INFORMATION SHEET
STRUCTURAL DESIGN

BEAM DESIGN
The information provided below has been taken from the New Zealand Timber Design Guide 2007, published by the Timber Industry Federation and edited by Professor A H Buchanan. To purchase a copy of the Timber Design Guide, visit www.nztif.co.nz

In bending the design equation for bending strength is:

\[ M^* \leq \phi M_n \]

where

- \( M^* \) is the design level of bending moment, resulting from the factored applied loads
- \( M_n \) is the nominal bending strength, given by:
  \[ M_n = k f_b Z \]

where

- \( f_b \) = characteristic stress in bending
- \( Z \) = section modulus
- \( k \) = product of all the modification factors appropriate to the service conditions

Some of the commonly used \( k \) factors are shown below.

Designers should refer to NZS 3603 for consideration of other items including:
- Strength of notched beams
- Radial stresses in tapered members
- Design for combined stresses

DURATION OF LOAD FACTOR FOR STRENGTH \( k_1 \)
The duration of load factor for strength recognises that timber has a greater strength under briefly applied loads than under long term loads. For design \( k_1 \) is chosen according to the duration of the shortest component of the total load.

Table 1 gives factor \( k_1 \) and examples of types of loads appropriate to different load durations. All combinations of loads should be checked using the value of \( k_1 \) pertaining to the load of shortest duration in each combination.

<table>
<thead>
<tr>
<th>Duration of load</th>
<th>Type of load</th>
<th>( k_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>Dead loads and live loads that are essentially permanent such as stores</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>(including water tanks and the like), library stacks, files, fixed plant, soil.</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>Snow loads, live loads, crowd loads, concrete formwork, vehicle, pedestrian, and livestock loads. Erection loads and maintenance loads.</td>
<td>0.8</td>
</tr>
<tr>
<td>Brief</td>
<td>Wind, earthquake, impact and pile driving loads.</td>
<td>1.0</td>
</tr>
</tbody>
</table>
BEARING AREA FACTOR $K_3$

The bearing area factor adjusts the bearing strength for the area of timber loaded in compression perpendicular to grain. This factor will apply for the end supports of beams or end bearing of columns. For values of $K_3$ see diagrams 1 and 2. The value of $K_3$ may also be calculated from

$$K_3 = 1 + 1.2e^{(-x/35.3)}$$

Diagram 1: Length of bearing surface

![Diagram 1: Length of bearing surface](image1)

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Diagram 2: Bearing area factor $k_3$

![Diagram 2: Bearing area factor $k_3$](image2)

PARALLEL SUPPORT FACTOR $K_4$

The parallel support factor $K_4$ can be used when two or more elements are connected so that they are constrained to the same deformation, as shown conceptually in diagram 3.

Diagram 3: Parallel support system

![Diagram 3: Parallel support system](image3)

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This apparent increase in strength results from the natural variability of strength and stiffness in timber members of a given size and grade. If a single member is carrying the load, the strength is based on the 5th percentile (or characteristic) strength of the population. If several members share the load, a higher design strength can be used because of the probability of stronger members being in the system. Factor $k_4$ also recognises that weaker timber is generally less stiff, which means that it can shed load to stiffer and stronger pieces. The factor $k_4$ is tabulated in Table 2 or may be calculated from:

$$k_4 = \left(1 - \frac{0.323}{\sqrt{n}}\right) \frac{0.677}{2}$$

where $n$ is the number of elements sharing the load.

The parallel support factor $k_4$ shall not be used for design of engineered wood products with low variability such as laminated veneer lumber because the precise properties of such materials give much less advantage from load sharing.

**Table 2: Parallel support factor $k_4$**

<table>
<thead>
<tr>
<th>Number of elements carrying a common load</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_4$</td>
<td>1.00</td>
<td>1.14</td>
<td>1.20</td>
<td>1.24</td>
<td>1.26</td>
<td>1.28</td>
<td>1.30</td>
<td>1.31</td>
<td>1.32</td>
</tr>
</tbody>
</table>

**GRID SYSTEM FACTOR $k_5$**

For indirect load sharing in a grid system of beams with span $L_B$ and spacing $s$ as shown in diagram 4, the grid system factor $k_5$ is given by

$$k_5 = 1 + (k_4 - 1)(1 - 2s / L_B)$$

but not less than 1.0

The factors $k_4$ and $k_5$ apply to bending, bearing and shear strength of most timber beams. They are not used for beams of engineered wood products such as LVL which have low variability in strength between members (where $k_4 = k_5 = 1.0$).

**Diagram 4: Grid system**

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COMPRESSION AT AN ANGLE TO GRAIN

Characteristic stress in compression at angles to grain other than 0° or 90° may be calculated from Hankinson’s formula:

\[ f_\theta = \frac{f_c f_p}{f_c \sin^2 \theta + f_c \cos^2 \theta} \]

EFFECT OF VARIATIONS IN MOISTURE CONTENT

Characteristic values for any product should be stated at the correct moisture content for design. In NZS 3603 this is 16% for dry timber and 25% or more for green timber. Table 3 provides adjustments to find values at any moisture content. Strictly speaking these adjustments apply only to small defect-free specimens of timber (small clears) and may be invalid in some cases for structural timber and for panel products. Direct measurements on the product in question is always to be preferred.

Table 3: Moisture content adjustments for strength properties

<table>
<thead>
<tr>
<th>Property</th>
<th>% reduction for each 1% increase in moisture content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of rupture (bending strength)</td>
<td>4</td>
</tr>
<tr>
<td>Compression parallel to grain</td>
<td>5</td>
</tr>
<tr>
<td>Compression perpendicular to grain</td>
<td>5</td>
</tr>
<tr>
<td>Shear strength</td>
<td>3</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>1.5</td>
</tr>
</tbody>
</table>

STABILITY

The strength of beams which are susceptible to buckling is less than the full flexural strength of the cross section. For slender beams held in position at their ends, lateral torsional buckling can occur if all or part of the compression edge of the beam is free to buckle sideways. Buckling need not be considered for beams with continuous lateral support of the compression edge, such as simply supported floor beams restrained by floor sheathing, or roof purlins fully restrained by roof cladding. Many types of roofing are fixed with nails or sliding clips that cannot be relied upon to give adequate restraint.

For individual beams, fly bracing to purlins can be used as shown in diagram 5, but in some cases it may be easier to increase the beam size to avoid instability or visual intrusion of the bracing.

Diagram 5: Fly bracing of roof beams using purlins

Stability is often critical in beams subjected to load reversal. For example, roof purlins which rely on roofing for lateral stability under gravity loads may have no compression edge restraint under wind uplift. Lateral restraint can be provided by herringbone strutting, or solid blocking or light gauge steel strap bracing fixed between adjacent beams as shown in diagram 6.
For rectangular beams with no lateral support of the compression edge, or with intermittent lateral support, the strength reduction is given by the factor $k_8$ which can be obtained from diagrams 7 and 8. $L_{cy}$ is the distance between the points of lateral restraint along the compression edge. The curves in diagrams 7 and 8 are the same as those in NZS 3603 with the addition of lines for more slender beams. The curves can all be obtained from diagram 10 using the slenderness coefficient of:

$$S = 1.35 \left( \frac{L_{cy}}{b} \left( \frac{d}{b} \right)^2 - 1 \right)^{0.5}$$

For beams with no compression edge restraint (except at the supports), lateral support of the tension edge provides some resistance to buckling of box beams or rectangular beams which have some torsional rigidity. For rectangular beams with torsional restraint at the supports, but no other compression edge restraint, $k_8$ can be obtained from the column buckling diagram in diagram 10, using a slenderness coefficient of:

$$S = 3 \frac{d}{b}$$
For I- and C-beams, the compression flange should be designed as a column element, because these beams have very little torsional rigidity. For box beams, the torsional stiffness of the whole beam should be considered when determining the design bending strength (Experienced designers should use Appendix C of NZS 3603 to determine $k_8$ for specific design loadings and restraint conditions.)

For a dry rectangular timber beam with constant moment, continuous restraint along the tension edge, full torsional restraint at the ends and intermittent torsional restraint along the length, the formulae in Appendix C of NZS 3603 have been used to determine $k_8$ for a range of sizes as shown in diagram 9.

Diagram 9: Stability factor $k_8$ for timber beams with continuous restraint along the tension edge, full torsional restraint at the ends and intermittent torsional restraint

Diagram 10

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**SHEAR STRENGTH**

Shear stresses are rarely critical in typical rectangular beams, but should be checked for heavily loaded short beams and beams with holes, also I-beams, C-beams, or box-beams, especially near the supports. To provide sufficient shear strength, a section size must be chosen which satisfies the design equation given by:

\[ V^* \leq \phi V_n \]

where

- \( V^* \) is the design shear force, resulting from the applied load
- \( \phi \) is the strength reduction factor
- \( V_n \) is the nominal shear strength, given by:
  \[ V_n = k f_s A_s \]

where

- \( f_s \) is the characteristic shear strength from NZS 3603
- \( k \) is the product of all \( k \) factors appropriate to the service conditions
- \( A_s \) is the shear plane area = \( b l/Q \)

Shear stresses are more likely to govern for beams with thin webs, i.e. plywood web beams or glue laminated I-beams. In these cases the shear stress in the web should be checked. For plywood web beams with glued web-flange connections, the rolling shear stress in the plywood should also be checked.

**BEARING STRENGTH**

Bearing stresses at supports should be checked when heavily loaded beams are seated on small supports. To provide sufficient bearing strength, the beam supports must satisfy the design equation given by:

\[ N^* \leq \phi N_n \]

where

- \( N^* \) is the design bearing force at the beam support, resulting from the applied load
- \( \phi \) is the strength reduction factor
- \( N_n \) is the nominal bearing strength, given by:
  \[ N_n = k_1 k_3 f_p A_p \]

where

- \( A_p \) is the bearing area loaded perpendicular to grain, see diagram 11 below
- \( f_p \) is the characteristic stress in compression perpendicular to grain
- \( k_1 \) is the duration of load factor from Table 1
- \( k_3 \) is the bearing area factor from diagrams 1 and 2.

If the design strength is exceeded, there will be crushing of the wood fibres at the support, leading to excessive deformations.
Diagram 11: Cantilever beam construction

(a) Long continuous beam
(b) Cantilever beam system with larger beam at centre
(c) Cantilever beam system with smaller beam at centre
(d) Column reared to such single beam depth
(e) Pinched connection detail

Diagram 12: Length of bearing surface

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NOTCHES AND HOLES

Any notches or sudden changes in cross section in timber members result in stress concentrations, which can lead to a significant loss of strength. Notches at the ends of beams are often convenient for detailing as shown in diagram 13, but they can lead to a serious reduction in strength, so stresses should be checked using Clause 3.2.6 of NZS 3603.

Holes for services should only be drilled into the central mid-height region of the beam cross section where flexural stresses are low. Special calculations are necessary when large holes are needed. This applies to timber beams of all materials and all cross sections.

Diagram 13: Avoid notch at beam support
GLUE LAMINATED TIMBER BEAMS

**Strength**

The Glulam GL grades are performance-based, meaning that they are manufactured to have the characteristic properties listed in Table 4. GL grades of glue laminated timber are verified for strength as set out in AS/NZS1328.2 1998.

**Table 4: Characteristic stresses for dry GL grades of glulam**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Bending $f_b$ (MPa)</th>
<th>Compression parallel $f_c$ (MPa)</th>
<th>Tension $f_t$ (MPa)</th>
<th>Shear in beams $f_s$ (MPa)</th>
<th>Modulus of elasticity $E$ (GPa)</th>
<th>Modulus of rigidity $G$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL18</td>
<td>50</td>
<td>50</td>
<td>25</td>
<td>5.0</td>
<td>18500</td>
<td>18.5</td>
</tr>
<tr>
<td>GL17</td>
<td>42</td>
<td>35</td>
<td>21</td>
<td>3.7</td>
<td>16700</td>
<td>16.7</td>
</tr>
<tr>
<td>GL13</td>
<td>33</td>
<td>33</td>
<td>16</td>
<td>3.7</td>
<td>13300</td>
<td>13.3</td>
</tr>
<tr>
<td>GL12</td>
<td>25</td>
<td>29</td>
<td>12.5</td>
<td>3.7</td>
<td>11500</td>
<td>11.5</td>
</tr>
<tr>
<td>GL10</td>
<td>22</td>
<td>26</td>
<td>11</td>
<td>3.7</td>
<td>10000</td>
<td>10.0</td>
</tr>
<tr>
<td>GL8</td>
<td>19</td>
<td>24</td>
<td>10</td>
<td>3.7</td>
<td>8000</td>
<td>8.0</td>
</tr>
</tbody>
</table>

GL grades greater than GL10 can be difficult to obtain in radiata pine. GL grades greater than GL12 can be difficult to obtain in Douglas fir.

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In addition to factors $k_1$ to $k_5$ and $k_8$ described above for sawn timber, the following $k$ factors apply specifically to glue-laminated timber.

**Curvature factor $k_{23}$**

The curvature factor allows for the additional stress induced in laminations that are bent to a tight radius to form curved glulam members. It is not applied to straight members with a slight camber. $k_{23}$ is applied to the bending strength of curved members and is given by:

$$k_{23} = 1 - \frac{2000}{R} \left(\frac{t_i}{R}\right)^2$$

where $t_i$ = lamination thickness

$R$ = radius of curvature

**Lamination and size factors $k_6$ and $k_{24}$**

The previous lamination factor $k_6$ and the size factor $k_{24}$ have been deleted with the introduction of GL grades because the GL grades are performance grades which are specifically manufactured to give the assigned characteristic stresses.

**Radial stresses in curved or tapered members**

The strength of curved glulam flexural members needs to be checked to ensure that failure does not occur due to stresses perpendicular to the grain. If the bending tends to increase the radius of curvature (bending in the opening mode), the stresses will be in tension perpendicular to the grain (splitting). If the bending tends to decrease the radius of curvature (bending in the closing mode), the stresses will be in compression perpendicular to the grain (crushing).
The design equation for curved members stressed in the opening mode is:

$$M^* \leq 2\phi k_1 k_4 f_s Rbd/9$$

The design equation for curved members stressed in the closing mode is:

$$M^* \leq 2\phi k_1 k_4 f_p Rbd/3$$

where

- $\phi$ is the strength reduction factor
- $k_1$ is the duration of load factor for strength
- $k_4$ is the load sharing factor for number of beams
- $f_s$ is the characteristic shear stress
- $f_p$ is the characteristic bearing stress perpendicular to the grain
- $R$ is the radius of curvature at mid-depth of the section
- $b$ is the breadth of the section
- $d$ is the depth of the section

Design equations for tapered or pitch cambered beams are given in NZS 3603.