CONNECTIONS IN TIMBER STRUCTURES

6.1 Introduction

The competitiveness of a timber structure, relative to other building materials, may be determined by the efficiency of the connections. In most cases the fastening of timber to timber requires little skill or knowledge of design. Consider the widespread use of nails in domestic situations where the handyman routinely uses nails and bolts to construct all manner of timber structures.

In heavy construction, joints may require ingenuity and the use of specialized connectors, such as nail-plates, bolts, shear-plates, split rings, coach screws or glued-in threaded rods. The application of these requires some knowledge of design and construction skills.

The shrinkage and swelling characteristics of timber in response to drying and wetting, the possibility of fungal decay in the presence of moisture and the need to protect metallic fasteners from fire or corrosion, call for special construction detailing.

6.2 Factors affecting the detailing of connections.

***Changes in moisture**.*

Changes in the moisture content of the timber will cause the timber to swell and shrink. The dimensional changes in the direction parallel to the grain can be ignored in most cases. The dimensional change in the perpendicular-to-grain direction can be large, especially if the moisture content variation is large. This must be borne in mind when a horizontal timber member is connected to a vertical timber or steel member. If the connectors prevent shrinkage, splitting of the timber may occur. This type of splitting often occurs when treated timber, which generally still has a high moisture content, is bolted to uprights. Figure 1 shows how the timber may split when movement is prevented. The splitting of the timber at the support may reflect negatively on the shear strength of the member.

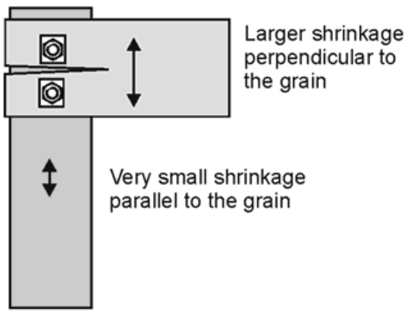

Figure 6.1: Splitting of timber as a result of differential shrinkage.

In the case of the connection in Figure 1, it would have been preferable to install only one larger connector.
Perpendicular-to-grain tensile strength

The drinking straw analogy for timber works well when one is designing connections. Remember that the adhesive sticking the straws together is weak. Any connection, which tends to cleave the wood, will of necessity be weak. Figure 2 illustrates the loads that can cause cleavage as a result of tensile loads perpendicular to the grain. If this type of connection cannot be avoided, it is always good policy to move the bolt down as far as possible.

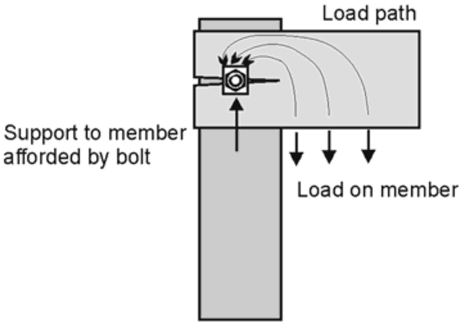

Figure 6.2: Loading of member in tension. Cracking may occur when end distance is insufficient.

Cleavage often occurs in trusses where one of the chords, i.e., top compression member or bottom tie, has to transfer the loads between the web members and the web members are some distance apart. Figure 3 shows such a cleaving action.

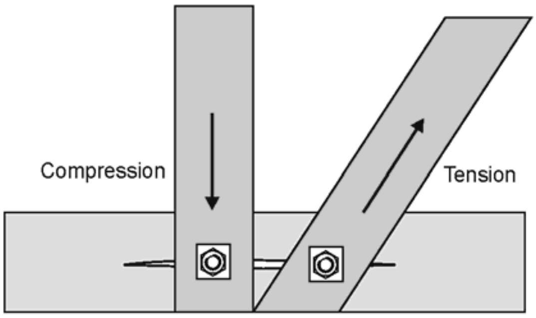

Figure 6.3: Cleaving of member as a result of tension perpendicular to the grain.

Shear strength

The horizontal shear strength of timber is low, typically one tenth of the bending strength. This can cause problems when there is an eccentricity between the loaded point and the support. This is aggravated when the loaded point has damaged the supporting member, by for instance, a bolt hole. The effective shear transfer area is greatly reduced at the bolt hole. Figure 4 shows an eccentrically loaded support for a truss. Note that the bolt hole is in an area of large shear as well as bending stress. The high stresses at these supports must be borne in mind, when designing the truss.

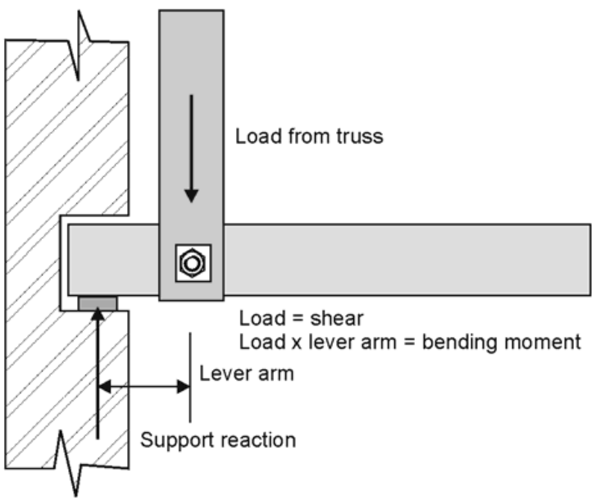

Figure 6.4: Shear force and bending in member as a result of an eccentric connection and support.

6.3 Selection of Fasteners.

Mechanical fasteners

A mechanical fastener is any device, metallic, plastic or timber, which transfers load from one piece of timber to another piece of timber. The most common types of fasteners are metallic and include:

- Nails
- Dowels
- Screws
- Bolts
- Coach-screws
- Toothed ring connectors
- Split rings
- Nail plates
- Proprietary or patented fasteners.

Most fasteners transfer forces through bearing on the timber and shear in the connector. Screws may under certain circumstances be used in withdrawal, although end grain withdrawal is not recommended.

Fastener strength

The strength of the various fasteners, together with end and edge distances is given in SABS 0163. SABS 0163 does not give strength values for proprietary or patented fasteners. Strength values for these must be obtained from the manufacturers' literature.

Structural efficiency

Structural efficiency can be described as the load that can be transferred divided by the area required by the connectors. It can be shown that nails or dowels into pre-drilled holes through steel plates, are the most efficient connectors. These are followed by bolts, toothed-ring connectors and split rings. Nails in pre-drilled holes are in the region of twice as efficient as any of the other connectors. In terms of cost efficiency, bolts may be cheaper than nails. The choice of connector will depend on the available space for the connection and the esthetics.

End-grain connectors, where the load transfer is through direct tension, are the most efficient connectors. The shorter the load path can be made, the more efficient the connector becomes. Glued-in threaded rods may be used to obtain very efficient connections.

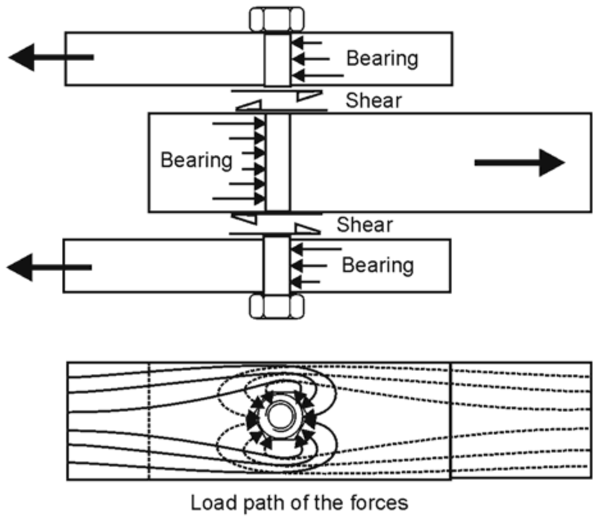

Figure 6.5: Bolted connection showing the convoluted load path for the transfer of the forces.

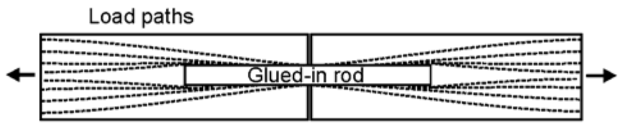

Figure 6.6: Shortened load path when glued-in rods are used.

6.4 Designing for durability

Irrespective of the fastener type, a joint should be designed and constructed for durability. The durability of timber structures is influenced by a number of factors.

Fungal decay

Decay or fungal attack is the result of the action of fungi, which break down the chemical structure of timber if suitable conditions prevail. A combination of the following circumstances creates such suitable conditions:

- The moisture content must be higher than 20%. It is unusual for this to happen except where timber is exposed to rain, timber is in direct contact with trapped water or placed directly in the ground. Fungal attack may also occur in the following: inadequately ventilated swimming pool structures, bathrooms, laundries, under-floor areas, saunas, cooling towers as well as bridge and pier structures close to the water.
- Oxygen must be present even in small quantities. Timber will not decay if permanently immersed in water.
- The temperature must be in the range of 5ºC to 40ºC. Above and below this temperature range, decay virtually ceases. The optimal temperature range for fungal growth is 25ºC to 35ºC.
- The timber on which the fungal lives must be either naturally or chemically unprotected.

End-grain is especially susceptible to the ingress of moisture and this is where decay usually begins.

Other Timber Hazards

Timber that is exposed to high levels of ultra-violet radiation, rain and extremes of temperature can suffer from splits, cracks and discolouration. It can also be subject to insect attack and marine borers. These factors do not affect the calculations of the design but must be borne in mind, when the connection is being detailed.

6.5 Joint Detailing Principles

To achieve good joint design and structural detailing, the following general principles should be observed:

- Avoid connections that can trap moisture. Ensure proper drainage and ventilation of especially the end-grain.
- Avoid exposing unprotected timber to the weather. If capping is used, ensure that all the moisture can escape and that the capping is properly ventilated. Capping that leaks and is not ventilated will hasten the onset of and promote fungal decay.
- Avoid placing especially the end-grain of timber in direct contact with concrete. Concrete is hygroscopic and will increase the moisture content on the interface between the concrete and the timber. If possible leave an air gap between the timber and the concrete. If the timber cannot be supported away from the concrete, insert a steel plate between the timber and the concrete. The steel plate will act as a moisture barrier.
- If moisture can enter at bolt holes, treat the timber in the hole with a preservative that does not leach out. If leaching is a problem, the bolts can be covered with a grease or a silicon sealant.
- Use chemically treated timber where moisture ingress could be a problem. Remember that CCA treatment stops fungal decay but not swelling and shrinkage due to moisture ingress. Always treat timber with an additional water-repellant.
- Corrosion resistant fasteners should be used in salt-water or seaside environment. Corrosion resistance in ascending order: steel, aluminium, stainless steel, copper and copper alloys.
- Where possible, transfer forces through direct bearing, thereby shortening the load path.

In coastal areas, large diameter bolts may be used, where a certain percentage of the area is sacrificial and the bolt maintains enough strength after corrosion has taken place. Bituminous or epoxy coating can improve the performance of bolts. Hot-dipped or electro-plated zinc coated bolts may be used in structures where a high chemical hazard exists.

6.6 Some Practical Joint Details

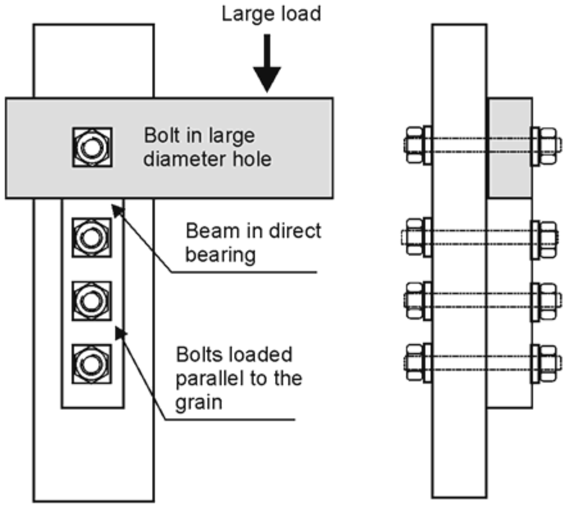

Figure 6.7: A method of avoiding splitting as a result of large tension perpendicular to the grain.

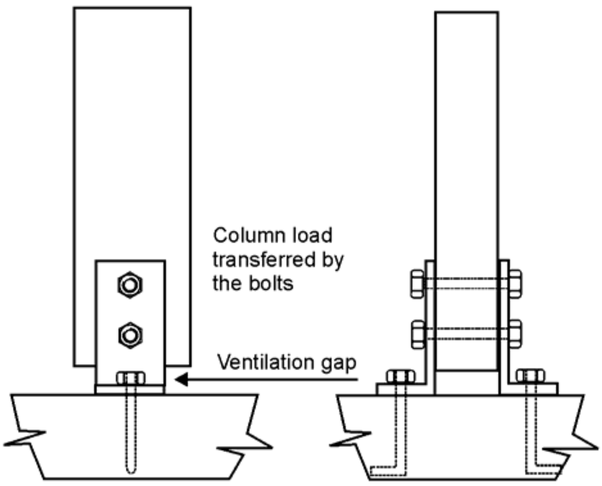

Figure 6.8: Air gap to prevent ingress of moisture into end-grain of column.

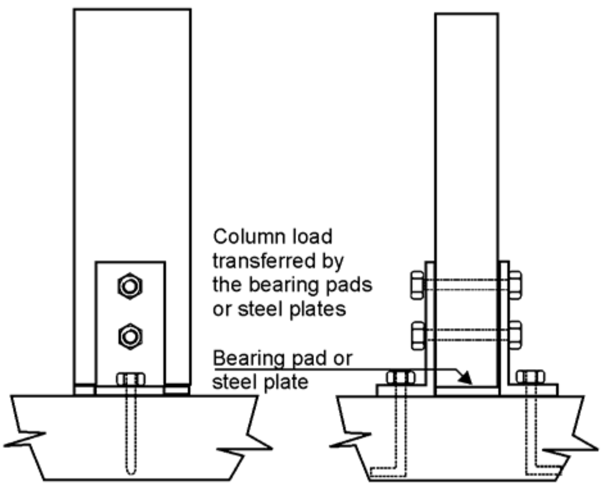

Figure 6.9: Transfer of loading through bearing pads.

6.7 Fire Resistance

Large cross-sectional timber members are fairly fire resistant, but exposed metal connectors are not as they lose strength fairly rapidly at elevated temperatures. They also conduct heat into the interior of the timber, where the timber then chars. SABS 0163 provides a basis for assessing the fire resistance of the timber section. It does not provide any guidance on the strength of metal connectors at elevated temperatures

Where a fire rating is required, the metal connectors may be protected by an intumescent paint or by embedding the connector in the timber. Non-conducting fibre bolts or dowels may be considered.

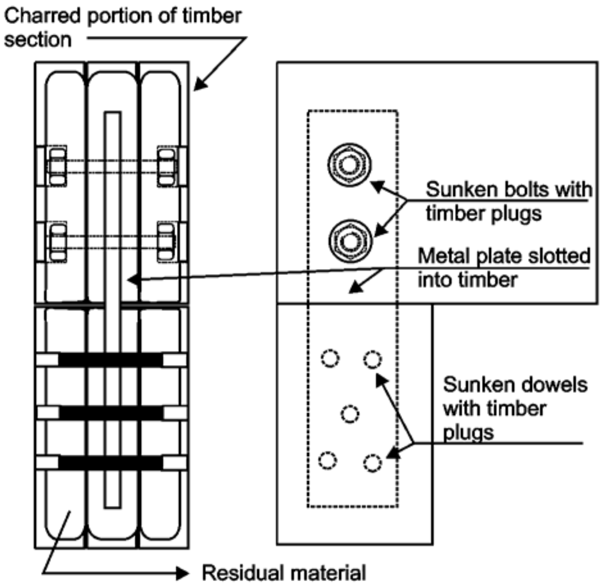

Figure 6.10: Protection of metal connection to achieve the required fire rating.

Design Check List

The following may be used as a checklist when considering the design of joints:

- ❑ Is the connection detail simple?
- ❑ Have I avoided shrinkage restraint of wet timber?
- ❑ Have I selected the connector type according to:
    - ❑ Structural requirement?
    - ❑ Cost efficiency?
    - ❑ Practical application?
- ❑ Is corrosion protection required?
- ❑ Are fastener spacing and end-distances maintained?
- ❑ Will service moisture content exceed 20% and if so has adequate provision been made for fungal protection?
- ❑ Have moisture traps been avoided and has adequate space been allowed for ventilation?
- ❑ Has the end-grain been protected against moisture ingress?
- ❑ Is it necessary to apply preservative treatment to the timber and/or the bolt holes of the connection?
- ❑ Must fire protection be applied to the connectors?

6.8 Design of Connections

Nails dowels and bolts

The failure mode of a connector determines the strength of the joint. By changing the failure mode of the metal connector, the size and strength of the connection can be vastly improved. Figure 11 illustrates the possible failure modes of dowel type connectors.

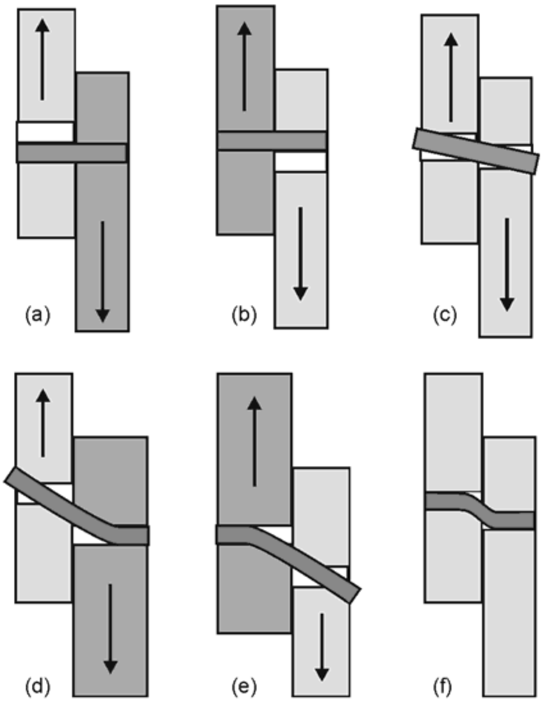

Figure 6.11: Possible failure mechanisms for nails, dowels and bolts.

The most likely failure mechanism for a nailed connection is failure (f) while for a large diameter bolt or dowel, (c). The strength values, for nails and bolts, given in SABS 0163 are based on the failure mechanisms (f) and (c) respectively. The failure mechanisms with the greatest strengths are (a) or (b). If one can force this type of failure by ensuring crushing of the timber, then the smallest, strongest connection will result. This type of failure mechanism can be induced if a stiff connector is used together with metal side plates, fastener in double shear. The possible failure mechanisms for fasteners in double shear are shown in figure 12.

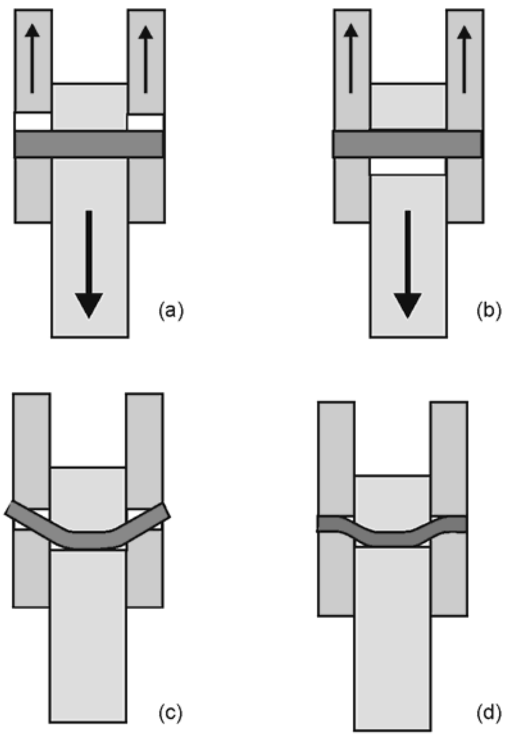

Figure 6.12: Failure on connections and connectors in double shear.

Failure type (b) would be the mechanism that is induced if the connector is very stiff, i.e., large diameter dowels.

Some propriety connectors use the metal to its full capacity. The strength of the connectors is based on test results and may be substantially higher than when the strength values in SABS 0163 are used.

For detail calculations of connection strength, the SALMA Timber manual should be consulted. A few typical connections will be given in this chapter, to illustrate good detailing practice.

6.9 Column Base Details

The following details illustrate how the timber is kept away from possible moisture ingress into the end-grain.

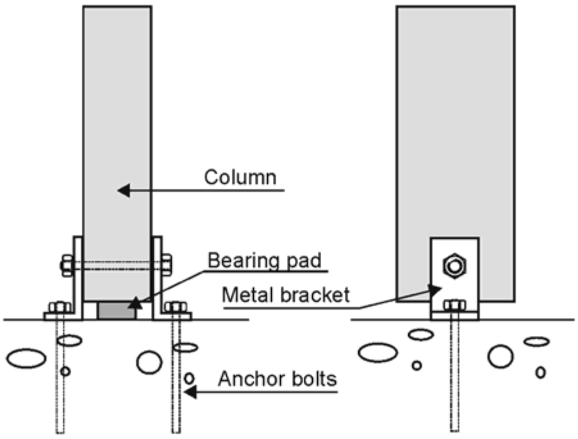

Figure 6.13: Column base with two angle brackets, force transfer through bearing on pad.

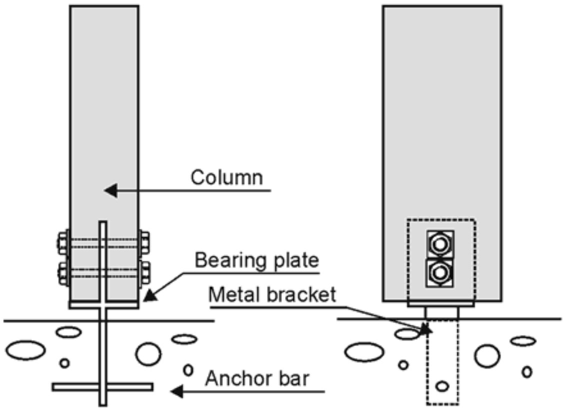

Figure 6.14: Column base with cruciform bracket slotted into the timber. Force transfer through direct bearing on metal plate.

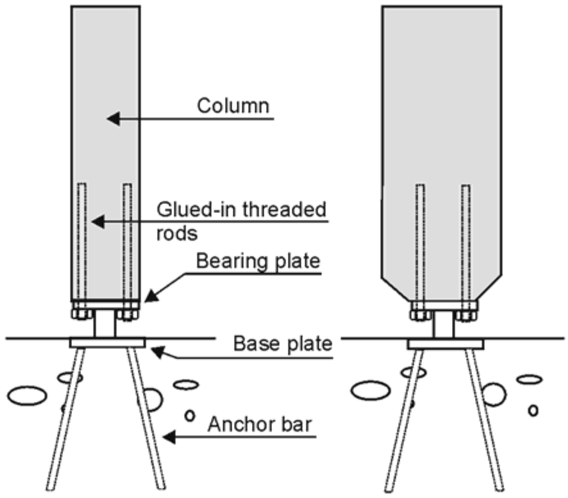

Figure 6.15: Column base with anchor bolts glued into timber column. Force transfer through direct bearing on metal plate.

6.10 Arch Bases

Arches can be either tied or the base can transfer the horizontal thrust into a concrete base that is designed to resist the horizontal forces. The following sketches show the two types of bases.

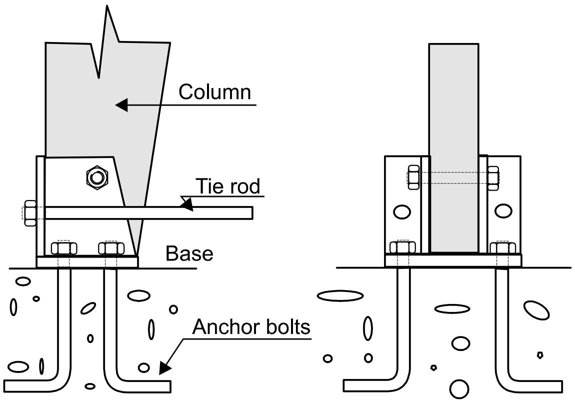

Figure 6.16: Arch or portal frame base plate with tie rod. Tie rod can be covered by an elevated timber floor.

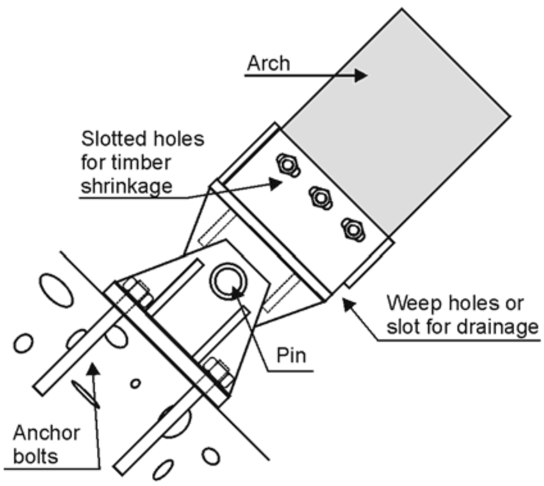

Figure 6.17: Pinned base for an arched structure.

Beam-to-column connections

Beam to column connections are generally not moment resisting. A few details are given in the following sketches.

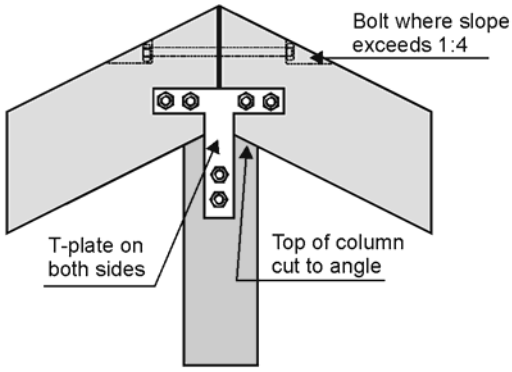

Figure 6.18: Beam to column detail where the beams are pitched.

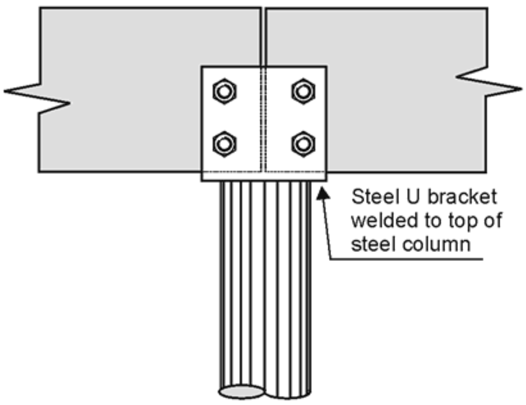

Figure 6.19: Beam to steel column detail.

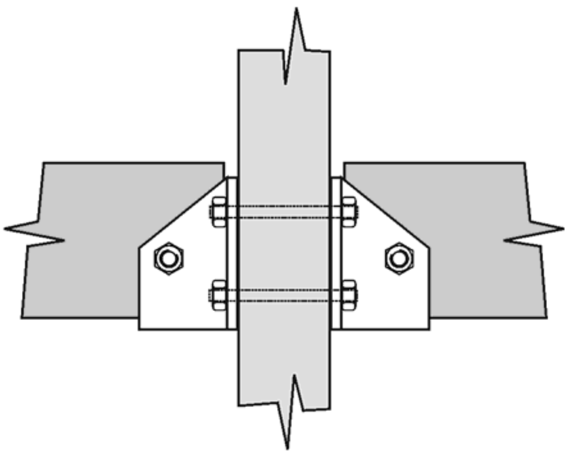

Figure 6.20: Beam to column connection where the column is continuous past the beam level.

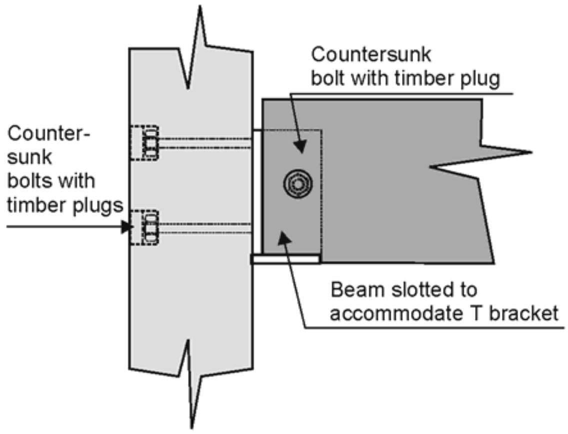

Figure 6.21: Beam to column connection, where the connectors have been recessed and are hidden.

6.12 Beam to wall or concrete connections.

The following details show how timber beams can be connected to brickwork and concrete walls and beams.

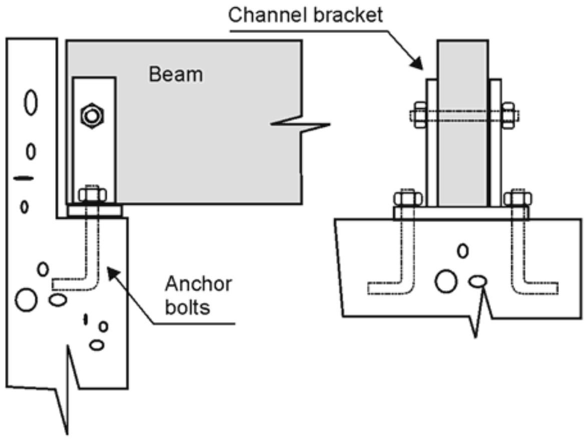

Figure 6.22: Beam to concrete connection. Channel bracket may be used to improve lateral torsional restraint at the support.

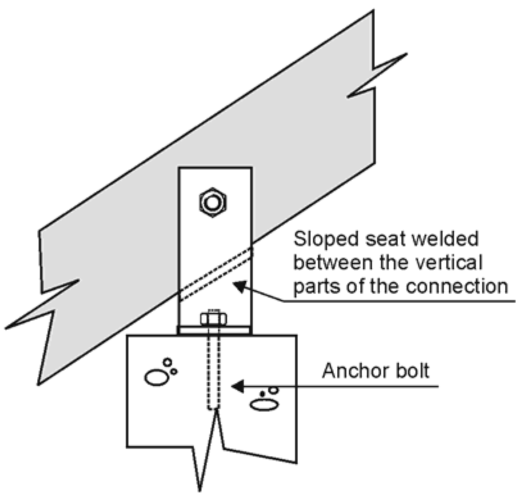

Figure 6.23: Connection for sloped beam.

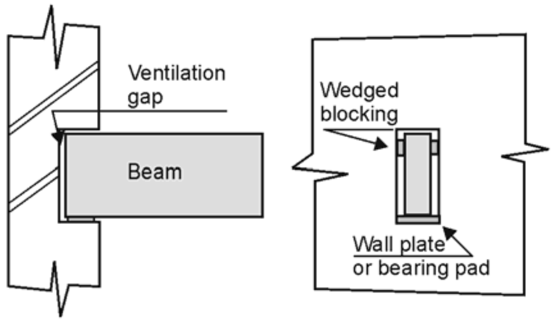

Figure 6.24: Beam built into brick wall with wedged blocking to improve torsional restraint.

6.13 Beam to beam connections

Beam to beam connections can be either exposed or hidden. It is important to avoid loading perpendicular to the grain if at all possible. The beam that is doing the loading should load the bracket in bearing if possible and the loaded beam should have the connectors as high as possible.

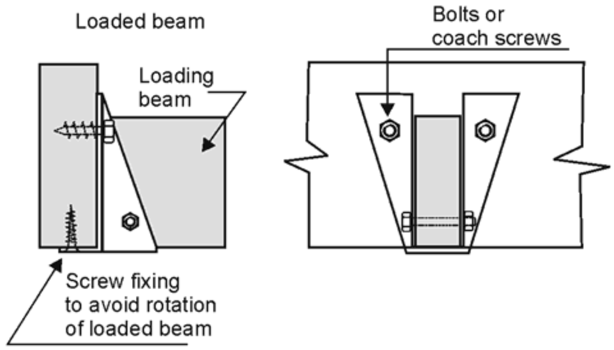

Figure 6.25: Force transfer in direct bearing and through coach screws or bolts. Note that rotation of loaded beam is prevented.

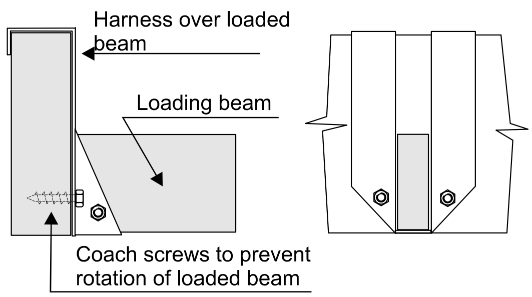

Figure 6.26: Harness over loaded beam, all loads transferred by direct bearing.

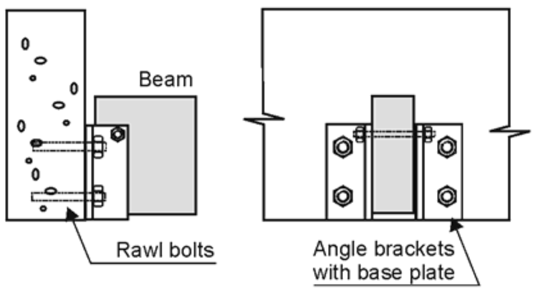

Figure 6.27: Timber beam to concrete beam or wall. It is preferable to transfer load in direct bearing.

6.14 Beam or column splices.

The following sketches may be used as guidelines for good splicing practice.

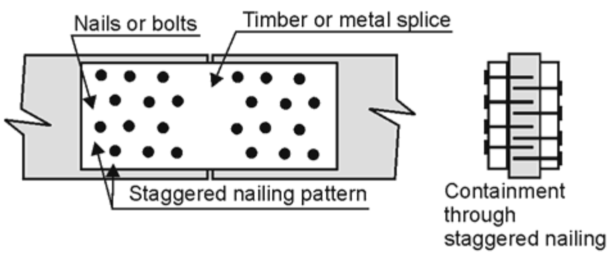

Figure 6.28: Splicing of member that must transfer bending moment and shear.

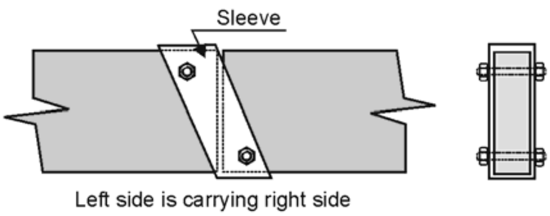

Figure 6.29: Splicing of beams when only shear force must be transferred between the right hand side and the left.

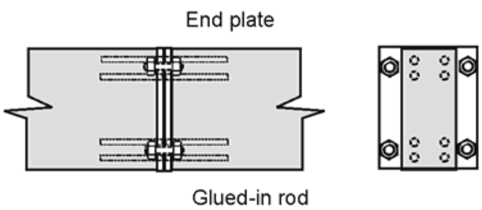

Figure 6.30: Splicing of members with glued-in threaded rods and end plates. Note that this method should not be used where large moisture content variation is expected.

6.15 Large-span truss connections.

The following are a few illustrations of large span truss connections that have been used very successfully in other countries.

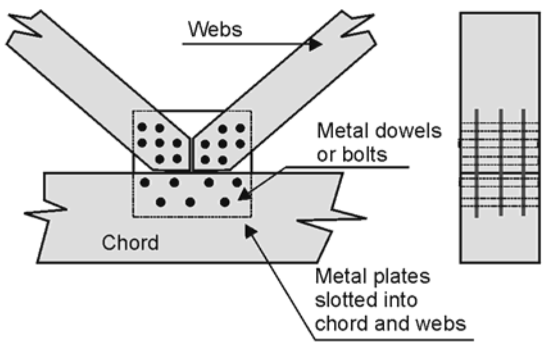

Figure 6.31: Metal plates slotted into the timber members. Connection completed by using metal dowels in tight fitting holes, or bolts.

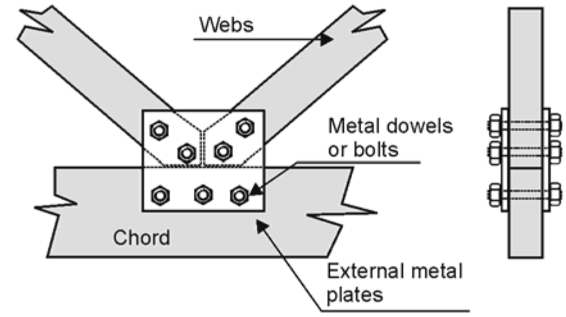

Figure 6.32: External plate connection for members with limited width.

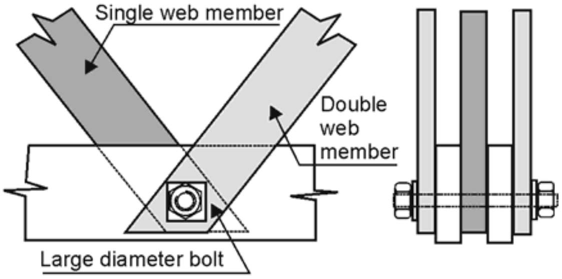

Figure 6.33: Spaced chords where, where the resultant forces lie in the same plane. Large diameter bolts or shear plates and split rings may be used.

6.16 Apex joints for portal frames.

Apex joints in portal frames may be pinned or may have to transfer limited moments. In all cases the apex joint must be able to transfer shear forces. The following sketches show a few possible details.

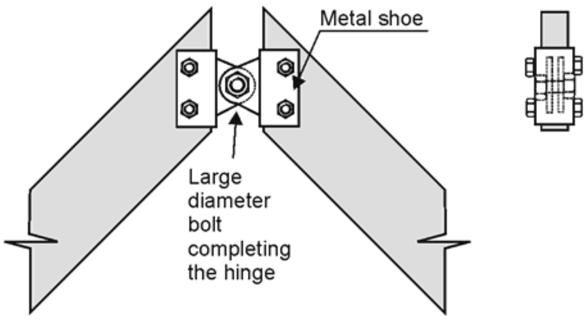

Figure 6.34: Hinged apex connection for a portal frame.

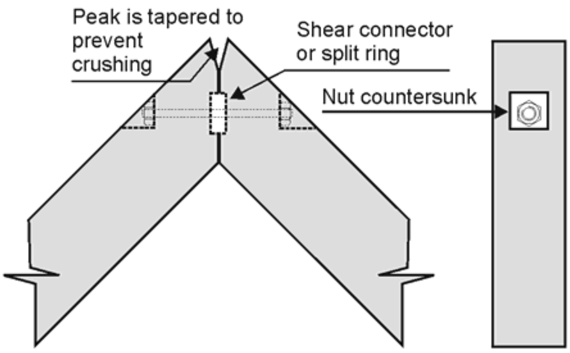

Figure 6.35: Pinned connection, using a shear plate or split ring to transfer the shear.

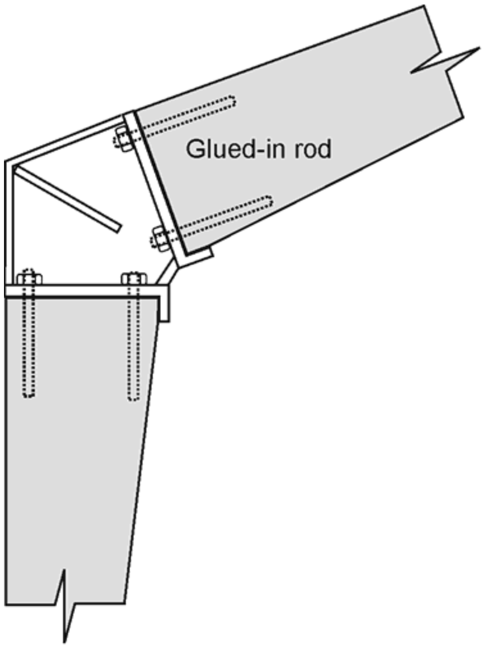

Figure 6.36: Moment connection at apex effected by nailing oval nails (glulam rivets) through round holes. The distortion of the nails ensures that the nails cannot be easily extracted.

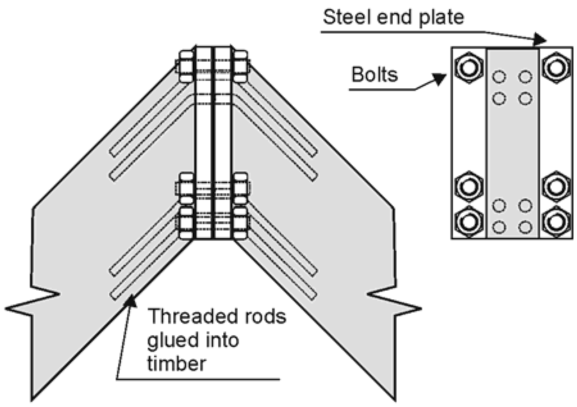

Figure 6.37: Moment connection using threaded rods and steel end plates. Rods can be threaded into the steel plates and then bent, or simply welded onto the end plates. Connection can be assembled on site.

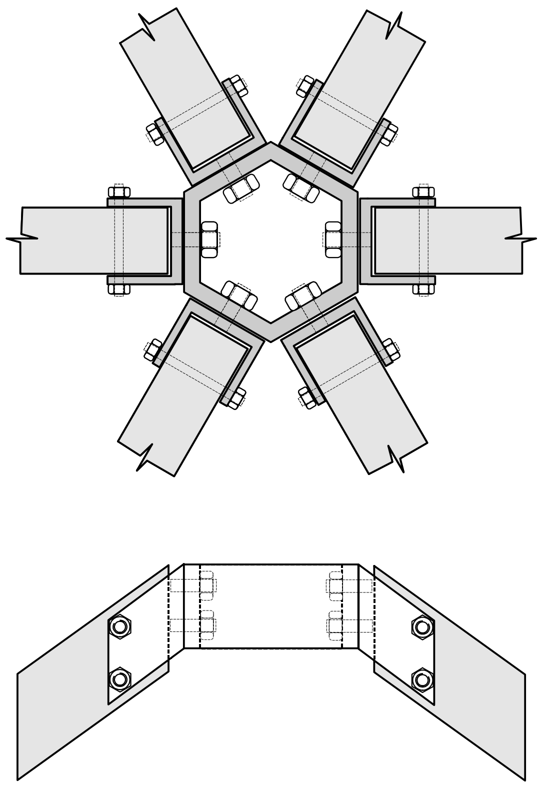

Figure 6.38: Compression ring for apex of dome type structure. Note that a certain amount of moment transfer is possible.

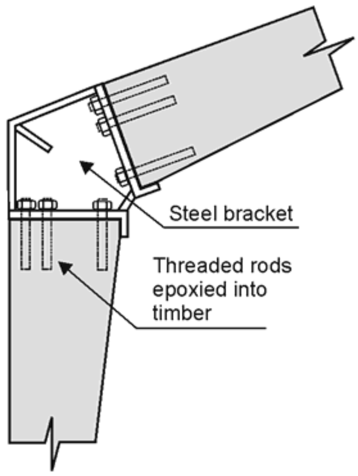

Figure 6.39: Eaves joint for portal frame. Steel bracket makes it possible to assemble the joint on site. Threaded rods must be glued under factory conditions.

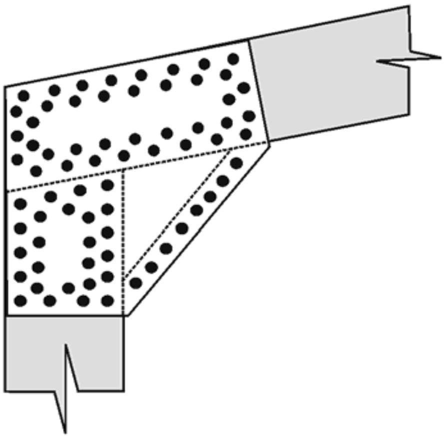

Figure 6.40: Eaves joint using plywood on either side and nailing.

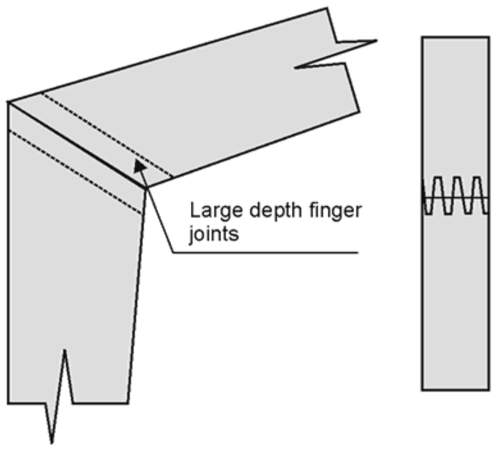

Figure 6.41: Eaves joint manufactured by using large finger joints.