

# Glued Laminated Timber (Glulam)

## Description

Glulam is an engineered structural material consisting of a number of graded, seasoned and mostly finger jointed laminations, bonded with a proven structural adhesive to form a solid member of cross-section, length and shape limited only by manufacturing, transport and handling capabilities.

Lamination has the benefit of using smaller pieces of timber which, when glued together may produce a member of higher grade than the individual pieces.

It is possible to manufacture a glulam beam with higher strength laminates in areas of high stress such as in the top or bottom of beams, and lower strength laminates in the areas of low stress.

Steel and fibre reinforcement can also be incorporated in areas of high tensile stress and may be positioned either parallel or perpendicular to the laminate direction.



## Design Ideas and Structural Form

Glulam can be used in almost any type of building from simple dwellings to major public buildings and even bridges.

Its strength, stability, chemical and fire resistance, and its almost limitless range of sizes and shapes makes glulam one of the most versatile building products available today.

The following photo library illustrates but a small sample of innovative uses of glulam and some of the wide range of structural forms that are possible.

- Residential
- Commercial
- Industrial
- Public Buildings
- Bridges

## Residential

[Structural/Lintels/Bearers]



[Feature Beams]

[Curved Beams]

## Commercial



[Shopping Centre]



[Office]



[Restaurant]



## Industrial



[Portal]







[Curved] [Flat Roof]

## Public Buildings





## Bridges



[Small straight beams]







[Large curved beams]

## International



[Tecoma Dome]



[Izumo Dome]



## Shapes and Sizes

Glulam can be custom built to almost any size, shape and length, including curved, tapered or profiled cross-section..

Members of the Glue Laminated Timber Association of Australia have adopted a range of standard section sizes that are applicable to each GL Grade as follows:-

Uniform GL Section Sizes

GL Grades	GL 18	GL 17	GL 13	GL 12	GL 10 & 8
Nominal beam widths in mm	40	38		40	38
	65	65		65	60
	85	85	80	85	80
	115	115		115	110
	135	135	130	135	
Nominal beam depths in mm	90				
	120	130		130	
	155	165	152	165	
	185	195	190	195	
	215				
	240	230	229	230	
	250	260	267	260	
	270				
	280				
	300	295	305	295	
	315				
	330	330	343	330	
	350	360		360	
	380	395	381	395	
	410				
	445	425	419	425	
	475	460	457	460	
	505	495	495	495	
	535	525	533	525	
	570	560	572	560	
600	590		590		
630	625	610	625		
660	655	648	655		
		686			

Most “straight” beams will be cambered i.e. pre-curved to allow for deflection due to deadload. ‘Off-the-shelf’ beams are usually manufactured with a camber equivalent to a 600 m radius. Straight beams, without camber can be manufactured to order.

## **Curved Glulam**

Curved glulam beams can be manufactured, within practical limits, to almost any shape including simple curves, multiple curves and parabolic curves.

The cost effectiveness of designing with curved glulam depends on three key manufacturing criteria.

- How many curved beams of the same shape are required? As the only way to manufacture curved forms involves setting up a jig to press the timber into, the material cost and time involved in setting up the jig must be amortised over the total number of beams able to be manufactured in that shape. Therefore, the more beams of the same shape (not necessarily the same length) the unit cost per member will reduce.
- Because there are limitations on the size of the laminae in bending to various radii, the radius chosen will influence the cost. If the curve required is a gradual one that can be manufactured using standard laminae sizes, the cost for the curved beam will be not significantly more than that for a straight beam. Very tight radii, (i.e. under 9.5 m) will require thinner laminae and this increases the price accordingly.

Also variations to a simple curve to a standard radii such as multiple curves, parabolic curves, etc will require additional workshop drawings and engineering. Additional cost may be insignificant if the charges can be amortised over more than one beam.

- If the length or span of the curved beam, combined with the radius, mean the rise in the centre of the beam is too great for the press capacity, then alternative manufacturing methods have to be used. This may involve a structural splice joint.

Curved roof beams can provide elegant yet functional structural solutions. To ensure the most economic solution, consultation with the beam manufacturer at the design stage will maximise cost efficiencies that can be achieved during the manufacturing process.



## Grades

Glulam is manufactured in accordance with *AS 1328.1 Glued laminated structural timber – Performance requirements and minimum production requirements* and standard grades are set out in *AS/NZ 1720 Timber Structures Code*.

The glulam grades have been developed with a suite of structural properties which are different from the 'F' ratings used on solid timber and the use of 'F' ratings to grade glulam is therefore inappropriate. Young's Modulus of Elasticity (E) is the structural property which generally governs the design of a glulam beam and for this reason, the Glued Laminated Timber Association of Australia adopted a descriptor based on the E value of the grade i.e. GL18 means it has an E value of 18500 Mpa.

Table 1 below is that adopted in AS/NZ 1720.1.

**Table 1 – Characteristic Strengths and Elastic Moduli for Horizontally Laminated Glulam Grades.**

Stress Grade	Characteristic Strengths (Mpa)				Elastic Moduli (Mpa)	
	Bending (f <sub>b</sub> )	Tension parallel to grain (f <sub>t</sub> )	Shear in beam (f <sub>s</sub> )	Compression parallel to grain (f <sub>c</sub> )	Short duration average modulus of elasticity parallel to grain (E)	Short duration average modulus of rigidity for beams (G)
GL 18	50	25	5.0	50	18500	1230
GL 17	42	21	3.7	35	16700	1110
GL 13	33	16	3.7	33	13300	900
GL 12	25	12	3.7	29	11500	770
GL 10	22	11	3.7	26	10000	670
GL 8	19	10	3.7	24	8000	530

## Surface finish (Appearance Grades)

Glulam can be manufactured to achieve three different appearance grades – A, B and C. Not all manufacturers supply the 3 grades.

### Appearance Grade A (Select)

This grade is intended for applications where a clear finish is to be used and the aesthetic values of timber are highlighted. All voids are filled and the surface is sanded.

### Appearance Grade B (Standard)

This grade is suitable for painting. The surface is machined on all four sides but minor voids etc. are not filled. Larger natural feature voids are filled suitable for painting.

### Appearance Grade C (Structural)

This grade is intended for use in applications where appearance is unimportant and all appearance blemishes are permitted.

## **Service Conditions**

The following defines the environmental conditions in which different glulam service classes can be used.

### **Service Class 1**

Service class characterised by a moisture content in the materials corresponding to a temperature of 20°C and relative humidity of the surrounding air only exceeding 65% for a few weeks per year.

*Note: In Service Class 1 the average equilibrium moisture content in most glulam will not exceed 12%.*

### **Service Class 2**

Service class characterised by a moisture content in the materials corresponding to a temperature of 20°C and relative humidity of the surrounding air only exceeding 85% for a few weeks per year.

*Note: In Service Class 2 the average equilibrium moisture content in most softwoods will not exceed 20%.*

### **Service Class 3**

Service class characterised by climatic conditions leading to higher moisture contents than Service Class 2, or where timber is directly exposed to sun and/or rain.



## **Performance**

### **Quality Control**

AS 1328.1:1998 specifies performance requirements for glulam members and quality control requirements for manufacturers.

The Glued Laminated Timber Association of Australia (GLTAA) which represents most glulam manufacturers in Australia conducts an independently audited Quality Assurance program for its members. This program includes regular independent testing of product. Products of participating GLTAA manufacturers are identified with the GLTAA logo.

### **Weather Exposure**

Providing the correct species/adhesive combinations are specified, and suitable protective design and maintenance measures are implemented, glulam members will have an adequate service life in Service Class 3 (exterior exposed) applications.

### **Species**

The species of hardwood timber used in laminated beams destined for Service Class 3 application should be Durability Class 1 or 2. AS 1720.1 lists the durability rating of most commercial timber species used in Australia.

Most softwood species can be treated with non-leechable preservative salts, which will impart decay resistance. The level of preservative treatment specified for softwood laminated beams used in Service Class 3 applications should be H3. Similarly LOSP envelope treatment can be used satisfactorily. Check with manufacturer for recommended use.

### **Adhesive Type**

Adhesives used to bond laminates together for Service Class 3 applications should be of the Polyphenolic/Resorcinol type.

### **Protective Measures**

A number of issues must be addressed to limit the adverse effects of ultra violet light and moisture on timber laminated beams. These are:

- (a) Design and Construction Best Practice
- (b) Protective Coatings
- (c) Maintenance

## **Fire Resistance**

Large glulam members have high and predictable fire resistance on account of the slow and predictable charring rate when exposed to a severe fire. Unlike steel and reinforced concrete, glulam will not twist or spall in fire.

When members are required to have a fire resistance rating, that can be calculated by subtracting a charred thickness from the original member size. Higher stresses can be used in combination with the reduced cross section. The fire resistance requirements can be calculated using the procedure given in AS 1720.4. Depending on the fire performance requirement, metal connectors may need special fire protection.

## **Chemical Resistance**

Timber is often used where chemical deterioration makes the use of other structural materials unsuitable. Since wood substance is relatively inert chemically, under normal conditions it is not subject to chemical change or deterioration. It is resistant to most acids, rust and other corrosive agents. Typical uses in corrosive situations include hide curing complexes, fellmongerys, fertiliser storage and swimming pools.

However, when exposed to strong oxidising agents, sulphides and alkalis, 'pulping' action (timber becomes very fibrous) may occur and therefore under these conditions specialist advice should be sought regarding the choice of timber species and adhesive.

## **Construction Practices**

While glulam has the same practical workability characteristics as solid timber, construction practices need to be modified to suit the specific characteristics of glulam. Reference should be made to the respective glulam manufacturers for specific recommendations regarding their products.

The following construction practice issues apply to all glulam.

- Handling, Storage and Protection
- Cutting Holes and Notches
- Joints and Connectors
- Weather Exposure

### **Handling, Storage and Protection**

Glulam may be supplied to site in one of the following ways:-

1. Without timber sealant or plastic wrapping
2. Without timber sealant but with plastic wrapping
3. With timber sealant but without plastic wrapping

### **Handling**

Glulam should not be dropped, jarred or dragged. Care must be taken to prevent damage to the finished surfaces in handling, as such treatment may cause damage to the surfaces and edges and possibly structural damage.

Lifting or securing glulam should employ the use of webbing slings only. Chains and wire slings should not be used. Glulam should be lifted on edge wherever possible and spreader bars of suitable length used on long members to eliminate the possibility of overstressing the member. Special lifting arrangements may be necessary for curved and tapered beams.

### **Protection (On-site Storage)**

Members should be supported with blocking so spaced as to supply uniform and adequate support. If covered storage is not available, the members should be blocked well off the ground at a well-drained location. Other glulam, such as reinforced glulam, curved glulam, fabricated items and other 'special application' glulam must be handled and stored in accordance with the manufacturer's specific requirements for that product.

Glulam should be maintained in a dry condition on-site and protected from direct exposure to the weather. If covered storage is not available, the members should be covered with suitable non-transparent plastic or tarpaulins. The cover should be placed to preclude moisture whilst maintaining good air circulation in and around the members. Glulam members that are supplied individually wrapped should be placed on the dunnage with the wrapping material edge or seal face down.



### **Protection (Fixed in Position)**

Glulam when installed should be protected from direct exposure to the weather (especially sunlight and moisture). Methods of protection may be a timber sealant coating or impervious covering/wrapping.

- (a) Protective timber sealant coating shall inhibit moisture ingress during normal domestic construction periods (around 6 weeks). Should this period be extended or signs that the sealant is no longer performing, renewal of the protective sealant may be necessary. Should the glulam be cut, checked, bolted or otherwise worked on, renewal of the protective sealer to the exposed or unsealed timber is required.
- (b) The impervious wrapper should be placed with the edge on the underside if possible and be slit on the underside to allow moisture to escape.

Where supports or intersecting members damage the protection, moisture ingress shall be prevented.

### **Cutting Holes and Notches**

#### **Holes for Services**

Where horizontal holes need to be drilled for services, the following guidelines apply:

- (i) Holes shall not be greater than 25 mm. If a hole greater than 25 mm is required, obtain the advice of a structural engineer or contact the beam manufacturer.
- (ii) Holes should be restricted to the middle third of the span only.
- (iii) Holes should only be cut within the middle third of the depth.
- (iv) If holes need to be drilled near the supports, obtain the advice of a structural engineer or contact the beam manufacturer.

#### **Vertical holes**

If vertical holes are necessary to provide electrical or plumbing services within the span, its suitability will depend on the size and location of the hole. Seek advice from a structural engineer or the beam manufacturer.

#### **Notches**

Notches seriously reduce the strength of a beam, particularly if located in the tension zone. Unless allowance has been made in the design, no notches should be made. Shear reinforcement may be necessary if notching is required.

Notches on the upper side at the bearing area may be made to a maximum of 40% of D (where D is the depth of a member).

## **Joints and Connectors**

The joining of glulam members usually involves steel connectors. For smaller members, proprietary light metal connectors are most commonly used but must be selected taking into account the imposed loads. Appropriate data is available from connector manufacturers such as Pryda, MiTek and Simpson Strong-Tie.

For heavy glulam construction, specifically designed and fabricated metal connectors are generally necessary and must be installed strictly in accordance with the design information e.g. number and size of nails, screws, bolts, edge distances, tolerances etc.

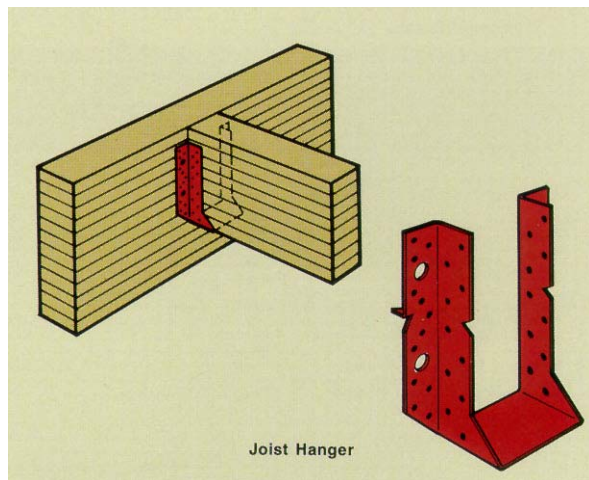
Structural plywood gussets may also be used to join glulam, such as in knee, butt and apex joints in portal frame construction. Gussets are normally nail fixed with many nails in a predetermined pattern. Only the specified nails should be used.





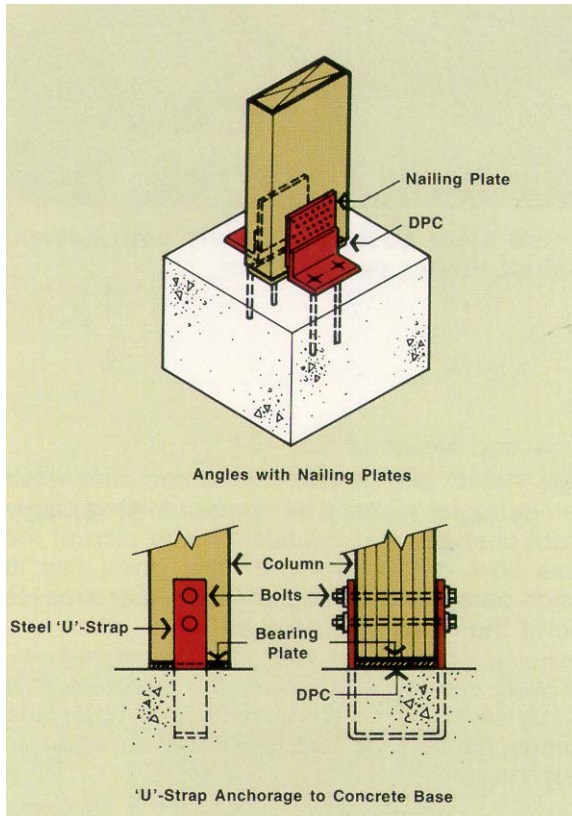
Typical joints and connectors include the following:-

- Face Mount Hangers

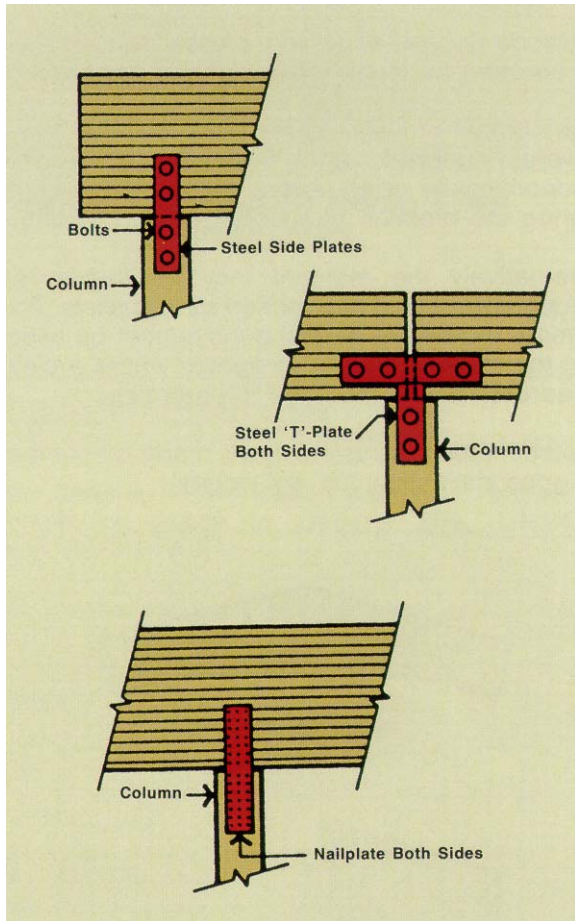


- Column Base Connections

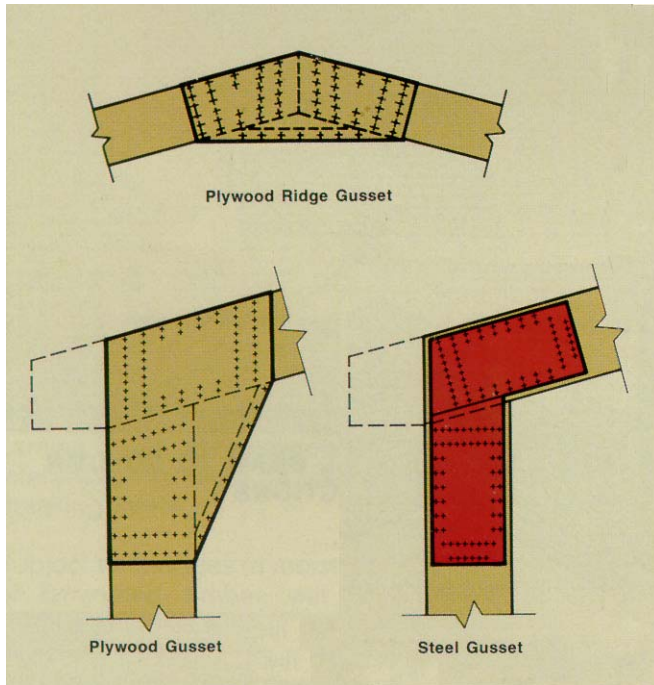




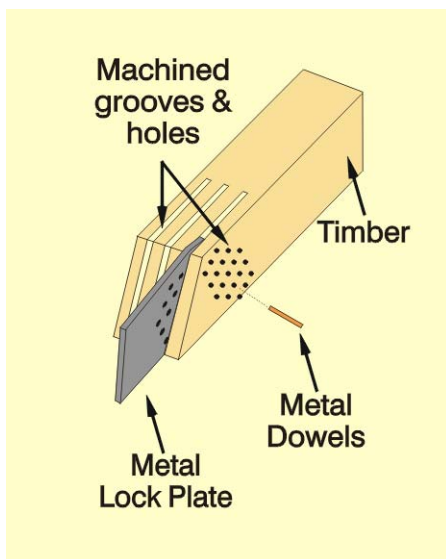
- Beam to Column Connections



- Plywood Gusset Connections
  - Nails must be of the specified type and size.
  - Plywood thickness and grade as specified.
  - Nailing pattern as detailed.



- Concealed Connections



## **Weather Exposure**

Glulam can be used in weather exposed conditions but it is essential that the product is suitable for Service Class 3 applications. This will ensure that the timber used is of the right durability, whether natural or preservative treated, and the adhesive is a Polyphenolic/Resorcinol type.

In addition to using a product suitable for Service Class 3, the glulam should be protected from UV light and moisture ingress.

A number of protective measures should be taken at both the design and construction stages to ensure good long-term performance.

## **Design and Construction Best Practice**

The design of structures incorporating timber laminated members, which will be fully exposed to the elements, should include measures to mitigate exposure to direct sunlight and moisture ponding and promote rapid shedding of moisture.

The following detailing and design practices are desirable with regard to enhancing the structure's service life:

- (i) Joint detailing should comply with the following:
  - ensure moisture entering the joint is not trapped but can run away freely
  - keep horizontal contact areas to a minimum, favouring self-draining vertical surfaces
  - use non-corroding fasteners which do not cause splitting during installation
  - minimise use of morticed joints.
- (ii) Beams should be provided with adequate ventilation.
- (iii) Damp proof membranes should be used where timber members are in contact with masonry.
- (iv) Metal or plastic shields on the top and ends of laminated timber beams can exclude moisture and sunlight.
- (v) Arrised edges on timber members help prevent the failure of coating systems.
- (vi) Building overhangs will provide protection from moisture and direct sunlight.

## **Protective Coatings**

Protective finishes will prolong the service life of structures incorporating laminated timber members by excluding UV light and moisture ingress and imparting dimensional stability to the timber members.



The following products are available:-

- (i) Oil based surface applied preservatives, in brushing and paste forms, impart fungal resistance and dimensional stability in the short term. They should be used to provide protection to laminated members from the elements during construction. Their compatibility with finishes intended for the long-term protection of the members should be confirmed prior to use.
- (ii) Oil based stains are non-film forming and penetrate the timber to provide weathering resistance while leaving the grain semi-exposed. This protective coating should be renewed annually if adequate on-going protection is to be achieved.
- (iii) Oil based paint systems will provide the best long-term protection of laminated members in Service Class 3 conditions. Paint manufacturers' instructions should be followed, but will usually consist of the following:
  - 1 coat of oil based primer
  - 1 coat of oil based under coat
  - 2 coats of oil based exterior house paint.
- (iv) Acrylic paint systems are popular. When combined with oil based primers and recoated every five years they will provide satisfactory protection.
- (v) Clear finishes are not recommended for timber used in exposed applications as they generally do not provide protection against UV light and require very regular recoating to maintain protection against moisture ingress.

In selecting a finish for laminated timber members in Service Class 3 conditions, consideration must be given to the need to effectively and permanently remove the effects of UV light and moisture ingress to the member. Special attention should be given to sealing exposed end grain at the end of members and joints.

### **Maintenance**

Timber laminated members in exposed applications will give excellent service life if the protective design and coating measures are maintained to limit the effect of weathering. A maintenance schedule should be documented and implemented for all structures. Coatings should be renewed in accordance with manufacturers' instructions and joint and capping details kept in good repair.

## Engineering Design

The engineering design of Glulam timber can have two differing approaches:

- Straight (off-the-shelf) glulam products can be designed using many of the same philosophies used in designing sawn timber.
- Elements with complex shapes must be designed as special units, and there will need to be dialog with the manufacturer in order to detail an appropriate shape and specify appropriate materials.

### Design of straight glulam members

AS1720.1 section 7 is the primary reference for the structural design of glulam elements.

#### *Glulam bending members*

The most common glulam element is the bending member.

The normal strength limit state capacity equation is given in Clause 3.2.1.1 of AS1720.1,  $(\phi M) = \phi k_1 k_4 k_6 k_9 k_{11} k_{12} [f'_b Z]$

- Capacity factor ( $\phi$ ) can be found in Table 2.5, and has high values relative to sawn timber, because of the high levels of quality control required in the manufacture of structural glulam to AS/NZS1328.
- Duration of load ( $k_1$ ), Partial seasoning ( $k_4$ ) and temperature factors ( $k_6$ ) are defined in Section 2 of AS1720.1 and are found in exactly the same way for glulam as for sawn timber.
- For Glulam timber, the strength sharing factor ( $k_9$ ) is 1.0. This is appropriate as there is already a high level of strength sharing between the laminates in the glulam beam.
- For glulam beams, the size factor for bending ( $k_{11}$ ) is also 1.0. Because the production of Glulam materials is a manufacturing process, it is possible for each manufacture to have controls in place to ensure that the design properties can be achieved regardless of the size.
- The stability factor ( $k_{12}$ ) is found using the normal slenderness calculations given in AS1720.1 Clause 3.2. The material constant ( $\rho_b$ ) for the normal Glulam grades (GL grades) is given in Table 7.2(A).
- The bending strength of the glulam material is a function of the grade awarded to the glulam. The normal glulam grades are given in Table 7.1 with the design strengths and design MoE.
- Minimum design dimensions (after allowing for tolerances) should be used to find the section modulus ( $Z$ ).

The strength limit state shear capacity equation is given in Clause 3.2.5 of AS1720.1,  $(\phi V) = \phi k_1 k_4 k_6 k_{11} [f'_s A_s]$

- Capacity factor ( $\phi$ ), duration of load factor ( $k_1$ ), partial seasoning factor ( $k_4$ ) and temperature factors ( $k_6$ ) are all found in the normal way using Section 2 of AS1720.1
- For glulam beams, the size factor for shear ( $k_{11}$ ) is 1.0. This is common with the size factor for shear in most other timber materials.
- The shear strength of the glulam material is a function of the grade awarded to the glulam. The normal glulam grades are given in Table 7.1 with the design strengths and design MoE.
- Minimum design dimensions (after allowing for tolerances) should be used to find the shear area ( $A_s$ ). For timber, the shear area is 2/3 the cross sectional area (Clause 3.2.5 of AS1720.1).

The strength limit state bearing capacity of timber is only a function of the species of the timber, the grade or manufacture of the material is not important. The strength limit state bearing capacity equation is given in Clause 3.2.6 of AS1720.1,  $(\phi N_p) = \phi k_1 k_4 k_6 k_7 [f'_p A_{p_s}]$  - applicable for bearing of beams.

- Capacity factor ( $\phi$ ), duration of load factor ( $k_1$ ), partial seasoning factor ( $k_4$ ) and temperature factors ( $k_6$ ) are all found in the normal way using Section 2 of AS1720.1 (The capacity factor for all timber materials is the same – it is independent of grade or method of production.)
- ( $k_7$ ) is a new factor for the length and position of bearing. It is defined in Clause 2.4.4 of AS1720.1 and is used in the same way for all timber materials.
- The bearing strength of the glulam material (and all other timber elements) is only a function of the species of the bearing layers. Table 2.1 or Table 2.2 in AS1720.1 is used to define a strength group to the species, and the bearing strength of the timber is given in Table 2.3(A) in AS1720.1.
- Minimum design dimensions (after allowing for tolerances) should be used to find the bearing area ( $A_p$ ).

Deflections of glulam members can be calculated using the same techniques as other timber structural beams. Some glulam members are built with a camber (A small upwards deflection).

*Camber:*

- Camber should always be installed upwards – cambered beams cannot be installed either way up, usually the top is marked with “TOP”.
- Camber is intended so that when the self-weight and other permanent structural loads are applied, the beam deflects so that it is flat.
- Camber affects the final position of a beam under load – so it can be quite useful in stopping beams resting on partitions or elements underneath them.
- Camber does not affect the displacement under imposed actions (live loads) alone. It is the relative deflection of the loaded beam compared with the member when unloaded that is important here, and camber does not affect that at all.
- Vibrations under repetitive loads are not influenced at all by camber.

*Glulam compression members*

Glulam compression members can be used in trusses, as large cross section columns or in reticulated arches or domes.

The normal strength limit state capacity equation is given in Clause 3.3.1.1 of AS1720.1,  $(\phi N_c) = \phi k_1 k_4 k_6 k_{11} k_{12} [f'_c A_c]$

- Capacity factor ( $\phi$ ) can be found in Table 2.5, and has high values relative to sawn timber, because of the high levels of quality control required in the manufacture of structural glulam to AS/NZS1328.
- Duration of load ( $k_1$ ), Partial seasoning ( $k_4$ ) and temperature factors ( $k_6$ ) are defined in Section 2 of AS1720.1 and are found in exactly the same way for glulam as for sawn timber.
- For glulam compression members, the size factor for bending ( $k_{11}$ ) is 1.0 (in this case, this is the same as the value for F-graded products).
- The stability factor ( $k_{12}$ ) is found using the normal slenderness calculations given in AS1720.1 Clause 3.3.3. The material constant ( $\rho_c$ ) for the normal Glulam grades (GL grades) is given in Table 7.2(B).

- The compression strength of the glulam material is a function of the grade awarded to the glulam. The normal glulam grades are given in Table 7.1 with the design strengths.
- Minimum design dimensions (after allowing for tolerances) should be used to find the compression area ( $A_c$ ).

#### *Glulam tension members*

Glulam tension members are really only found in very large trusses, though designers may have to calculate tension capacity to check compression members that may experience load reversal, or for combined actions (such as portal frames).

The normal strength limit state capacity equation is given in Clause 3.4.1 of AS1720.1,  $(\phi N_t) = \phi k_1 k_4 k_6 k_{11} [f'_t A_t]$

- Capacity factor ( $\phi$ ) can be found in Table 2.5, and has high values relative to sawn timber, because of the high levels of quality control required in the manufacture of structural glulam to AS/NZS1328.
- Duration of load ( $k_1$ ), Partial seasoning ( $k_4$ ) and temperature factors ( $k_6$ ) are defined in Section 2 of AS1720.1 and are found in exactly the same way for glulam as for sawn timber.
- For glulam beams, the size factor for tension ( $k_{11}$ ) is given in Clause 7.4.4 of AS1720.1. The value found is the same one for F-graded timber products. This is likely to be quite conservative, but because tensile failures are brittle, that is wise.
- The tension strength of the glulam material is a function of the grade awarded to the glulam. The normal glulam grades are given in Table 7.1 with the design strengths.
- Minimum design dimensions (after allowing for tolerances) should be used to find the tension area ( $A_t$ ). The tension area is the minimum net cross sectional area. For large or complex connections, this may involve calculation of area of cross section removed for large connectors (such as split rings or shear plates), bolts or dowels, and any embedded steel plates.

#### **Design of complex, curved or tapered glulam members**

As well as complying with the clauses of AS1720.1 section 7, curved and tapered glulam elements must also satisfy other provisions in AS1720.1 Appendix E12 and Appendix E13. Manufacturers may also have some practical limitations on the manufacture such as span length, maximum width of laminations or minimum radius of curvature.

Tapered cuts of one or both edges cause the flexural stresses (that are parallel to the edge of the member) to be at an angle to the grain. The calculations to model this behaviour are given in Clause E12 in AS1720.1.

Members with curved centre-lines can easily be fabricated in a curved clamping frame. The curves introduce residual stresses in the timber as each laminate is locked into a bent profile. As well, moments that cause opening of the curved shape can induce tension perpendicular to the grain near the centre-line of the curved member. Calculations to model these behaviours are given in Clause E13 in AS1720.1

The serviceability calculations of curved or tapered members follow a similar methodology to those for straight members, though some adjustment should be made for the slope of grain at the edge of tapered members.



This can be approximated by using Hankinson's formula and by assuming that the MoE of wood perpendicular to grain is about 1/50 the value of MoE parallel to grain. Hankinson's formula is:

$$E_{\theta} = \frac{E_{\ell} E_p}{E_{\ell} \sin^2 \theta + E_p \cos^2 \theta}$$

with

$E_{\ell}$	MoE parallel to grain (as given in Table 7.1 of AS1720.1)
$E_p$	MoE perpendicular to grain (estimated as 1/50 to 1/30 $E_{\ell}$ )
$\theta$	angle of slope of grain (taper angle at the edge)

Other guidance and some examples of the calculations required for curved and tapered members are given in "Timber Design Handbook" HB108 from Standards Australia

### **Manufacturers' Information**

Product specific information is available from individual glulam manufacturers.