	Light loaded structural purpose, where the head must be flush with the surface	
Threaded Rod	Applications where it is challenging to specify bolt length, e.g. tie-down rods, cross bracing, pole frame construction	

Figure 45: Various bolt types and heads. (Image credit: Australian Hardwood Manual)

3.8.2 Materials

Bolts and threaded rods are generally made from low-carbon steel and, in some instances, brass or stainless steel. The choice is often driven by corrosion resistance which is discussed in more detail in Section 7.

3.8.3 Finishes

Zinc is a readily available bolt coating, either hot-dipped galvanised or electro-plated.

Hot dipped galvanised bolts and coach bolts may be used to advantage in corrosive environments such as swimming pool structures, bridges, marine structures and farm buildings such as piggeries. Washers and nuts should also be similarly coated. Cadmium and chrome finishes are available, but like electro-plated zinc coatings, these do more to improve the appearance than provide corrosion resistance. Hot-dipped galvanising is generally a more effective finish because it has a thick sacrificial coating deposited on the surface of the fastener.

3.8.4 Coach bolts

Coach bolts have a large bolt with a round head used for fixing panels (see Figure 44). They are often confused with coach screws as the heads are the same; however, coach screws have a screw body.

3.8.5 Timber Engineering Standard AS1720.1 Requirements

The characteristic capacities are given in AS 1720.1 [3] apply to steel bolts as specified in AS 1111.1 [1] when fitted with washers and fitted into pre-bored holes of a diameter that is about 10% greater than the bolt diameter. Washer sizes for timber joints are specified in Table 5; note that they have a larger diameter and are thicker than standard washers.

Table 5: Washer selection guide.

Bolt	Thickness (mm)	Washer Size	
		Round Washer Minimum Dia. (mm)	Square Washer Min. Side Length (mm)
M8	2.0	36	36
M10	2.5	45	45
M12	3.0	55	55
M16	4.0	65	65
M20	5.0	75	75

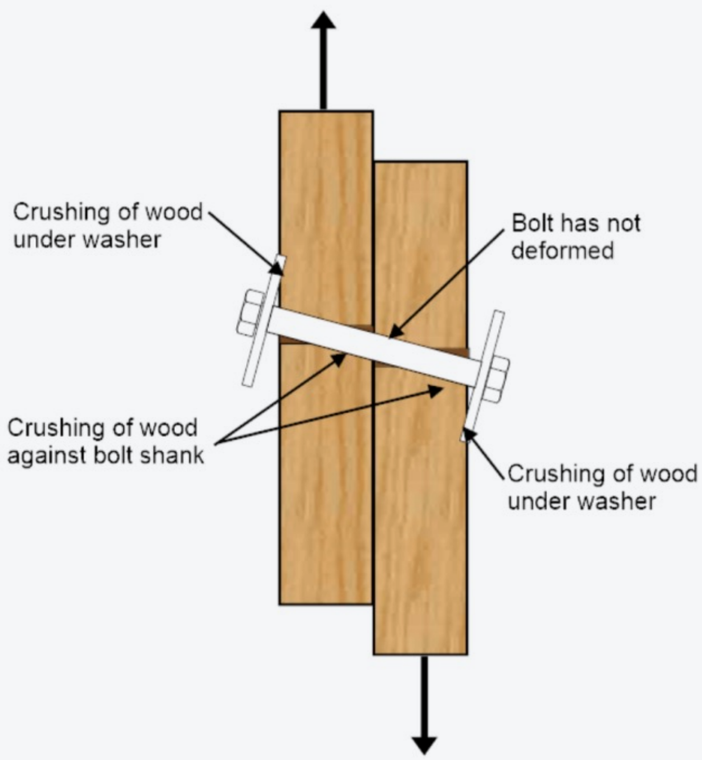


Figure 46: Behaviour of a bolt in a timber to timber connection. (Image credit: TDA)

3.8.6 Bolt behaviour

The timber engineering Standard AS 1720.1 [3] assumes the bolt hole in the timber element are 10% greater in diameter than the bolt shank. This oversizing of the hole causes the load to be applied to one side of the bolt and bolt hole in the timber element. The load transfer of the bolt to the timber mechanism differs from that of nails or screws. In contrast, nails and screws have bearing and friction, resulting in a similar strength, irrespective of the direction of the grain. If a stiff bolt is used, the bolted connection will be dependent on the strength of the timber it bears on, and consequently, the direction of the load onto the grain. Timber loaded parallel to the grain is much stronger than perpendicular to the grain as the load on the wood fibre is along its length and strength direction.

Bolted connections are therefore characterised by:

- crushing of wood fibre against the shaft of the bolt
- crushing of wood fibre under washers at either the nut or bolt head
- splitting of timber parallel to the grain
- fracture of the timber through the bolt holes.

Refer to HB108 for more information on the behaviour of bolts under load.

3.8.7 Specifying bolts

Bolt diameters and lengths are available in certain combinations. Table 6 gives an indication of the available bolt diameter and length. It is the practice to specify bolts by their overall diameter, e.g. an M12 refers to a 12 mm overall shank diameter of the bolt and the only additional information required is the length.

Length is always measured from the underside of the head to the tip (see Figure 47). The minimum bolt length is the thickness of timber to be joined plus the thickness of the washers and the nut, which is approximately equal to the diameter of the bolt, plus a small margin of 3 mm, to allow at least 1½ turns, past the end of the threaded section of the bolt. The bolt length is generally rounded up to the nearest preferred length. The commonly available lengths of metric hexagon commercial bolt are listed in Table 6. Bolts generally have a thread length twice the bolt diameter.

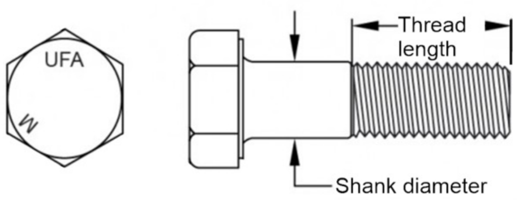


Figure 47: Bolt dimensions. (Image credit: TDA)

Table 6: Common bolt dimensions.

	Commonly Bolt Length (mm)	Length Range (mm)
M10	40, 50, 75, 90, 100, 110, 120, 130	20 to 300
M12	50, 65, 75, 100, 110, 120, 130, 150, 180, 200, 220	25 to 300
M16	65, 75, 100, 120, 150, 200, 250, 300	25 to 300
M20	150, 200, 300	35 to 500

Longer lengths are usually available from bolt manufacturers; however, a threaded rod often can be used as a substitute.

3.9 Dowels

Dowels are circular rods of timber, steel or carbon-reinforced plastics driven into holes within the timber element to form a joint with another timber element. Dowels are similar to bolts in that they transfer load in bending and then bearing onto the timber but there is no head or nut. The function of the head and nut is carried out by relying on friction along the dowel's shaft. The capacity in rotational restraint would not be the same as provided by a washer and nut.

Timber dowels are a traditional joint in heavy timber construction (see Figure 48) and are still used today. Dowels are driven into marginally undersized holes relying on friction to lock the joint together.

Figure 48: Modern timber dowel joint. (Image credit: Australian Timber Frame)

Where high forces are required to be transited, metal dowels, usually with a minimum diameter of 6 or 8 mm, are used with fin plates (see Figure 49). Dowels have an advantage over bolts in the joint deformation as dowels are fitted into tight holes, resulting in less overall joint movement than a bolted connection with an enlarged hole to assist installation. This makes the connection stiffer. Section 6 discusses connector deformation. In addition, as the dowels are generally smaller in diameter than bolts, they are less prone to have stress concentration. They are also less sensitive to the effects of shrinkage than a fastener with a larger diameter.

Figure 49: Dowel used in a joint in a large timber truss. (Image credit: Rothoblaas)

Dowel joints and self-drilling dowels have an application with Fin plate connectors and are discussed in more detail in Section 5.

4 Lightweight timber-frame connectors

Connectors in this section are predominately used for lightweight timber-frame construction for single-family to multi-residential buildings. Thin gauged metal plate timber connectors consist of a flat metal plate with fasteners connecting to the timber by either nails, screws or spikes. Spikes are generally formed by punching down the thin metal of the plate to form sharp-ended protrusions at right angles to the plate.

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4.1 Hangers

Brackets that generally have one side of the connector fixed to the side or top of a timber element, and the other side is a seat, allowing the other timber element to sit in it, are termed hangers (see Figure 49). When the hanger is fixed initially to one element, this seating arrangement aids in construction, as the timber element can be placed into the connector without additional support.

4.1.1 Joist hanger

Joist hangers are used in timber-framed construction to support regularly spaced horizontal elements such as floor joists, roof rafters and ceiling joists (see Figure 50). The joist hanger is manufactured from thin gauged steel fixed to the side of a supporting beam using unique nails or screws that are a part of the joist hanger system. Originating in the US in the mid-1950s, this system has made the connection of lightweight timber-framing installation of timber elements simple.

Figure 50: Joist and I-joist hanger. (Image credit: Pryda and Multinail)

Most joist hangers surround the faces of the timber element on three sides and are attached to it with nails. Sometimes the joist hanger is top-mounted onto the wall framing or another timber beam (see Figure 49). The joist hanger sometimes comes in variations to suit the common everyday application, e.g. a 45° joist hanger is for elements at 45° to the support of the beam or truss (see Figure 51). They can also be attached to a steel beam or masonry wall by including a timber plate.

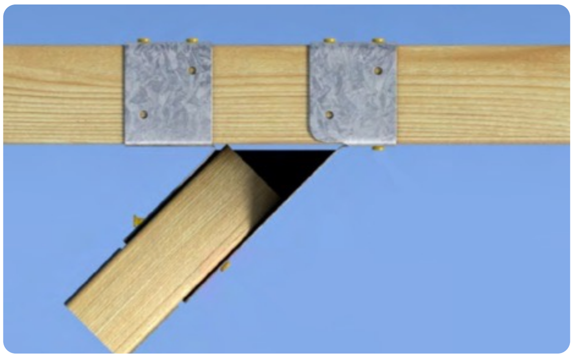


Figure 51: Joist hanger at 45°. (Image credit: MiTek)

Other examples include the I-joist hanger, which suits the variety of widths and depths of proprietary I-joists. Another unique joist hanger is a split hanger (see Figure 52), and they are used when standard hangers sizes don't fit the element. In this case, the hanger has no seat for the joist but relies on nail or screw fixing to transfer the load. The bent base to the hanger is for locating purposes.

Figure 52: Split hanger. (Image credit MiTek)

Joist hangers are proprietary to the manufacturer and compliance with building regulations depends on all parts of the system being used, including the nails. Consequently, machine-driven or clout nails cannot be used unless they meet the manufacturer's requirements. Proprietary nails are often coloured to aid in compliance checking (see Figure 53).

Figure 53: A coloured flat head nail used in joist hanger connectors. (Image credit: MiTek)

4.1.2 Truss boots or girder brackets

Truss boots or girder brackets are a compact and thin gauge galvanised metal bracket designed to fix trusses to the bottom chord of girder trusses or the face of beams (see Figure 54). It includes a tab to locate the bracket, which also reduces the rotation of the supporting member – often designed so that either bolts or screws can be used to fix the timber truss to the girder truss and take a load in a vertical direction, either gravity or uplift.

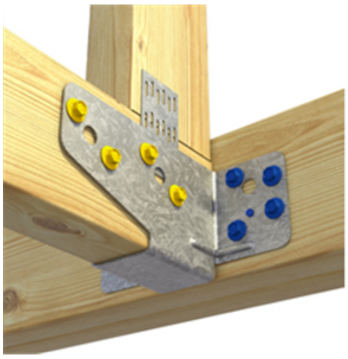


Figure 54: Girder bracket. (Image credit: MiTek)

Some girder brackets are manufactured at 45° to accommodate a hip junction at an angle to the girder. Although technically not a thin gauged metal plate connector, heavy-duty brackets are also made from a steel plate for high load situations (see Figure 55).

Figure 55: Heavy duty gurder bracket. (Image credit: MiTek)

4.2 Straps

Straps are a thin, gauged metal strapping fixed to each timber element to resist tension forces, and they are generally nail fastened. They are predominately used to resist uplift forces or to transfer lateral loads. Strap tensioners are typically needed to ensure a sufficiently tight fit on installation.

4.2.1 Tie down connectors

These are a range of light gauge galvanised metal brackets used to tie or hold down elements subjected to wind uplift. Applications include a roof rafter or truss to the wall plate, batten to roof rafter, roof or joist to the wall plate, wall plate to stud truss to the wall plate. The bracket fastener may be either a metal punch plate or unique nails, as with other brackets.

The capacity of tie-downs varies due to the type of nail used, the number of nails and the timber's joint group (see Figure 56).

Figure 56: Metal straps connectors. (Image credit: Pryda)

4.2.2 Trip-L-grips

The Trip-L-Grip or triple-grip has been developed as an economic connector to simplify structural jointing in lightweight timber framing. The Trip-L-Grip incorporates light gauge metal plate connectors that have fold points so that they can be bent on the job to suit a range of applications (see Figure 57). Often they are pre-punched holes for nails to be placed.

Figure 57: Trip-L-grip or triple-grip. (Image credit Pryda and MiTek)

4.3 Splice or connector plate

A splice or connector plate is a thin gauge metal plate that joins two timber elements together. They generally use fasteners that are nailed or punched nail plates mainly used to provide continuity of an element.

4.3.1 Connector plate

A light gauge metal plate is used to join timber elements together, e.g. wall junctions (see Figure 58). These are available as a nail-on plate or punched plate.

Image credit: Pryda

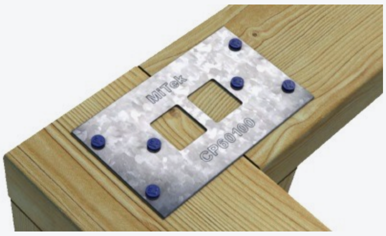


Image credit: MiTek

Image credit Multinail

Figure 58: Connector plate

4.3.2 Butt joining plate

The Trip-L-Grip or triple-grip has been developed as an economic connector to simplify structural jointing in lightweight timber framing. The Trip-L-Grip incorporates light gauge metal plate connectors that have fold points so that they can be bent on the job to suit a range of applications (see Figure 57). Often they are pre-punched holes for nails to be placed.

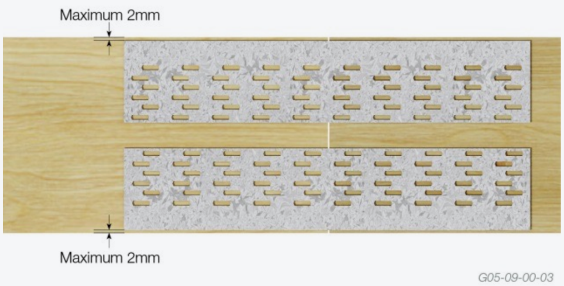


Figure 59: Butt joining plate. (Image credit: Multinail)

4.4 Brackets

A light gauge metal bracket that is generally in an ‘L’ or right-angle shape.

4.4.1 Right angle bracket

A thin gauge metal plate connector used in multiple applications, but generally as side support or a bearing application (see Figures 60 and 61).

Figure 60: Right angle bracket. (Image credit: Multinail)

Figure 61: L Brackets. (Image credit: Pryda)

4.4.2 Internal wall brackets

Internal wall brackets are used to stabilise the top of a wall frame to a truss chord (see Figure 62). The bracket is designed with slotted holes so that the truss chord can move as it settles. The connection is not a structural element and has no published capacities. It has a vital role in the day-to-day use of a house (stabilising doors closing) and during construction (straightening walls), so its installation method needs careful attention.

Figure 62: Internal wall bracket. (Image credit: MiTek)

4.5 Using machine-driven nails

Care is required when using machine-driven nails through joist hangers, framing anchors and tie-down straps, etc, as the thin gauged metal connectors' design capacities may not have been determined with the use of these nails. Connector manufacturers' tests often establish the bracket's capacity, and specific nails or screws have been used in the test or subsequent calculations. Where different nails or machine-driven nails are used, there may not be any evidence to demonstrate compliance with building regulations.

4.6 Punched nail plate (truss connector plate)

A punched nail plate or truss connector plate is a light gauge metal plate used to connect lightweight prefabricated timber-framed elements. They are produced by punching light gauge galvanised steel to create teeth on one side. Nail plates are used to connect timber of the same thickness in the same plane and are often used in timber truss roofs (see Figure 63).

When used on trusses, they are pressed into the side of the timber using a hydraulic press or a roller. As the plate is pressed in, the teeth are all driven into the wood fibres simultaneously. The compression between adjacent teeth reduces the tendency of the wood to split, allowing the teeth in the nailplates to be more closely spaced than for common nails. Metal nail plates are manufactured with varying length, width and thickness (or gauge) and are designed to transmit loads in wood laterally. Capacities of nail plate joints are generally proprietary and can only be designed with the support of the manufacturer's software or in consultation with the manufacturer.

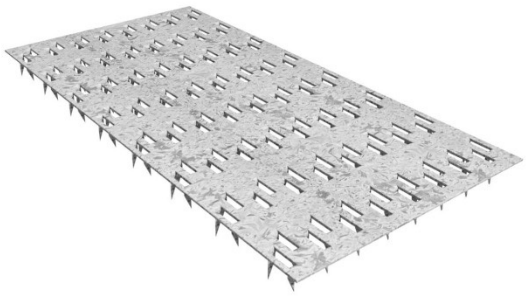


Figure 63: Punched nail plate connector. (Image credit: Multinail)

4.7 Selecting lightweight timber connectors

4.7.1 House frame

Many locations require connectors to transfer the various forces applied to a house of lightweight timber frame construction. Generally, every element requires to be connected to another. The NCC DTS solution AS 1684 Residential Timber Frame Construction Standard [2] requires fixings for gravity loads, uplift from wind, lateral wind loads, overturning loads, racking and shear (sliding). In addition, there are minimum fixings, termed nominal, and other fixings that are required for special forces termed specific fixings.

If a house is exposed to increased wind speeds, additional specific fixings and tie-down connections are required to resist the increased uplift and sliding or lateral forces (shear forces between wall/floor frame and supports) generated by the higher winds. As a minimum, fixings occur at every joint, e.g. batten to trusses, trusses to the top of the wall plate, top wall plates to studs, studs to bottom wall plate, and so on, until the load is diminished due to the weight of the structure or connection to the ground (see Figure 64). Nominal fixings are required, even when the force being transferred diminishes to zero, as the frame often has to be robust and account for forces in a variety of directions and situations.

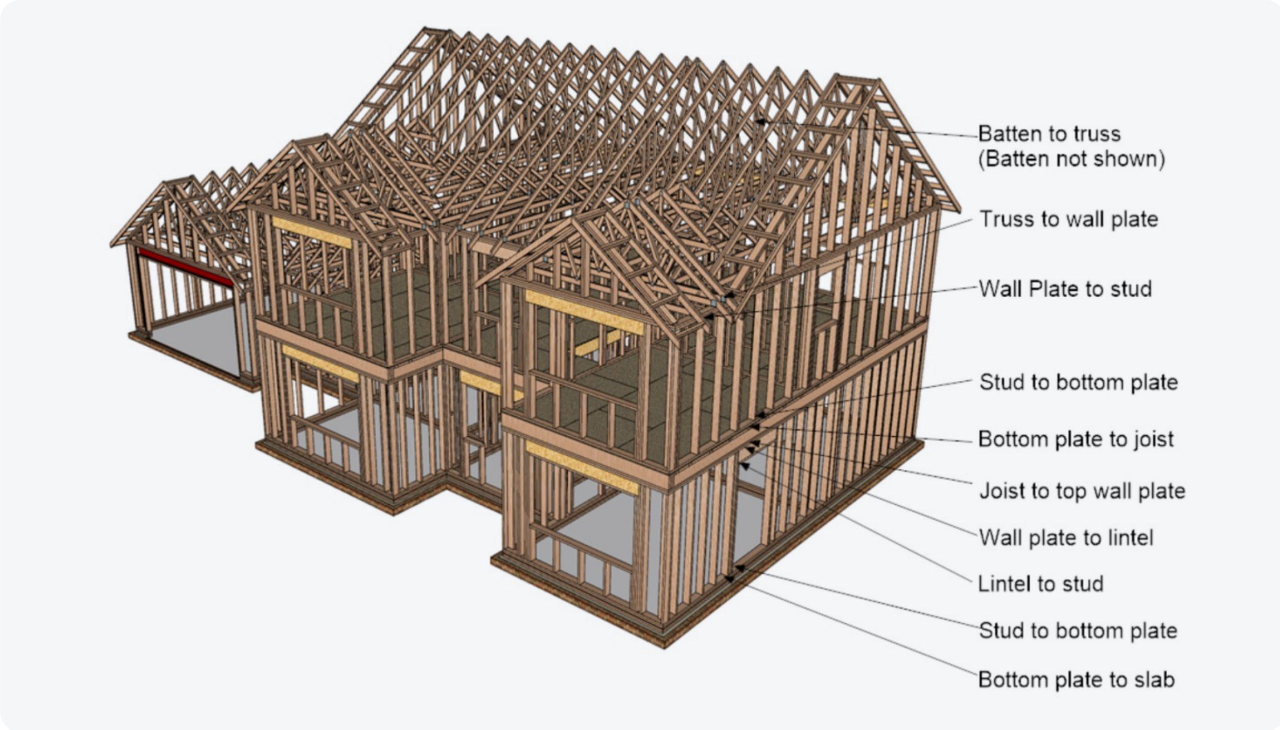


Figure 64: Common fixing locations in lightweight timber-framed construction. (Image credit: TDA)

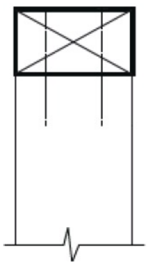
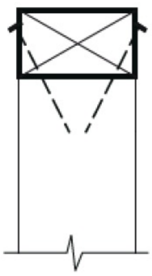
Selection of fixing

There is no best fixing for a particular connection; it depends on the preference of the fabricator, installer or designer. However, the connection must meet the requirements of the load or application it is being used in. Typically, it's a balance between the cost of the connector and speed of installation that determines the most appropriate connection. In the case of wall frames, another factor is spacing or the number of connectors needed. A wide spacing needs fewer connectors but is likely to require more expensive connectors for tie-down. Sometimes a more expensive connector is cheaper overall as the cost of labour is high, meaning the speed of installation may dominate the selection.

Wall plate to studs – example

The following is an example of the different types of connectors used in lightweight timber framing with different capacities. The type of connector to be used would be dependent on the load to transmit. In this case, the load applied is uplift as it is a wall plate to stud connection. Table 7 illustrates the various connectors and their capacity in uplift. Each has a different capacity, cost and speed to install, so these factors need to be balanced to determine the most appropriate connector.

Table 7: Methods to tie-down wall plate top studs. (Image credit: MiTek)

	Straight Nail	Skewed Nail	WallStrap	Tiedown Strap	StudLok 125	StudStrap	PlateTie
Image							
Description	2 x 3.15 hand-driven nails, with 40 mm penetration into stud	2 x 3.15 hand-driven nails, with 40 mm penetration into stud					
Capacity	0.17 kN	0.27 kN	3.2 kN	3.8 kN	5.0 kN	6.1 kN	7.0 kN

Notes:
1. *Image credit: MiTek and TDA*
2. *The joint group is assumed to be JD5*
3. *Straight and Skew nail capacities are from AS 1684.2 [2]*
4. *Tie-down straps use a 10 + 10 nail fixing*
5. *Framing bracket, screw details and capacity from MiTek's wall plate to stud connection guide*

Compliance

A vital aspect of a successful connector is the ability to demonstrate compliance with building regulations. If the design is to be carried out in accordance with AS 1684 [2], then fixings with that standard must be used. Where fixings don't comply with AS 1684 [2], the connector manufacturer should have the necessary evidence for compliance. Usually, there is certification via a structural engineer contained within the design guide from the manufacturer.

Where available to assist in verifying compliance during a frame inspection, fixings supplied by companies have unique identification methods such as marks on the head of the screw, colour coding for nails used in brackets, or even tags for screws (see Figure 65).

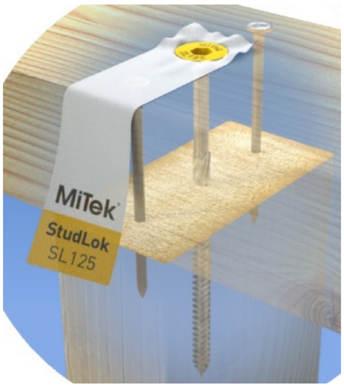


Figure 65: Identification tag to identify the screw used in the connection. (Image credit: MiTek)

5 Mass timber connectors

This section covers the range of fasteners and connectors associated with mass timber construction. These connectors differ from those found in lightweight timber-framed construction, as they join large-sized timber elements together. These connectors having more onerous requirements for load, aesthetics and fire, and are also often prefabricated. However, the range of connectors discussed in this section may have applications within lightweight timber-frame construction.

5.1 Hook connectors

Hook connectors are a range of modern connectors that generally utilise two metal plates screwed into two timber elements. The two metal plates come together and either slide or hook together to form a connection. The type of connector has been developed to make on-site installation quick and an assembly exercise rather than carpentry.

This range of connectors can either be concealed by recessing into the timber or affixed directly to the face or end of the timber elements. They are a fast and exact on-site assembly requiring no additional screwing or machining. The connector can often be disassembled and reassembled if needed and fasten to timber, steel and concrete (see Figure 66). They are available in various sizes; 50 mm up to 450 mm, and a load capacity up to 300 kN. The connectors can also be paired to increase capacity or connected through a beam or column to provide continuity.

Figure 66: Macquarie University Innovation Hub – designed to be relocated. (Image credit: Lipman)

5.1.1 Compliance

This type of connector is proprietary, and to utilise the full load capacity requires the use of the manufacturer's information. The timber engineering Standard AS 1720.1 [3] does not directly cater for this connector type due to concepts not contained within it, such as inclined to the grain screws. Therefore, to utilise the full capacity of the connectors, a performance solution is recommended.

The following discusses the range of connectors that utilise a hook connection format.

5.1.2 Pin type hook connector

This connector consists of two metal plates that are individually screwed to the timber elements that they are to join. Traditionally at the end grain of a beam to a primary beam or column (see Figure 67). This system has one plate with a top-mounted pin, and the paired connector has a bottom-mounted pin. The connector then has a recess so that the opposite pin can slot into it to form the joint.

Figure 67: Pin hook type connector. (Image credit: Rothoblaas)

They are also available with a through bolt to connect neighbouring pairs of connectors to provide continuity of load (see Figure 68).

Figure 68: Pin hook connector with through bolt. (Image credit: Knapp Connectors)

5.1.3 Dovetail connector

A dovetail joint is widely known as a joinery technique most commonly used to join the sides of a drawer to the front. It is noted for its resistance to being pulled apart, as a series of trapezoidal shapes are cut to extend from the end of one board and interlock with a series of cuts into the end of another board.

Modern timber connectors have taken this concept and developed a version utilising the trapezoidal shape slots in metal that slip together and form a joint. Each side of the connection is pre-screwed to the connecting timber elements, using fully threaded modern screws usually inclined when inserted into the end grain of a timber element (see Figure 69).

Figure 69: Dovetail connectors. (Image credit: TDA)

The connector can be concealed within the joints providing a fire rating when embedded within the timber (see Section 7.4). The connector is primarily used for wood-wood connections but can be adaptive for wood-steel or wood-concrete. Suppliers of the connectors generally have a range of size and load capacity, up to 300 kN per connector.

An all-timber version is also possible, where the end of a beam is milled to form a wooden tongue that can be slipped into another beam with a milled-out slot. The slot is tapered to lock the elements together (see Figure 70).

Figure 70: An all-timber dovetail joint.

5.2 Fin plate connections

This connector utilises a metal fin plate usually slotted into the timber and uses dowels or bolts as the fastener. They are an efficient joint method for truss nodes or beam to beam

Figure 71: Fin plate connector. (Image credit: Rothoblass)

They are particularly efficient when the fin plate is slotted into the timber multiple times across the width of the members. Compared to steel plates located on the outside of the timber element using bolts to make the connection, placing two slotted plates internally to the timber member doubles the shear planes. Where fin plates are arranged on the outside surface of the timber element, they can only produce two shear planes. When the same fin plates are slotted into the timber element, they are able to produce four shear planes. This arrangement doubles the connector's capacity. Another way to look at it is that if the same number of dowels and bolts were used, the dowels could be half the diameter. See Figure 72 and Section 4 for information on connection capacity.

Figure 72: Slotted fin plate connector. (Image credit: Rotho Blaas)

AS 1720.1 [3] does not include a specific design method for dowel and fin plate connections. However, it is possible to develop a design method for this type of connection. For design guidance, HB108 [12] provides an excellent commentary for this type of connector. Figure 73 illustrates a truss that spans more than 70 m, and the truss node utilises dowels and nine separate fin plates.

Figure 73: Main truss of the Hamar Olympic Amphitheatre, Norway. The span is 71 m. The truss nodes consist of nine slotted-in plates and dowels. (Image credit: Moelven Limtre A/S).

Fabrication

Generally, this type of connector needs the slots to be machined via a computer numerically controlled milling machine or chain saw slotting tool (see Figure 74). Dowel holes are drilled, usually slightly less than the dowel's diameter, while the steel fin plate is generally slightly larger than the dowel. The dowel is then pushed into the hole and plate with a palm hammer (see Figure 75). Internal fin plates require more care in fabrication and installation than the plates used outside the member.

Figure 74: Mortiser or slot chain saw. (Image credit: www.timberwolftools.com)

Figure 75: Palm hammer. (Image credit: Android Widget - http://androidwidget.info/how-to-use-palm-nailer-full-guide/)

Sometimes the friction of the wood on the dowel may not provide enough lateral resistance within the connector to provide long-term structural integrity of the connection. Where this occurs, a bolt is added and is most likely needed when multiple fin plates are used. Also, the dowel may be driven below the wood surface and plugged or into a blind hole that does not pass all the way through the timber element. This covering to the dowel improves the fire resistance of the connector as well as its appearance.

5.2.1 Self-drilling dowels

Self-drilling dowels are dowels attached with a tip that can drill into timber and metal plates without pre-bored holes that form the connection (see Figures 76 and 77). They have many applications from beam to beam, beam to column, column to concrete, moment connection and bracing connections. Self-drilling dowels can be used with steel plates from 5 to 10 mm thick. They can also be used in multiple plate arrangements, up to three plates. Each additional plate adds to the joint's capacity.

The connectors allow for the potential creation of rigid joints to transfer bending moment stresses (moment-resisting joints). The relatively small diameter also provides ductile connections for earthquake designs. Self-drilling screws have countersunk heads allowing them to be driven below the timber's surface, aiding in fire resistance and visual appearance.

Figure 76: Self drilling screws. (Image credit: Rothoblaas)

Figure 77: Self-drilling dowels T plate connector. (Image credit: Rothoblaas)

Slotted fin plate T – bracket

Another variation on this type of connector is a fin plate T bracket that is placed into the end of a beam in a slot, and self-drilling dowels fix the timber to the fin plate. The base of the T section is typically screwed fixed to the column or beam (see Figure 76 and 77).

Punched metal plates

Although traditionally used in lightweight timber frames, punched nail plates have found application with mass timber design. In this case, a metal strip with punched nails protruding from each surface is used to transfer forces within a connection (see Figure 78).

Figure 78: Punch nail plates used in mass timber construction connections. (Image credit: Rotho Blaas)

5.3 Other modern and older connectors

5.3.1 Quick-connect moment connection

The Quick-Connect joint is a semi-rigid moment-resisting connection that has been developed as an alternative to current nailed solutions for timber portal frame buildings (Scheibmair, 2014) by the research company Structural Timber Innovation Company. The Quick-Connect moment connection has the specific objective of minimising on-site work required to produce the joint—the joint consists of a rod-based system that can be used as a moment-resisting connection. Applications include connections of a portal frame, such as column to foundation, knee, rafter splice and apex.

The connection is based on a system of pre-tensioned rods placed at the upper and lower extremities of the portal frame members, bearing some conceptual similarity to the partially restrained bolted connections often used in steel construction. When the structure is loaded, a tensile force is applied to one set of rods while the other set remains unloaded. The compressive force in the connection is transferred in an elastic parallel to grain bearing at the sleeve interface. This sleeve interface allows a moment couple to be developed, facilitating the transfer of load across the joint. The rods are housed in U-shaped timber members (see Figure 79). Placing the rods on the extremity of the portal member's sleeves allows for the total bending moment capacity of the members to be developed at the joint. The timber sleeves are fixed to the portal frame using fully threaded timber screws inserted at 60° to the load. The orientation of the screws at this angle results in both reduced demand on the screws and a stiffer connection overall (Blass, 2001).

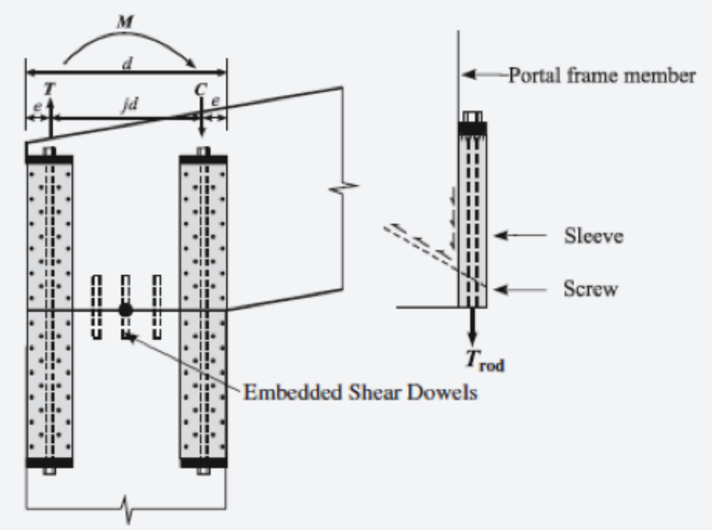


Figure 79: Quick Connect. (Image credit: Structural Timber Innovation Company)

The quick-connect moment connection can be used for moment-resisting knee, apex and splice joints and column-to-foundation connections, offering solutions for a complete portal frame (see Figures 80 and 81). Also, the Quick-Connect moment connection can be easily adapted to fix timber members to steel or concrete. The Quick-Connect moment connection can be applied to box beam portal frames, with the added advantage that the connecting elements are located within the inside of the box beam, providing a hidden connection and therefore improved aesthetic appeal. The design is exactly the same as with solid sections, the only difference being the location of the steel rods.

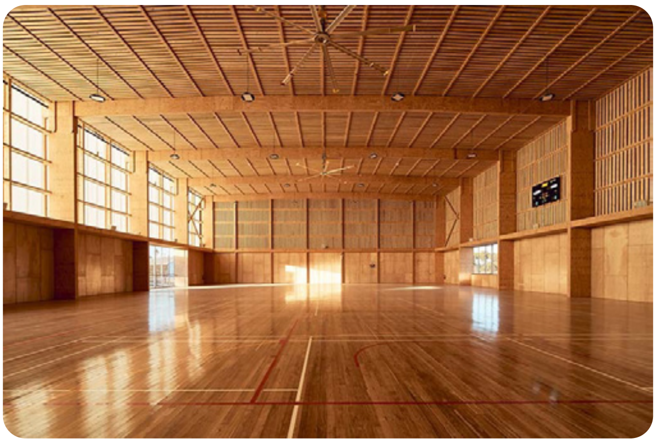


Figure 80: Pingelly Recreation and Cultural Centre – Iredale Pedersen hook architects with Advanced Timber Concepts Studio. (Image credit: Peter Bennetts)

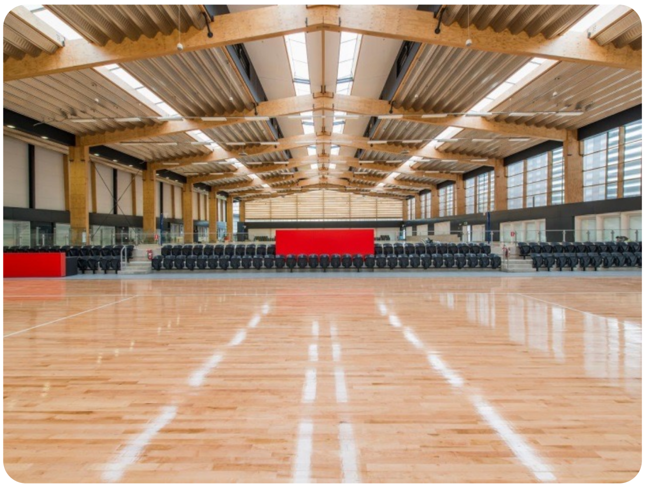


Figure 81: Netball Central Scott Carver. (Image credit: Geoff Ambler; Ethan Rohloff)

Design

Refer to WoodSolutions Guide #33 Quick-Connect Moment Connection.

5.3.2 Timber rivets

Timber rivets are hardened steel nails with a rectangular cross-section used in making connections with steel plates (see Figure 82). The rivets are driven through holes in the steel plate, and timber rivets are available in three lengths; 40, 65 and 90 mm (see Figure 83). They have high load and stiffness capacity, and the load capacity depends on the steel plate capacity and the rivet connection capacity.

Figure 82: Application of Timber Revits. (Image credit: Specialized Timber Fasteners Ltd, Canada)

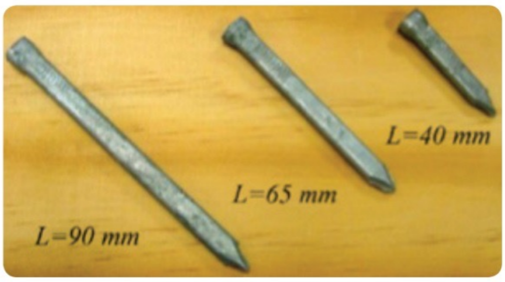


Figure 83: Timber Revets. (Image credit: Specialized Timber Fasteners Ltd, Canada)

Timber rivets are driven into the side plates by the use of either a standard hammer or a palm pneumatic hammer until the conical heads are firmly seated with a maximum projection of 3.2 mm (half of the tip taper of 6.4 mm). When seated in this manner, the rivet head slightly deforms the steel side plate and wedges in place, creating a fixing that restricts the rivet head from rotating under load, contributing to the overall stiffness of the connection.

Timber rivets are always driven with the major axis, the long side of the rectangular nail, parallel to the grain of the timber. They are installed in a spiral pattern from the outside of the group towards the centre. This way, the pre-stressed fibres will minimise splitting.

Timber rivet connections have been used successfully in Canada and the US for the past four decades in different types of structures, including:

- long span truss connections
- long span beam splices
- beam-to-column and column-to-foundation connections
- couple moment connections
- energy dissipating connections
- shear wall hold-down anchorages.

Design

Timber Rivets are part of the Canadian CSA-O86 [10] and American NDS6 Wood Standards [26]. However, the Structural Timber Innovation Company developed a design procedure that has been reproduced in the *WoodSolutions Guide #34 Timber Rivet Connection* [36].

5.3.3 Adhesive bonded connection

Connections discussed up until this point have been based on mechanical fixings. Several connections are possible using adhesives only or a combination and adhesive and rods or plates, discussed below.

Full adhesive bond

A system developed by Timber Structures 3.0 [30] utilises butt-jointed timber glued to each other. The panel faces are pre-treated with the special primer Henkel's patented potting technology with two-part polyurethane adhesive (see Figures 84 and 85).

Figure 84: Bonded adhesive joint in CLT. (Image Credit: TDA)

Figure 85: Adhesive connected CLT panel. (Image credit: TS3)

Epoxy glued in rods

This is a joint in which the timber elements are joined by metal dowels that have been set in the timber in oversized holes with epoxy resin (see Figures 86 and 87). The epoxy resin is pumped into the holes, which binds the dowel to the timber.

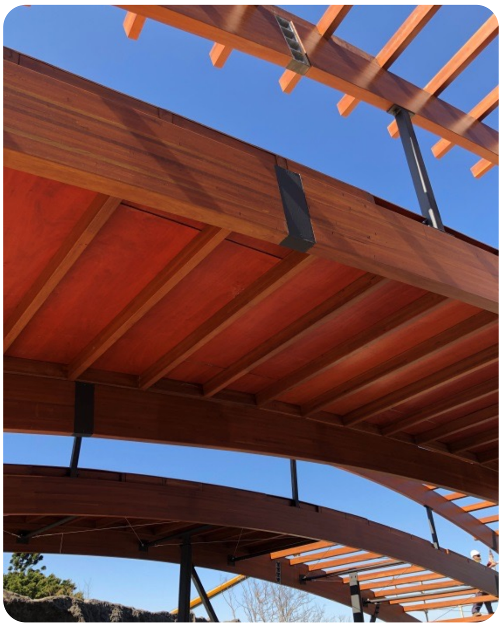


Figure 86: Epoxy dowelled connection system. (Image credit: XLam Solutions)

Figure 87: Epoxy dowelled connection system. (Image credit: XLam Solutions)

Glue-in fasteners

Another option is the use of adhesives to glue in fasteners that provides the connection between the elements. Figure 88 illustrates a composite timber concrete floor system that has used a perforated thin metal plate and coach screw shear keys to connect the concrete layer to the timber substrate. An adhesive is used to connect the shear keys to the timber.

Figure 88: Glued-in shear connectors in a timber-concrete composite floor panel. (Image credit: TDA)

This is a joint in which the timber elements are joined by metal dowels that have been set in the timber in oversized holes with epoxy resin (see Figures 86 and 87). The epoxy resin is pumped into the holes, which binds the dowel to the timber.

Figure 89: Metal fin plates and adhesive connection. (Image credit: Rotho Blaas)

5.3.4 Wood to wood connection

A modern version of dowel joints is to use wood as a pin in a beam to column connection using an oversized hardwood dowel as a bearing pin (see Figure 90). The dowel is oval in shape to aid in a degree of fixity to induce some moment capacity into the joint. Also used in the connection is a beech bearing surface, as the increased density of the beech increases the bearing's resistance of the dowel.

Figure 90: Timber dowel beam to column connection – Tamedia Zurich. (Image credit: TDA)

5.4 Older connectors

Split-ring and shear-plate connectors are not often used in modern timber construction. They are, however, still included within the design standard as there are structures that remain in services that utilise this form of connection. Their inclusion within the timber engineering Standard allows designers to check their capacity to assess the strength of an older structure. The following describes these two old styles of connection.

5.4.1 Split-rings

Split-rings transfer load from one piece of timber to another directly through a large diameter circular steel ring set into a groove on both sides of the connecting elements (see Figure 91). The ring is embedded into the groove of one of the two facing members and the other half into the groove of the other member so that when the two members are joined face to face, the ring is wholly embedded between them.

There are two common split-ring sizes, 64 mm and 102 mm. The bolt through the centre has the sole purpose of holding the joint together, and it does not contribute to the transfer of shear. The metal ring has a purpose placed split in it to permit free movement of the wood with the moisture content changes, which occur in service. The bolt used with the ring principally serves the purpose of holding two members together. A special tool is required to cut the grooves in the timber accurately.

The split-ring connector is not used today as the modern connectors are superior for load transfer and degree of ease in fabrication. Any error in the split-ring groove milling leads to a reduction of load and, more significant, joint deformation.

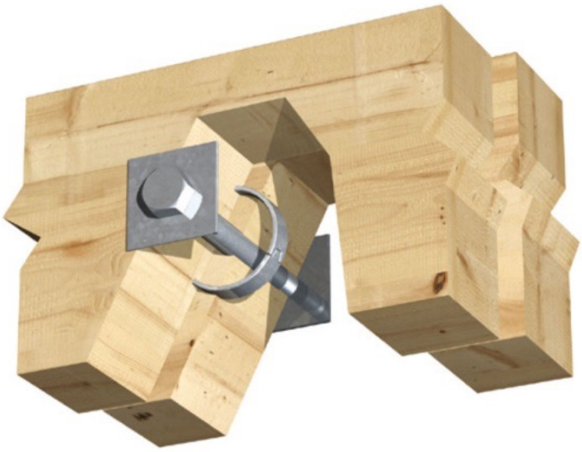


Figure 91: Split-ring connector. (Image credit: https://www.expamet.co.uk/product/srtc64/)

5.4.2 Shear-plate connectors

Shear-plate connectors are similar to split-ring connectors; however, the metal shear plates are located within the timber element. The load is transferred to the bolt that carries the shear across the interface (see Figure 92). The shear plate increases the bearing surface within the timber element, increasing the load capacity. Thus, the bolt in a shear-plate joint performs the dual role of holding the joint together and transferring shear.

It is essential when using shear plates that the timber is seasoned close to its service moisture content, as the rigid shear plate is intolerant to timber moisture movement. As for split rings, a high degree of milling is required to ensure adequate bearing. They are available in two diameters, 67 mm and 102 mm, and have a similar load carrying capacity to split-rings and require similar installation procedures.

Figure 92: Shear-plate connector. (Image Credit: Portland Bolt)

5.4.3 Tooth plates timber connectors

Tooth plate timber connectors (single and double-sided) are modern split and shear plate timber connectors (see Figure 93). The connector has teeth embedded fully into the timber's contact surface to increase the bearing area, which increases the connector's design capacity. Like a shear plate, they also have a bolt that transfers the load from one tooth plate to another.

Tooth plate timber connectors are easily installed to improve timber connection efficiency and do not suffer the same moisture issues that moisture change has on shear or split ring connectors. They are available in single and double-sided configurations; a single side tooth plate connector is used outside of the timber element, while the double-sided connector is used on the interface between the two timber elements.

Figure 93: Single tooth nail plate connector. (Image credit: Simpson Strong-Tie)

6 Timber Joint Design to AS 1720.1

The timber engineering Standard AS 1720.1 [3] is the National Construction Code [25] – Deemed-to-Satisfy method for the design of connections in timber structures. A design carried out by a suitably qualified person, e.g. a structural engineer, means the connection complies with Australian building regulations. The following section discusses the scope and limitation of this Standard.

6.1 AS 1720.1 scope

AS 1720.1 [3] has a calculation method for mechanical fasteners used in timber joints, these include nails, wood screws, bolts, and coach screws. It also has historical types of fasteners, split-ring and shear plates. Plywood connections are also covered within a normative appendix.

The Standard does not explicitly cover glued timber joints or timber to plywood joints; however, there is some advice given. Other specific limitations are discussed in more detail under relevant sections.

6.2 Background

Australian timber joint design procedures are derived from early North American studies conducted by Trayer [31] in 1932. Studies on Australian timbers supplemented this information, where hardwoods and local practices and conditions were studied. The current design provisions are primarily due to the work of former CSIRO researchers, Mack and Lhuede [15-23]. Later Leicester[15] provided an overview of timber joint code development in Australia. The timber joint design provisions of AS 1720.1 [3] are based solely on an empirical fit of test data.

However, modern design methods employed internationally use the European Yield Model, based on Johansen's research in 1949 [14]. This approach is under discussion for the future version of the AS 1720.1 [3]. For more information, refer to Development of Limit States Design Method for Joints with Dowel Type Fasteners Part 1: Literature Review [12].

6.3 Understanding AS 1720.1 joint types

The timber engineering Standard has several assumptions that are key to the design of timber joints. These assumptions simplify the design process and account for the extensive commercial range of timber species available.

6.4 Joint type

To decrease design calculations, AS 1720.1 [3] reduces all connection types to just two types called Type 1 or Type 2. Various configurations of Type 1 and Type 2 joints are given in timber engineering standards and calculation methods to determine the design capacities of the connection.

Type 1 joint: Fasteners are subject to shear loads where the fastener is into the side or end grain of the connected member. The load is applied to the timber to bear on to the grain, either parallel, perpendicular or a combination of both (see Figure 94).

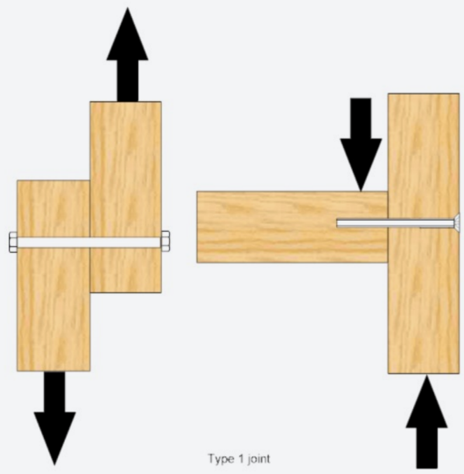


Figure 94: Joint Type 1 – shear load (Image credit: TDA)

Type 2 joint: Fasteners are subject to an axial load where the fastener is installed into a connected member's side or end grain. The load is applied to the timber in tension onto the grain, either parallel, perpendicular or a combination of both (see Figure 95).

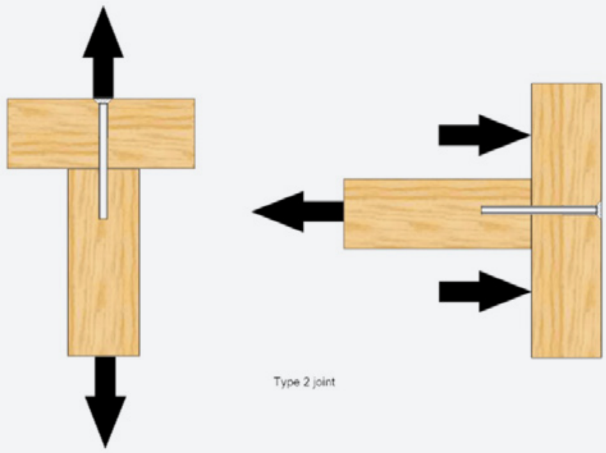


Figure 95: Joint Type 2 – withdrawal load (Image credit: TDA)

6.5 Joint group

Due to the extensive commercial range of timber species available, timber species are grouped by their density and moisture condition to streamline design calculations. There are six joint groups: J1, J2, J3, J4, J5 and J6 for unseasoned timber, and a similar number for seasoned timber JD1, JD2, JD3, JD4, JD5 and JD6 (see Table 8.

Table 8: Timber joint group for density.

Unseasoned Timber		**Seasoned Timber**	
Joint Group	**Basic Density (kg/m³)**	**Joint Group**	**Design Density[2] 12% MC**
J1	750	JD1	940
J2	600	JD2	750
J3	480	JD3	600
J4	380	JD4	480
J5	310	JD5	380
J6	245	JD6	310

Note:

1. Basic Density is the ratio between an oven-dry or air-dried mass of wood (meaning the lightest it will ever get) divided by the green volume of the wood (when it's freshly cut and has its most significant water volume).

2. Design Density: Mass and volume measured at 12% moisture content.

Table 9 contains the joint group of commonly used timber species. Where a joint has more than one timber species, use the species with the lowest joint group classification to calculate the capacity of the joint. However, an alternative approach is to design each part of the joint separately and use the weakest value as the joint capacity.

Table 9: Strength group and joint group classifications for some common hardwood species.

Timber Species	Moisture Condition	Strength Group	Joint Group
Blackbutt	Unseasoned	S2	J2
	Seasoned	SD2	JD2
Jarrah	Unseasoned	S4	J2
	Seasoned	SD4	JD2
Ash-type eucalypts from N.S.W. Highlands, Victoria and Tasmania	Unseasoned	S4	J3
	Seasoned	SD4	JD3
Pine, radiatea (Australia and New Zealand)	Seasoned	SD6	JD4(3)
Mixed Pinus species (Australian grown)	Seasoned	SD7	JD4

6.5.1 MGP10 stress graded joint group

For MGP10 stress graded timber, generally made up of pinus species or imported softwoods, the Engineering Standard AS 1720.1 [3] Table 3 assumes a Joint Group of JD5. This assumption is based it is generally challenging to exclude heart-in material within the design and that the Strength Group is a minimum of SD6. Imported softwoods may have a Strength Group greater than SD6 and consequently have a weaker Joint Group.

6.5.2 Strength-reducing characteristics at joints

Strength-reducing characteristics are knots, gum veins, splits, checks and other characteristics that reduce timber's strength. AS 1720.1 [3] assumes that the fastener is not in the vicinity of these features.

6.6 Tendency to split

The splitting of timber has a detrimental effect on the timber's joint capacity. The timber engineering Standard AS 1720.1 [3] provides advice that timber with a splitting parameter greater than 0.8 has a high tendency to split, while a timber with a splitting parameter of $\alpha<0.55$ usually has little tendency to split. Most eucalypt and corymbia species and most hardwood species of dry sclerophyll forests have a basic density of less than 700 kg/m^3 have a splitting parameter $\alpha>0.8$ while most softwoods have a splitting parameter $\alpha<0.8$.

The capacities for fasteners in the AS 1720.1 [3] have generally been derived on the assumption that splitting of the timber does not occur to any significant extent. Where nails are used in unseasoned timber that show a high tendency to split, the use of pre-bored holes of diameter 80% of the nail diameter is recommended. However, for screws, the diameter of the pre-bored holes is the shank diameter. The use of pre-boring also helps reduce the end and distance between nails.

Standard AS 1720.1 [3] details a method of determining the tendency of timber species to split, including references to where shrinkage and cleavage strength can be found.

6.7 Eccentric joints

It is sometimes impracticable to have all the members of a joint arranged symmetrically, i.e. centre lines intersecting on a common axis. This arrangement could be caused by the end, edge and spacing requirements for fasteners in timber elements, or simply where the effective point of load application at the centre of the fastener array in the beam, or column, requiring the fastener array to carry a moment. AS 1720.1 [3] does not give advice other than stating that consideration of the combined effects of primary and secondary stresses due to the resulting bending and shear stress. The use of symmetrical joints may reduce the amount of design calculation required.

6.8 Loads at an angle to the grain bearing type fasteners

Timber has different material properties parallel to grain compared to perpendicular to the grain, and due to this, timber is termed orthotropic. It is well known that timber has a much greater strength parallel to the grain than perpendicular to the grain; AS 1720.1 [3] acknowledges this by giving value for each bearing fastener type.

For fasteners such as bolts, coach screws, shear-plates and split-ring connectors that apply bearing action into the wood fibres, as the means to transfer load, is affected by the angle between the grain and the direction of the load applied. Where a load is applied at an angle to the grain, the capacity of the fastener is needed to be considered in relation to this angle. AS 1720.1 [3] provides a method that utilises Hankinson's formula, which is a mathematical relationship for predicting the compressive strength of wood at an angle to the grain; for further information, refer to HB108 [12].

6.9 Spacing, edge and end distance

AS 1720.1 [3] lists various fastener capacities and assumes that the fastener is not in a zone of weakened wood or that there is adequate spacing between fasteners to prevent splitting or breaking of the timber. The dimensions for spacing parallel to the grain and for spacing perpendicular to the grain varies and can be calculated using Hankinson's formula due to the orthotropic properties wood has; for further information, refer to HB108 [12].

6.9.1 Nail spacing, edge and end distances

AS 1720.1 [3] provides recommended minimum spacing, edge and end distances for nails in terms of the nail diameter (D) and whether the timber is pre-bored or not. Pre-bored holes assume 80% of the nail diameter hole is formed before driving the nail. Table 10 details the minimum distance for the end, edge and between nails.

Table 10: Minimum spacing, edge, end and between nails.

Spacing Type	Minimum Distance	
	Holes not pre-bored	Holes pre-bored to 80% of nail diameter
End Distance	20D	10D
Edge Distance	5D	5D
Between nails along the grain	20D	10D
Between nails across the grain	10D	3D

Note: The table is reproduced from AS 1720.1 Table 4.4 [3]

6.9.2 Screw, edge, spacing and end distances

AS 1720.1 [3] provides recommended minimum spacing, edge and end distances for screws in terms of the shank diameter (D), and they are listed in Table 11 and Figure 96.

Table 11: Minimum spacing, edge, end and between screws.

Spacing Type	Minimum Distance
End Distance	10D
Edge Distance	5D
Between nails along the grain	10D
Between nails across the grain	3D

Note: The table is reproduced from AS 1720.1 Table 4.8 [3]

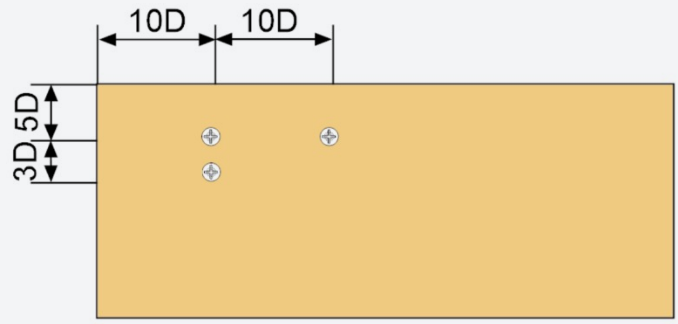


Figure 96: Edge, end and spacing of screws. (Image credit: TDA)

6.9.3 Bolts edge, spacing and end distances

As discussed before, timber's strength capacity is different when the load is applied parallel to the grain compared to perpendicular to the grain. For bearing type fasteners, like bolts, its capacity also varies due to the moisture content of the timber. Therefore, for edge, end and spacing, these two factors are considered.

The measurement is always taken from the centre-line of the fastener to the centre-line of an adjacent fastener or end or edge of the timber element. Refer to Table 12 for the minimum edge, end and spacing between bolts. Where the fasteners are not aligned with the grain, then the minimum spacing of fasteners can again be found by using Hankinson's formula.

Table 12: Edge, end and spacing distance for bolts.

	b/D ratio		Seasoned	Unseasoned
Load parallel to the grain, including loads at 0 < 30O to the grain	NA	Tension	7D	8D
	NA	Compression	5D	5D
Load perpendicular to the grain including load 30o to 90o	≤ 2	Tension or compression	2.5D	2.5D
	3	Tension or Compression	3.1D	3.1D
	4	Tension or Compression	3.7D	3.7D
	5	Tension or Compression	4.35D	4.35D
	6	Tension or Compression	5D	5D

Note: 'b' is the effective thickness of the member loaded perpendicular to the grain.

Refer to Figures 97 and 98 for a visual representation of the end distances.

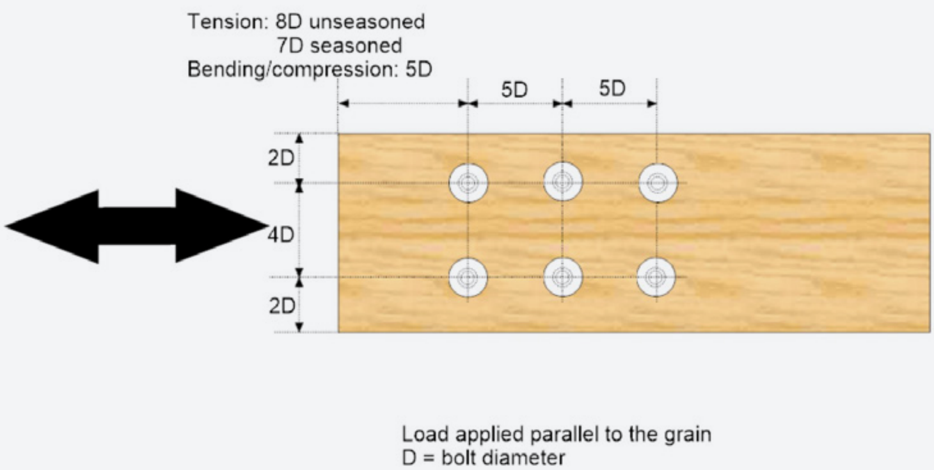


Figure 97: Edge, end and spacing for load applied parallel to grain. (Image credit: TDA).

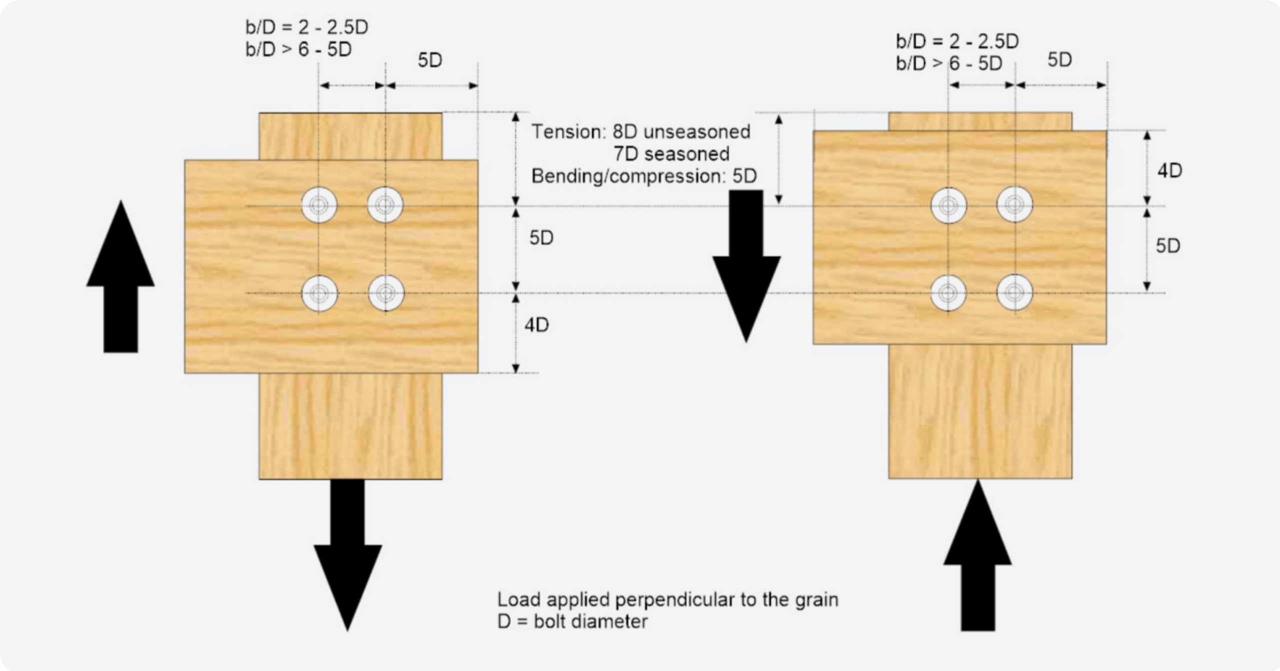


Figure 98: Edge, end and spacing for load applied perpendicular to grain. (Image credit: TDA).

6.10 Connector or joint deformation

Where joints are placed into a system such as a truss or other system, the total deformation experienced by the structure may be higher than the deflection calculated under normal static conditions. This increase in deformation is due to movement in the fastener type from tolerance in the fabrication of the fastener, i.e. bolt hole oversizing, eccentricities in the connection, etc, or the elastic movement of the fasteners. This characteristic is called joint slip, and the load-displacement characteristics of a joint are exceedingly nonlinear. Therefore, it is not possible to precisely predict the amount of slip at each joint and, for that matter, the overall deflection of the element.

AS1720.1 provides some advice on the deformation of timber joints; however, characteristic of joints is extremely nonlinear, and the calculated deformations of connections should be regarded as an estimate at best. AS 1720.1 Appendix C [3] presents some empirical models for the serviceability behaviour of members, using nails and screws, bolts, split-rings and shear plates. They rely on appropriate elastic deformation analyses modified for the creep that use serviceability duration of load factors.

Further Reading: HB108 contains a commentary on deformation calculations for timber.

7 Detailing timber connections

This section deals with connector detailing and discusses common considerations required to provide an adequate service life for a connector and its fastener. These considerations include cracking of the timber due to perpendicular-to-grain stresses, the durability of the connector and fasteners, as well as degradation of timber due to environmental conditions or fire.

7.1 Connector detailing to prevent cracking and splitting

Successful detailing of timber connectors requires a different approach to other structural systems such as steel. This difference mainly occurs where timber is joined to other materials or where other materials are used to join timber. In these situations, careful consideration is necessary, as common practices employed for steel connection may induce cracking in the timber due to restraining of the timber. Several reasons for the timber to become restrained include the timber shrinking, point loading, deflection of the element, or stresses induced by offset load paths. All of these can lead to the splitting of members parallel to the grain and corresponding significant reductions in member or joint capacities. The following section describes the common situations that lead to cracking or splitting and suggests details to avoid or reduce this potential. In most cases, the issue being dealt with is to reduce the stress that causes perpendicular to grain load, leading to cracks and splits.

7.1.1 Moisture content change leading to crack formation

Timber may increase or decrease in size, depending on the change in relative humidity of the environment. Where large dimensions of timber are used, it is likely to obtain more significant movements. For example, radiata pine has a Unit Tangential Movement percentage of 0.27. The Unit Tangential Movement is the dimensional percentage change for each 1% moisture content change between about 3% moisture content and the fibre saturation point for the particular species. Values of Unit Tangential Movement percentage for different timber species can be found in AS 1684[2]. For example, in a deep beam, say 600 mm, 1% moisture content change is estimated to be 1.62 mm. The WoodSolutions Guide #50[37] suggests that a building site may have a moisture content of up to 5% higher than the expected moisture content during service. For the deep section radiata beam, there would be an 8.1 mm movement if there were a 5% moisture content change.

Metal connectors are not affected by relative humidity change. Therefore, having a continuous metal plate connector that is located on the outside or slotted within the timber element, with a fastener at the top and another at the bottom, may create tension perpendicular to the grain as the timber changes moisture content. This is because the metal connector through the fasteners restrains the timber, causing this tension. In practice, it is possible to detail connections to minimise this transverse restraint, reducing tensions perpendicular to the grain.

Restrained timber due to the connector

As the timber shrinks, even to a minor extent, the extreme fasteners fixed to metal connectors restrain the timber from movement, placing tension into the perpendicular to the grain resulting in cracking and splitting. This cracking and splitting commonly occur when the fin plate type of connections are used. One method to reduce splitting is to use a bearing type of connector where the beam sits onto a seat. This type of connector also reduces the number of fasteners required, making it easier to place, and speeding up the installation process. Table 13 give examples of connector that are likely to cause the timber to become restrained. For each example, a solution is provided.

Table 13: Common situation to cause cracks in timber due to connector restraining the timber.

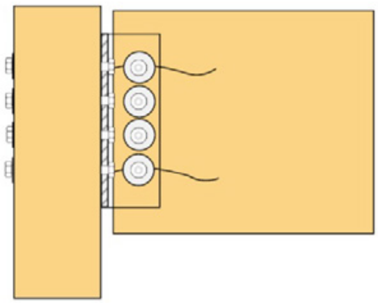
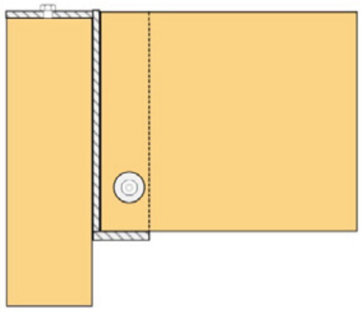
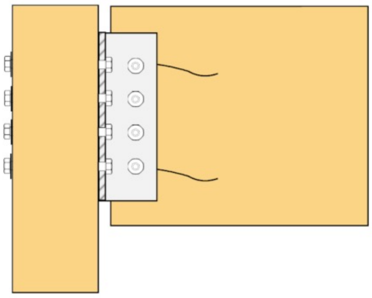
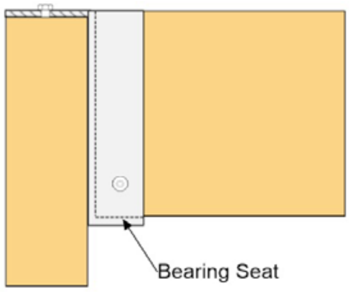
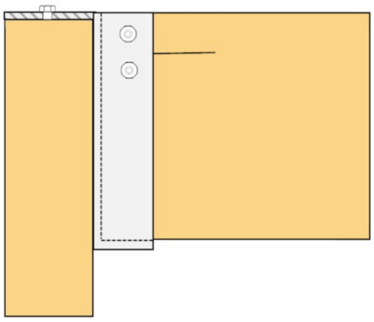
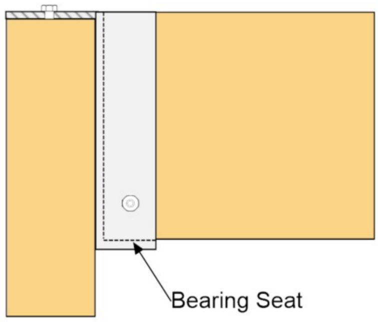
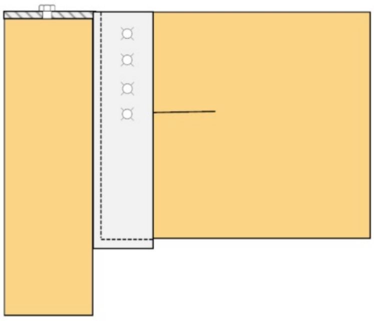
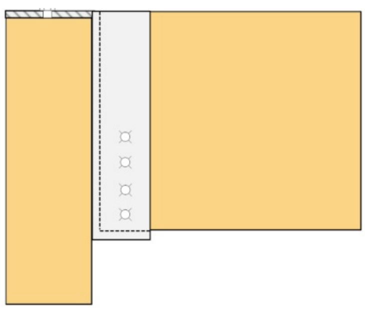
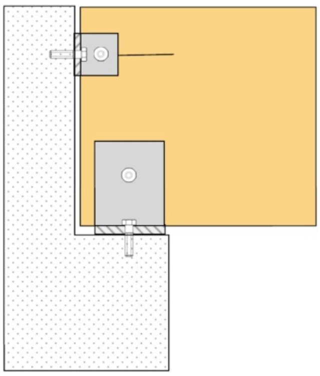
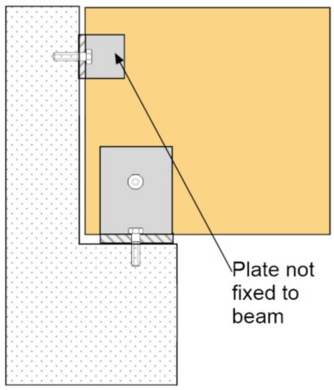
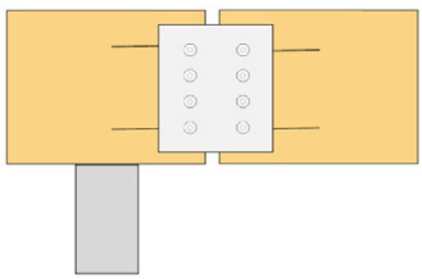
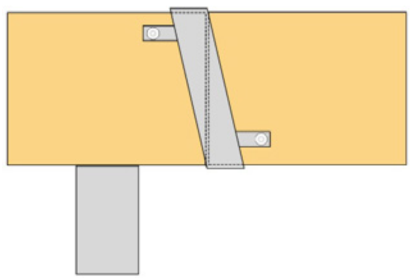
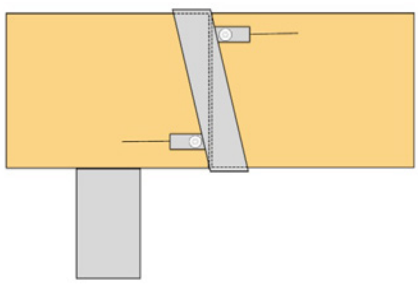
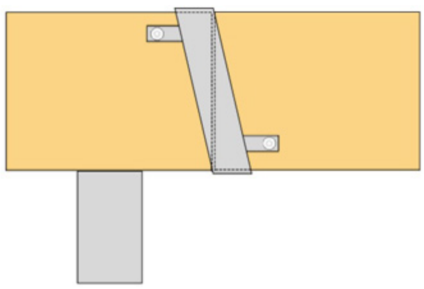
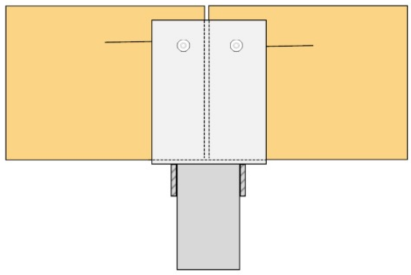
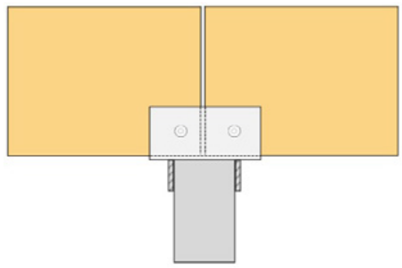
Problem	Solution	Comment
		Angle or fin plates with rows of fasteners may induce splitting due to the bolts restraining the timber as it shrinks, inducing tension to grain
		Slotted plates with rows of fasteners may induce splitting due to the bolts restraining the timber as it shrinks, inducing tension to grain
		In this situation, the shrinkage of the beam lifts the beam off from the connector's seat, placing all the load onto the locating bolt
		This illustration is the same situation as discussed above, but using nails as the fastener.
		Again the fasteners are restraining the timber in the joint. The top connector is for locating the beam and does not need to have a fastener installed.

Table 13 continued: Common situation to cause cracks in timber due to connector restraining the timber.

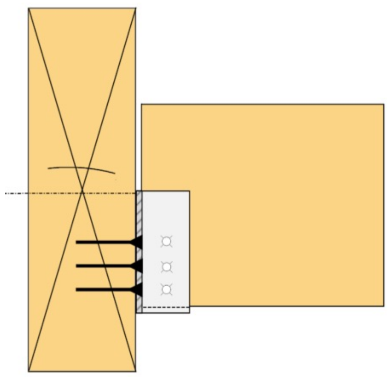
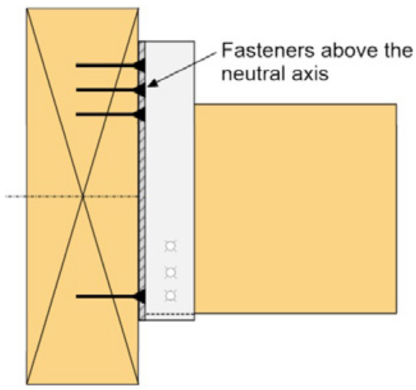
Problem	Solution	Comment
		Angle or fin plates with rows of fasteners may induce splitting due to the bolts restraining the timber as it shrinks, inducing tension to grain
		Slotted plates with rows of fasteners may induce splitting due to the bolts restraining the timber as it shrinks, inducing tension to grain
		In this situation, the shrinkage of the beam lifts the beam off from the connector's seat, placing all the load onto the locating bolt

Note: Images inspired by APA Glulam Connection Details – Construction Guide

Location of the fasteners

A load suspended from the lower half of the beam is another opportunity for perpendicular to grain issues to form. Applying the load via fasteners below the neutral axis may cause tension perpendicular to the grain. This issue is due to load overcoming perpendicular to the grain strength, resulting in cracking. The common situation and the respective solution is discussed in Table 14.

Table 14: Common arrangement in timber connectors that cause cracking

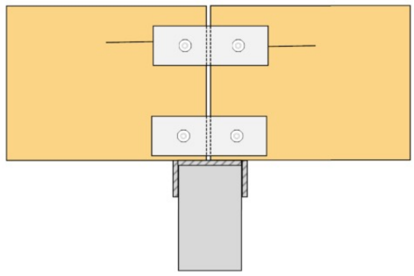
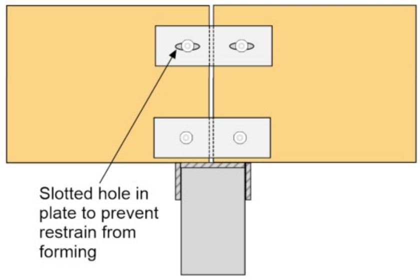
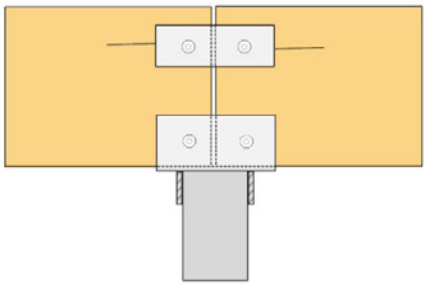
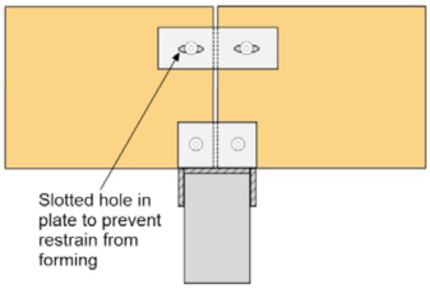
Problem	Solution	Comment
		The connector may need to lengthen place fasteners above the beam's neutral axis

Note: Images inspired by APA Glulam Connection Details – Construction Guide

Restraint of beam end rotation

Another situation is where a beam end is prevented from rotating due to the deflection of the beam. In this case, the load is applied along the grain. This situation is common, and the solution is discussed in Table 15.

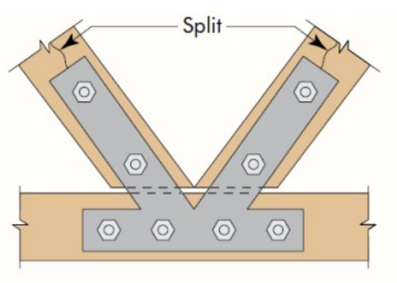
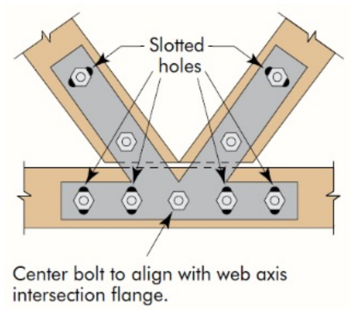
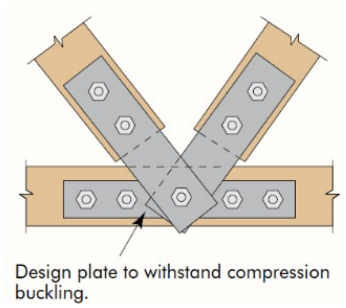
Table 15: Common timber connector configuration to cause cracking in timber.

Problem	Comment	Solution
		The top of the beam should be allowed to rotate. This rotation allowance can be achieved by slotting the metal plate or placing the slots into the timber elements.
		

Note: Images inspired by APA Glulam Connection Details – Construction Guide

Secondary actions

In this situation, the off-set forces in the truss element caused by the inability to place fasteners close together can induce shear and moment leading to tension perpendicular to the grain.

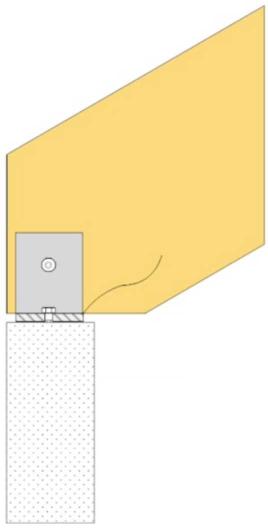
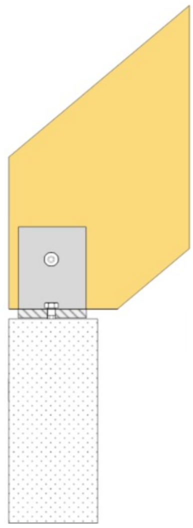
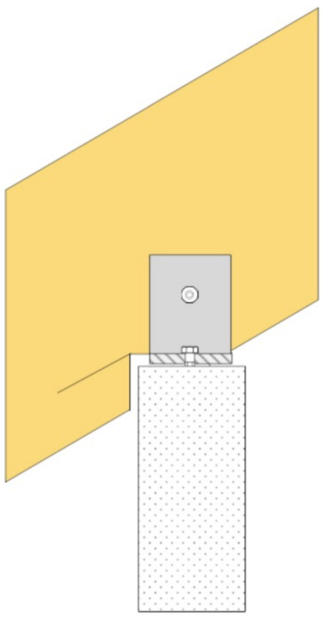
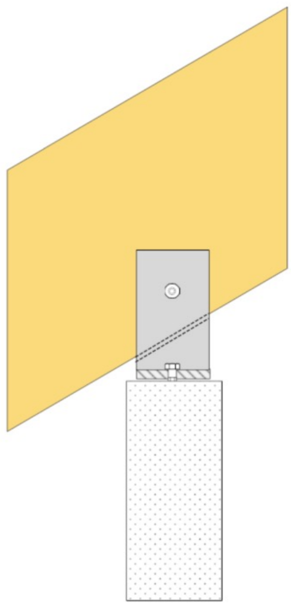
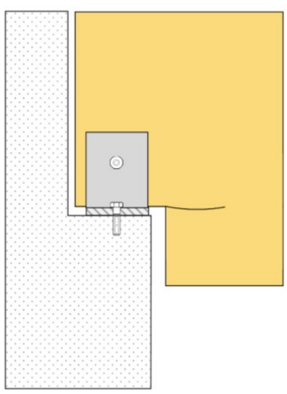
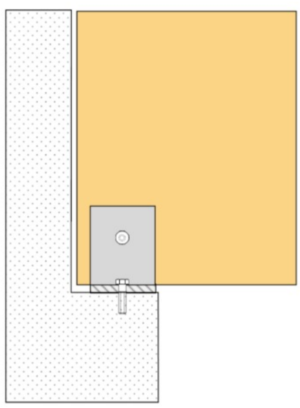
Problem	Solution	Comment
		Place slots into the metal connector to reduce restraint.
		

Note: Images inspired by APA Glulam Connection Details – Construction Guide

Stress concentration

Sometimes the detailing of connectors may induce stress concentration that initiates cracking. Table 16 highlights several details that may cause this to occur. Accompanying the situation is a suggested solution.

Table 16: Common configuration of connectors to cause stress concentrations.

Problem	Solution	Comment
		Due to the proximity of end grain, shrinkage is higher. This proximity of end grain, may induce perpendicular to the grain failure.
		Shear stress concentration may occur at the corner of the cutout, leading to perpendicular to the grain failure.
		Notching at the end of the beam may cause splitting at the inside corner due to shear stress concentrations, inducing tension perpendicular to the grain.

Note: Images inspired by APA Glulam Connection Details – Construction Guide

Reinforcing against perpendicular to the grain

Despite attempts to detail connections with consideration of perpendicular to grain performance, there still may remain a risk of splitting/cracking. The use of reinforcements, such as fully threaded screws, to improve the timber's perpendicular to grain strength may reduce cracking.

7.1.2 Durability of connectors and timber

The durability of timber structures is often dependent on the timber's durability, which varies as the timber's exposure to moisture increases. Connectors should also be considered for their durability as their service life is also affected by the level of exposure to the weather and moisture. In addition, connectors are affected by exposure to hazardous environments such as industrial and coastal zones where salt spray may reduce the connector's life. It is essential to ensure that the durability of metal connectors is appropriate to the environment in which they are used.

7.1.3 Degradation of timber

In certain conditions, the wood around a metal connector may weaken. This weakness is often seen in nails in timber, where the wood that surrounds the nail is usually stained black, indicating degradation. A steel connector often produces iron salts that are strongly acidic, and in the presence of moisture for long periods of time, iron can have a hydrolysing action (a reaction in which a molecule of water breaks one or more chemical bonds) on the wood adjacent to the embedded metal. This deterioration is most noticeable in timber species that are strongly acidic or high in tannins. Table 17 lists common timber species and their pH level.

This process weakens the wood, nails, and similar fixings may pull out easier or have a loss of bearing resistance. This may occur is nailing into decks in exposed conditions using hardwood decking boards. This condition does not occur if the timber is in a seasoned condition or is kept dry. To minimise the corrosion of the metal fasteners, they should be detailed and specified using a material with the required resistance to corrosion that is appropriate to the structure's life.

Table 17: pH of common timber species.

Timber Species	pH
Blackbutt	3.4
Cypress	5.7
Jarrah	3.0 to 3.7
Radiata pine	4.0 to 4.8
Spotted Gum	4.6 to 5.0

pH is a measure of how acidic/basic(alkaline) water is. The pH range goes from 0 to 14, where 7 is neutral. A pH of less than 7 indicates acidity, whereas a pH greater than 7 indicates a base (alkalinity). pH is a measure of the relative amount of free hydrogen and hydroxyl ions in the water.

Along with the deterioration of the timber in wet wood, the slightly acidic condition is likely to corrode unprotected metal fasteners. In certain conditions, the wet wood in combination with the unprotected connector can accelerate the corrosion of the metal. The migration of chloride ions into the crevice accelerates the corrosion rate, accelerating the production of acid, speeding up the process. The situation can be explained by crevice corrosion, which occurs in confined spaces.

For unprotected connectors, the corrosion on the metal is greater than the corrosion on the timber and protecting the metal connector prevents this issue from occurring. Again, a dry environment prevents corrosion from occurring.

The durability of timber in the vicinity of concrete or masonry

As most connectors occur at the end of the beams or column where the timber end grain is exposed, moisture should be prevented from accumulating in these locations. A drain hole or gap of around 10 mm between the timber and concrete or masonry is recommended (see Figure 99).

Further reading: WoodSolutions Guide #5 [33] provides additional design advice.

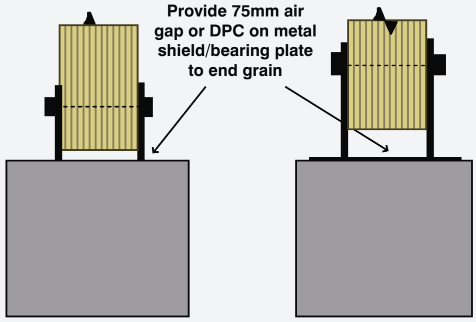


Figure 99: Air gap between the timber element to the masonry or concrete (Image Credit: WoodSolutions)

7.2 Degradation of metal fasteners

Corrosion is a natural process that converts metal into a more chemically stable form such as oxide, hydroxide or sulphide; for connectors containing iron (steel is an iron alloy), the corrosion of iron forms a reddish-brown oxide known as rust. The reaction of iron and oxygen in the catalytic presence of water or air moisture forms the iron oxide – rust. Salt is present in seawater, salt spray and industrial activity, and iron tends to rust more quickly due to electrochemical reactions. Therefore, a steel connector in the presence of salt requires extra protection.

For more information on the corrosion of fasteners, refer to WoodSolutions Guide #5 [33].

Corrosion of metal fasteners needs to be considered in terms of the type of exposure of the fastener. Most timber connections and fasteners have an 'exposed' portion (exposed to the atmosphere) and an 'embedded' portion (embedded in the timber). Corrosion of the embedded portion of the fastener will be dictated by the moisture content of the timber, the timber's natural 'pH', the availability of oxygen and any electrolytic action that may be facilitated via other influences such as a preservative treatment of the timber, e.g. a copper-based preservative treatment; refer to the section below. The natural pH of many species of timbers is given in Table 17.

Corrosion of the 'exposed' portion of the fastener is dictated by all of the above factors but can also be influenced by air-borne contaminants such as salt deposition and, in industrial areas, other chemicals.

Most timbers are slightly acidic (pH 3.5 to 5.5 with species such as western red cedar and Kapur being at the low end); therefore, when moisture is present, and the metal is in contact with the timber, it will have a low resistance to corrosion (unprotected steel) causing chemical reactions that result in a strength loss in the surrounding timber (dark staining around steel fasteners).

The corrosion of metals is well known and is not just applicable to the metal connector used in timber construction. The prevention methods are also well known and are based on exposure conditions. Depending on the level of exposure, a suitable protection method is available. Australian Standard AS 4312 [7] describes the atmospheric corrosive zones within Australia, the suggested protection methods, and is briefly described below.

7.2.1 Corrosion zone definitions

The following are environments with differing corrosion behaviour.

- ***Sea Spray Zone*** – Less than 1 km from a surf coast or 100 m from bayside areas.
- ***Coastal Zone*** – 1 km to 10 km from a surf coast or 100 m to 1 km from bayside areas.
- ***Industrial Zone*** – Close proximity to industrial complexes where corrosive gases may be emitted, e.g. Port Pirie and Newcastle.
- ***Special Hazard Zone*** – The environment within a building may also adversely affect the durability of connectors. For example, enclosed swimming pools, fertiliser sheds, tanneries, chemical plants, piggeries, poultry sheds and similar, may cause rapid corrosion of galvanised metal products and may also impact stainless steel. Corrosion in these buildings will require special attention and is beyond the scope of this Data Sheet.
- ***Low Hazard Zone*** – Generally locations not described by the above.

7.2.2 Exposure conditions

In timber design, there are three general exposure conditions, and they are:

- ***Enclosed***: contained fully within the building's envelope – for example, enclosed roof, wall or floor.
- ***Sheltered***: a connector that may not be in direct weather exposure; however, it may receive wind-blown spray or other corrosive chemical vapours – for example, open subfloor, carports, verandas.
- ***Exposed***: exposed to direct rain, decks, pergolas, subfloor framing.

Table 18 describes the particular exposure conditions as defined in AS 4312 [7] that requires extra protection.

Table 18: Corrosively in Australia as defined in AS 4312.

Category		Generic examples	Specific examples	Exposure conditions	Suggested Corrosion Protection
CX	Severe surf shore-line	Surf beach shoreline regions with very high salt deposition.	Some Newcastle beaches	Enclosed	Galvanised Z275 Class
				Sheltered	Stainless Steel 304 or equivalent
				Exposed	Stainless Steel 304 or equivalent
C5	Surf	Within 200 m of rough seas and surf beaches. May be extended inland by prevailing winds & local conditions.	More than 500 m from the coast in some areas of Newcastle	Enclosed	Galvanised Z275 Class
				Sheltered	Stainless Steel 304 or equivalent
				Exposed	Stainless Steel 304 or equivalent
C4	Calm Sea-shore	From 200 m to 1 km inland in areas with rough seas and surf. May be extended inland by prevailing winds & local conditions.	All coasts	Enclosed	Galvanised Z275 Class
				Sheltered	Galvanised Z275 Class with Soft Seal (or equivalent) Coating or Stainless Steel 304 or equivalent
		From the shoreline to 50 m inland around sheltered bays. In the immediate vicinity of calm salt water such as harbour foreshores.		Exposed	Stainless Steel 304 or equivalent or 600+ gsm Hot Dipped Galvanising
C3	Coastal	From 1 km to 10 km inland along ocean front areas with breaking surf & significant salt spray. May be extended inland to 50 km by prevailing winds & local conditions.	Metro areas of Perth, Wollongong, Sydney, Brisbane, Newcastle, & the Gold Coast	Enclosed	Galvanised Z275 Class
		From 100 m to 3–6 km inland for a less sheltered bay or gulf.	Adelaide	Sheltered	Galvanised Z275 Class with Soft Seal (or equivalent) Coating or Stainless Steel 304 or equivalent
		From 50 m to 1 km inland around sheltered bays.	Port Philip Bay & in urban & industrial areas with low pollution levels	Exposed	Stainless Steel 304 or equivalent or 600+ gsm Hot Dipped Galvanising
C2	Arid/Urban Inland	Most areas of Australia at least 50 km from the coast.	Canberra, Ballarat, Toowoomba & Alice Springs	Enclosed	Primed Galvanised Z275 Class
		Inland 3–6 km for a less sheltered bay or gulf.	Adelaide & environs	Sheltered	Galvanised Z275 Class
		Can extend to within 1 km from quiet, sheltered seas.	Suburbs of Brisbane, Melbourne, Hobart	Exposed	Galvanised Z275 Class
C1	Dry indoors	Inside heated or air conditioned buildings with clean atmospheres.	Commercial buildings	Enclosed	Primed Galvanised Z275 Class

Note:

1. *The table is based on AS 4312 [7] and Technical Data Sheet #35, Corrosion Resistance of Metal Connectors [29].*
2. *The majority of light gauge metal connectors are manufactured from Z275 galvanised steel.*
3. *The recommendations in Table 18 are only applicable to timber that has not been treated with timber preservatives that can cause accelerated corrosion. Refer to additional advice that follows.*
4. *Toothed metal plate connectors (truss plates) should not be used in any exposed applications as cyclic wetting and drying (expansion/shrinkage) will cause the plates to disengage from the timber.*
5. *Soft Seal*

Treated timber

In the presence of moisture, copper-based timber preservatives such as CCA, ACQ and copper azole may cause accelerated corrosion of metal connectors, particularly galvanised coated connectors. The cause of this is the presence of dissimilar metals and again the presence of moisture, in the process called galvanic corrosion. The wet metals behave like a battery and produce an electrical current; the anode provides protection for the metal lower in the series, the cathode. Refer to the dissimilar metal chart, Table 19. The surfaces of one or both metals become pitted and corrode as the exchange of electrons takes place. Therefore, metals close together in the galvanic series don't corrode, but metals far apart do. In the preservative-treated situation, the copper within the chemical preservative is the cathode (protected end), and the steel is the anode, the corroded end. The same situation occurs with aluminium and stainless steel. However, the placement of zinc (galvanising) on steel does not cause this reaction.

Table 19: Galvanic series.

Corroded End
(Anode)
Magnesium
Zinc
Aluminium
Steel
Lead
Tin
Nickel
Brass
Bronze
Copper
Stainless steel (passive)
Protected End (Cathodic)

In these situations, galvanised metal connectors require additional coatings such as epoxy paint or epoxy coated (fusion coated) to isolate the zinc in galvanising from the copper in the timber treatment; alternatively, stainless steel should be used.

LOSP timber preservatives have a negligible effect on corrosion rates, and no special additional corrosion considerations are required for LOSP preservatives treated timber.

Connections should be designed to prevent the build-up of moisture that could lead to the decay of the timber, e.g. allow for drainage holes in shoes.

To prevent deterioration of timber around metal (particularly fasteners) where moisture is present, the following can be employed:

- Use non-corrosive or protected metals. (i.e. galvanised, coated, stainless steel or Monel metals).
- Countersink and plug or 'stop' fasteners.
- Avoid the use of dissimilar metals in contact with each other (copper as in CCA and ACQ, etc, with zinc).
- Grease, coat or sheath fasteners in contact with CCA treated timber, i.e. shrink wrap with prophylactics or coat with bituminous or epoxy paint.

7.2.3 Predicting service life of metal connector and fasteners

WoodSolutions Guide #5 [33] details a procedure to determine the service life of a metal connector, taking into account the environment, timber and protection of the connector used.

7.3 Fire resistance of connectors

For timber-framed buildings, the connection is often the weak point in fire resistance, as connectors are often made from metal that loses strength with increased heat. The design of the connection system is critical for a fire-safe building.

7.3.1 National Construction Code compliance

NCC Deemed-to-Satisfy fire resistance in the building regulations requires an assemble must meet Fire-Resistance Specification within the NCC. This NCC specification sets out the procedures for determining the Fire Resistance Levels of building elements and provides several methods to achieve this. There are three prescriptive pathways for connections in timber: a test to the standard fire test procedure, i.e. AS 1530.4 [5], or report or calculation based on the standard fire test or using the Australian Standard AS 1720.4 [4].

Standard fire test

A standard fire test is defined as meeting the Australian Standard AS 1530.4 [5]. This Standard contains test methods for various building elements such as walls, floors, roof, columns, beams, doorsets, glazing, and penetration. It does not directly have a test method for connections, but the principles within the Standard can be used with a report (called assessment) by an Accredited Testing Laboratory. AS 1530.4 [5] procedures can be followed, as the intent of AS 1530.4 [5] is to demonstrate that the structure is still supporting load after exposure to a standard fire for a nominated period.

Australian Standard AS 1720.4

This Standard is a primary reference document in the NCC. The Standard describes an alternative method to assign Fire Resistance Levels. Section 3 of the Standards provides two methods: embedding, where metal connectors are fully embedded within the timber element, or a fire-resistance protective insulation cover is placed over the connector.

However, AS 1720.4 [4] is for particular engineered wood and sawn timber, for example, plywood, LVL, glulam, round timber and stress graded sawn timber that meets an Australian manufacturing Standard. Engineered timber has an additional requirement that the adhesive used is to be a thermosetting adhesive, such as the phenol family of adhesives. Engineered timber products outside these limits cannot use this pathway of compliance and must then comply with the Standard Fire Test or use the Performance Solution pathway. However, the principles of fire protection can also be utilised for these engineered timbers.

Embedment method – metal connectors

This method relies on the timber cover as protection. The metal connector is covered with timber with a thickness equivalent or better than the effective depth of charring for the exposure period, as calculated in the Standard AS 1720.4 [4] (see Figure 100). Because the effective depth of char is dependent on the density of the covering timber, the depth of coverage varies for different timber species, and for that matter, the fire resistance period. Fire tests have shown that this is an effective method of protection.

WoodSolutions Design Guides #3 and #15 describe how to calculate the effective depth of char.

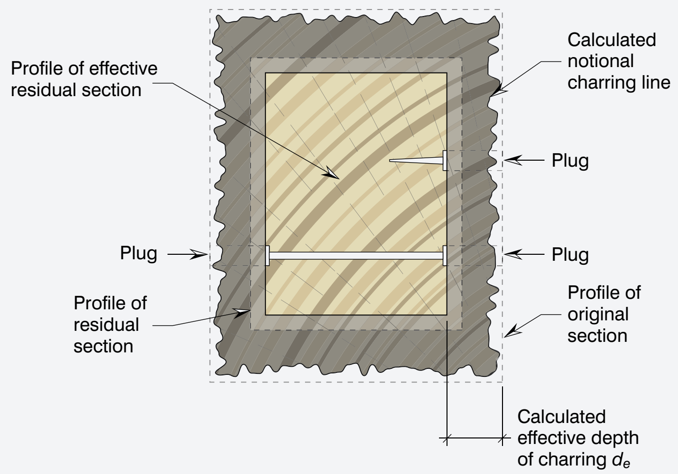


Figure 100: Fire resistance of a metal connector embedded in timber.

AS 1720.4 [4] also requires any holes resulting from bolts, dowels or screws to have these elements below the effective depth of char and plugged with timber. The plug requires to be glued in place; no limit on the adhesive is given.

Fire-resistant protective covering

Alternatively, the metal connectors can be covered with an insulating fire-resistance covering, such as a fire protective plasterboard. The Standard has a requirement that the temperature under the insulation does not exceed a certain temperature for metal plate connectors or dowel types of fasteners. Metal plates have a temperature rise limit of 120°C, while dowels have a 300°C temperature rise limit. This difference is because dowels are likely to be closer to the surface of the timber element and, because timber is a great insulator, the temperature along the dowel interface with the wood reduces as it is embedded further into the timber. The lower temperature dowel and timber still retain the capacity to carry the load.

The establishment of fire-resistant protective insulation covering is again to be provided by a standard fire test.

Combination of embedded and fire-resistant protective insulation covering

Often connections that utilise embedment may have a part of the connection where there is no cover. This gap may occur at the interface between the two elements, where a gap may occur because of tolerance issues or assisting in the installation of the connection.

Where this occurs, embedment may be the primary solution, but insulating coverings can be used where gaps occur (see Figure 101).

Figure 101: Protection of a metal connector from fire achieved by a combination of embedded within the timber and fire-resisting insulation. (Image credit: TDA)

8 References

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