NZ Wood
For a better world

# NZ Wood Design Guides

## TREES, TIMBER, SPECIES & PROPERTIES

**Chapter 1.2 | February 2020**

## NZ Wood Design Guides

A growing suite of information, technical and training resources, the Design Guides have been created to support the use of wood in the design and construction of the built environment.

Each title has been written by experts in the field and is the accumulated result of years of experience in working with wood and wood products.

Some of the popular topics covered by the Design Guides include:

- Timber, Carbon and the Environment
- Seismic Design of Timber Buildings
- Holes, Notches and Cutouts
- Post and Beam Buildings
- Working Safely with Prefabricated Timber
- Structural Forms and Exemplars

To discover more, please visit http://nzwooddesignguides.wpma.org.nz

NZ Wood Design Guides is a Wood Processors and Manufacturers Association (WPMA) initiative designed to provide independent, non-proprietary information about timber and wood products to professionals and companies involved in building design and construction.


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# 1. BACKGROUND

## 1.1 FORESTRY

Native indigenous forest covers 23% of New Zealand (6.2 million hectares); however, virtually none of this forest is harvested, as the New Zealand forest industry is almost entirely based on 1.8 million hectares of sustainably managed planted forest, of introduced “exotic” species.

Most timber produced in New Zealand is plantation grown radiata pine (*Pinus radiata*) which is used in timber structures throughout New Zealand. Significant quantities of radiata pine are exported as structural framing timber, glue laminated timber, laminated veneer lumber and panels for use in overseas markets. Smaller quantities of douglas fir and minor species (such as macrocarpa and eucalypts) are also planted, harvested, and used in structural engineering applications.

## 1.2 NATURAL QUALITIES

Wood is the only major building material that is a sustainable and renewable resource (i.e. able to be replenished in a reasonable time period). It is tough and attractive, and gives a pleasant feel to any surroundings. Timber is easy to handle and work using basic tools and equipment, and has been used by builders and craftspeople for centuries. It has earned its key role in our lives through a process of “natural selection”. The very qualities that ensure timber’s continuing importance are those that are most difficult to simulate in other materials. The appearance of timber is unique and even if the eye is temporarily fooled by artificial substitutes the hand is not. The thermal insulation properties of timber make it pleasantly warm to the touch.

## 1.3 NATURAL VARIETY

In ancient times, humans created structures using timber in its natural form - the trunks or branches of trees. Timber milling has come a long way since those times, as have methods of processing. Sawn timber boards have been complemented by a huge variety of panels products such as plywood, fibreboards and particle boards in a wide range of thicknesses and sizes. For structural uses there are laminated timber beams and other engineered components including LVL, CLT, timber trusses and composite structures.

The natural properties of wood can be enhanced by processing and finishing to improve strength, hardness, durability and resistance to attack from insects and weather. Chemical treatment of wood is one way to ensure long life under extreme conditions. Timber buildings can be designed with excellent resistance to hazards such as wind, fire and earthquake.

## 1.4 NATURAL CHOICE

New Zealand has a large and increasing resource of plantation grown radiata pine, and a growing number of smaller plantations of special purpose species. Wood from these plantations has largely replaced scarce New Zealand native species for structural purposes. The wide variety of quality timber and wood products produced in New Zealand are complemented by a range of imported timbers, used mainly for appearance purposes.

The use of timber and wood products is supported by codes and standards, together with manufacturers’ product information. Specifying timber and wood products for your next project adds structural flexibility, high strength-to-weight ratios, excellent insulation properties and a unique bonus in terms of appearance and “feel”. With care and attention to detail, the benefits of designing, working and living with wood can be something that both you and your clients can enjoy.

# 2. FOREST MANAGEMENT

This section gives a brief description of the practice of exotic forestry in New Zealand, where the trees are primarily radiata pine, but also douglas fir and many others in smaller quantities.

## 2.1 PLANTING

In a typical commercial forestry operation, small pine seedlings are planted in a manual process using hand tools. Planting is usually on bare ground or pasture or cleared forest. Typical spacing is a 3 metre grid (about 1000 stems per hectare). This number of trees is far more than will be carried to maturity, to allow for control of grass and weeds and future thinning to remove poorer quality trees.

## 2.2 PRUNING

Pruning is the process of cutting branches off young trees to avoid the formation of knots in the timber. On maturity, pruned trees will have a knotty core of low quality wood in the centre of the butt log, surrounded by high quality wood with no knots. Logs cut from higher in the tree will contain knots the same as unpruned trees. Trees are usually pruned to a height of about 6 metres in one or two lifts, before the stem gets larger than about 100mm in diameter. Removing too many branches will reduce the growth rate of the trees. Pruning produces higher quality timber, but it is not essential if the cost of pruning will exceed the increased value of the pruned sawn timber.

## 2.3 THINNING

Thinning is the process of cutting down unwanted trees after a few years of growth. Unnecessary trees are removed to ensure that the final crop has maximum size and quality, hence maximum value. The thinned trees are occasionally taken out of the forest and used for fence posts or other uses ("production thinning") but this is usually uneconomic so the felled trees are left to rot on the ground ("thinning to waste"). Thinning is usually carried out after the trees are about 10 years old, to leave between 300 and 600 trees per hectare (4m to 6m spacing between trees). The trees selected for thinning include smaller or deformed trees unsuitable for commercial production.

## 2.4 HARVESTING

Harvesting is the process of removing trees from the forest for processing. Trees are harvested (logged) when the trunk reaches an optimum size for processing. This is usually a base diameter between 400mm and 800mm. Radiata pine is usually harvested at an age between 25 and 35 years. douglas fir is more often harvested at an age between 35 and 50 years. Logging may be manual (with a chainsaw) or by machine. Modern logging machines can cut the trunk at its base, cut off all the branches, cut the logs to length, and load them on to a truck. At the time of harvesting, the tree trunk is cut into logs 4 to 6 metres long, depending on the eventual market. Each tree usually produces up to four logs, the bottom log known as the butt log.

## 2.5 SPECIES

### HARDWOODS AND SOFTWOODS

The terms “hardwood” and “softwood” are botanical terms which do not necessarily indicate hardness of the wood (for example, a well known hardwood is balsa wood, which is very soft). Softwoods, known botanically as *gymnosperms*, are coniferous trees which have needle-like leaves usually staying on the tree for several years. Hardwoods, known as *angiosperms* are usually deciduous trees which lose their leaves in winter.

### EXOTIC SOFTWOODS

**Radiata pine**

Radiata pine (*Pinus radiata*) makes up 90% of the sawn timber produced in New Zealand. Radiata pine is a native of California, where it is known as Monterey pine. Radiata pine wood is light coloured with an even texture, and a low proportion of heartwood. The natural durability is low, but it is easily treated. It is moderately strong, has excellent gluing, nailing and machining properties and is suitable for an extremely wide variety of uses. To establish its engineering properties, radiata pine has been extensively researched by independent organisations including Scion (formerly the New Zealand Forest Research Institute), BRANZ and universities. Many of New Zealand’s consulting engineers and timber product manufacturers have specific expertise in working with this species of timber. Radiata pine has proven suitable for a very extensive range of building materials and structural applications, some unique to this country.

**Douglas fir**

Douglas-fir (*Pseudotsuga menziesii*) accounts for 5% of annual production of sawn timber in New Zealand. Douglas-fir is a native of western regions of the USA and Canada. The wood has a high proportion of heartwood, which is pinkish brown in colour, with prominent high and low density wood in the annual rings. Douglas-fir is mostly used for structural applications, where it is stiffer and stronger than radiata pine and knots are generally smaller, intergrown and randomly located. Douglas-fir is slightly more durable than radiata pine so it is not required to be treated for some low decay risk applications.

**Cypress group**

This large group of species includes macrocarpa (*Cupressus macrocarpa*) and Lawson’s cypress (*Cupressus lawsoniana*). Most cypress species have similar wood properties characterised by a distinctive smell, an attractive grain, a medium to low density, natural durability and excellent stability. The wood is suitable for interior and exterior joinery, weatherboards, and boat-building. It also suits general construction uses, being slightly stronger than radiata, but dry wood is prone to splitting when nailed.

**Other exotic softwoods**

Other softwoods are available in small quantities, usually being used for specialist decorative applications. European larch (*Larix decidua*) is used in some applications where high toughness or small knot size is important.

### EXOTIC HARDWOODS

There are several species of Eucalyptus which have been planted widely in New Zealand. They are mostly medium to high density, with a red or brown heartwood. They are often used for panelling, furniture, flooring and joinery, but can be used for general structural uses. They are stronger than radiata, but can be difficult to dry in large sizes. Locally grown European and American hardwood species are also available in small quantities for specialist uses.

### NATIVE SPECIES

Native species are *indigenous* New Zealand trees. Most native trees are *endemic* to New Zealand which means that they do not grow naturally anywhere else in the world. Natural growth rates are often very slow. Native timber is not widely available because of restrictions on logging on many land tenures. Most native timber is used for decorative rather than structural uses, often in thin sections or veneers.

### NATIVE SOFTWOODS

The native softwood species with the most potential for future growth is totara (*Podocarpus totara*). After a long period of poor availability, production is steadily increasing, especially in Northland. Totara is widely used for Maori carving and other non-structural uses.

Rimu (*Dacrydium cupressinum*) is commercially available in very small quantities, mostly in the South Island. It is a brown, fine grained, even-textured medium density wood with reasonable strength. It has been used for framing, joinery, furniture manufacture and a variety of other purposes. Other native softwoods are only available in very small quantities for special uses such as kauri (*Agathis australis*) for boat building.

### NATIVE HARDWOODS

Native hardwoods include silver beech (*Nothofagus menziesii*), red beech (*Nothofagus fusca*) and tawa (*Beilschmiedia tawa*). They are available in small quantities in particular areas. Because they are harder and more dense than radiata pine, good quality wood is usually used in furniture, panelling or manufactured items.

### INFORMATION SHEETS

Information sheets on native species and some less common exotic species are available from the NZ Wood website www.nzwood.co.nz. Additional information sheets are available from the website of the New Zealand Farm Forestry Association www.nzffa.org.nz.

All of these data sheets provide useful information, but they are not a complete path to compliance without verification of structural properties, as described below.

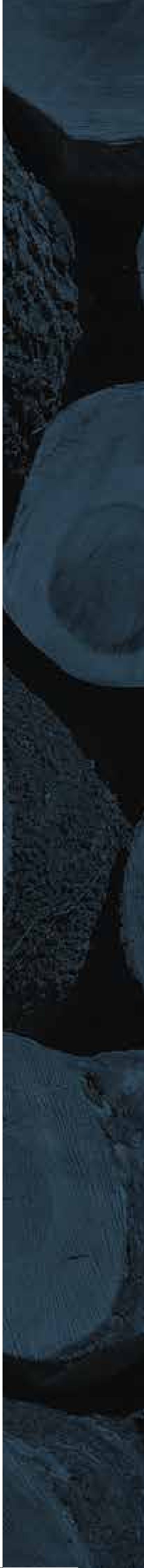
### IMPORTED TIMBER

Not much timber is imported into New Zealand for structural purposes, but a number of species are imported in small quantities for decorative or durable uses.

## 2.6 SUSTAINABILITY

Wood which is harvested from well managed forests is a renewable resource, with excellent sustainability credentials.

The WPMA Design Guides on Sustainability describe responsible forest management in accordance with FSC and PEFC guidelines, the benefits of carbon forestry, carbon and the environment, and the social and economic benefits of timber construction.



# 3. WOOD STRUCTURE

## 3.1 TREE GROWTH

Trees take in water and minerals from the soil through their roots, and absorb carbon dioxide from the air through their leaves or needles. Using the process of *photosynthesis*, using the energy of sunlight, basic carbohydrate compounds are formed in the leaves. These travel in the sap to the *cambium layer*, the thin active growth layer under the bark (see Figure 4), where they provide food for the growth of the fibres, which make up most of the wood. During the growing season, cells in the cambium layer are continually dividing, creating new wood on the inside and new bark on the outside.

## 3.2 CELLULAR STRUCTURE

Wood is a cellular material mainly comprised of long, tube-like cells, or fibres. Chemically, the cells are mainly cellulose, and they are bonded together with lignin. The main cells in softwoods are called *tracheids*, about 4 mm long and 0.04 mm in diameter. The tracheids are oriented vertically in the tree, to provide the main strength of the wood and also to conduct mineral solutions in the sapwood. *Rays* are collections of smaller storage cells oriented horizontally from the centre of the tree (the pith) to the bark as shown in Figure 1.

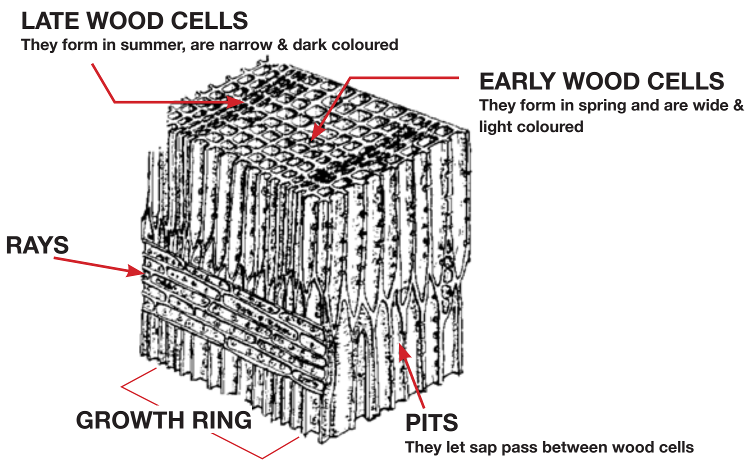



*Figure 1. Cellular structure in one growth ring of softwood*

The strength and stiffness of wood is mainly related to the mechanical properties of the main cells in the wood. The wall of each cell consists of a composite matrix of several layers, as shown schematically in Figure 2. The part of the cell having most influence on wood strength and stiffness is the middle layer of the cell wall. This layer consists of closely packed cellulose chains (*microfibrils*) which are aligned close to the longitudinal axis of the cell. Inclination of the microfibral angle is a major factor affecting wood stiffness.

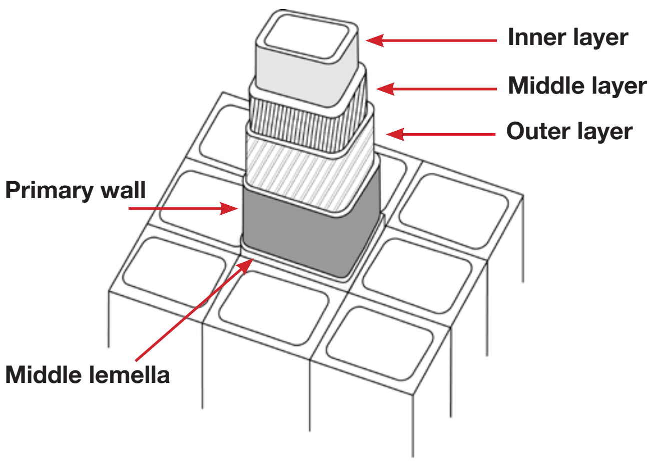



*Figure 2. Schematic sketch of cell wall showing orientation of microfibrils*

## 3.3 DENSITY

The size of cell cavities and the thickness of cell walls affect the density of wood. Density can vary within a tree, from tree to tree, and from species to species. The apparent density will also change with moisture content, and with the presence of preservative treatment. For wood free of major defects, dense wood is usually stronger, harder and stiffer than less dense wood, but density is difficult to assess in a sawmill environment. The density of most softwoods (at 12% moisture content) is about 500kg/$m^3$ (weight 5 kN/$m^3$). Green wood in a standing tree or a freshly cut log is approximately double this value (1000kg/$m^3$).

Care must be exercised when referring to wood density because there are several different definitions.

- The **"basic density"** is the oven dry weight of the wood divided by the volume in the green condition. This is a rather artificial definition of density which is often used by forest growers.
- The **"oven dry density"** is the oven dry weight of the wood divided by the oven dry volume.
- The **"nominal density"** at any moisture content is the oven dry weight of the wood divided by the volume at that moisture content.
- The **"test density"** at a specific moisture content is the most commonly used definition for estimating the weight of timber in a structure. It is the weight divided by the volume, both at the measured moisture content of the wood.

For conversions between these different definitions of density, see Mike Collins FRI Bulletin No. 49.

Derived using the equations in Bulletin No. 49, Table 1 shows the different values of density for one typical piece of radiata pine wood with a basic density of 4.15 kN/$m^3$. The oven dry density is 4.70 kN/$m^3$ (a higher value because it is the same weight divided by a smaller volume). These values are properties of the wood material, independent of moisture content. The nominal density and the test density depend on the moisture content, so at a moisture content of 12%, the nominal density is 4.46 kN/$m^3$ and the test density is 5.00 kN/$m^2$.

| Moisture Content | Basic Density | Oven Dry Density | Nominal Density | Test Density |
|---|---|---|---|---|
| | kN/m3 | kN/m3 | kN/m3 | kN/m3 |
| 8% | 4.15 | 4.70 | 4.54 | 4.90 |
| 12% | 4.15 | 4.70 | 4.46 | 5.00 |
| 20% | 4.15 | 4.70 | 4.32 | 5.18 |

The new timber design standard, NZS AS 1720.1, gives a value for Design Density in Table 2.1 which is the nominal density at 15% moisture content, to be used for calculation of fastener strength in accordance with Chapter 4.

The new standard for fire design of timber structures, AS/NZS 1720.4, specifies a density of 550kg/$m^3$ at 12% moisture content, for all sawn timber and manufactured products from radiata pine grown in New Zealand. This notional value of density was back-calculated to give a charring rate of 0.65mm/min in standard fire exposure, the same value as in NZS 3603, previously verified by fire resistance testing.

## 3.4 GRAIN DIRECTION

The cellular structure of wood gives rise to anisotropic properties. Wood has different properties in three perpendicular directions as shown in Figure 3; *longitudinal* (parallel to the grain), *radial*, and *tangential* (both perpendicular to the grain).

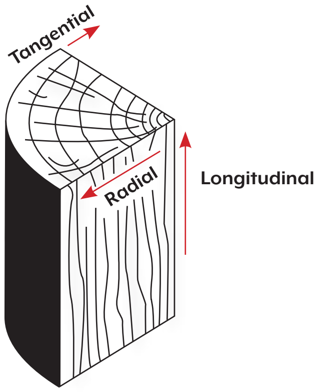



*Figure 3 Anisotropic directions for describing wood properties*

## 3.5 LOCATION IN THE TREE

Wood properties can depend on the position in the tree. The greatest difference is over the log cross section, with both strength and stiffness increasing from the pith to the outside of the log. The wood in the five to ten growth rings closest to the pith is very weak (see Corewood, page 10). There is a small reduction in strength moving up the tree from the butt log to the top logs, but this is not significant for structural engineering properties.

# 4. FEATURES VISIBLE IN A LOG

## 4.1 BARK

The *bark* is the weatherproof covering at the outer surface of the log. During tree growth, new bark is formed continuously as cells divide in the *cambium layer* between the bark and the wood. Outer layers of bark slowly fall off the tree as it gets older. The bark is removed when logs are processed.

## 4.2 PITH

The *pith* is the small core of soft material at the very centre of the log, as shown in Figure 4. The pith at the centre of every log was originally formed as the new shoot of the growing tip of the young tree.

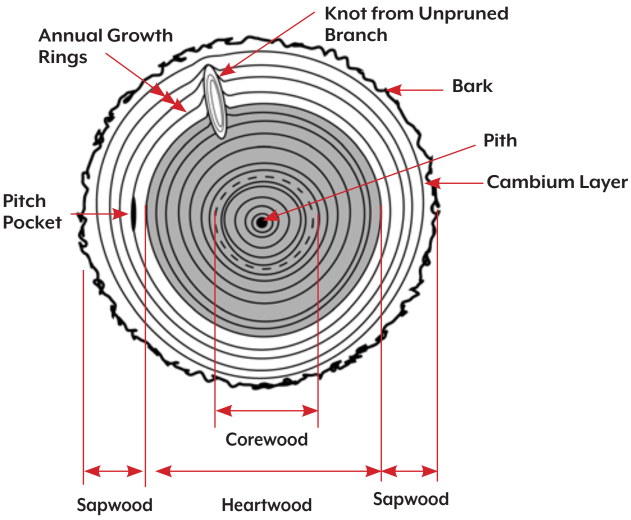



*Figure 4. Cross section of tree trunk*

## 4.3 GROWTH RINGS

Each year, trees increase in diameter by adding new layers of cells at the cambium layer. Annual changes in these layers make up the *growth rings*, or *annual rings*, which vary in thickness with the species, growth conditions and tree age. In most softwood trees grown in temperate climates, large thin-walled cells are formed in the spring, when the wood is growing faster, and thicker-walled cells are formed in the slow summer growing season. The areas of fast growth are called *earlywood* or *springwood*, and are lighter in colour; the areas of more dense slow growth are called *latewood* or *summerwood* which are darker in colour. Counting the number of rings at ground level gives the age of the tree. Figure 1 shows an enlargement of the wood cells in one annual growth ring.

As an interesting diversion, *dendrochronology* is the science of dating past events or estimating the age of ancient wood relics by looking at tree rings. It is based on the principle that all the trees in a region have similar variations in the width of the growth rings from year to year due to climatic and other factors.

## 4.4 SAPWOOD AND HEARTWOOD

*Sapwood* is the wood in the outer region of the tree trunk where the wood cells support tree growth by conducting sap and storing food. As a tree increases in diameter the cells towards the centre become inactive and function only as support for the tree. This older wood is called *heartwood*. Complex organic compounds known as *extractives* are deposited in the heartwood, often giving it a darker colour and some increased decay resistance. It is easy to visually identify heartwood and sapwood in most softwood species by the different colours. Sapwood, although it has lower natural decay resistance, is more easily treated by preservatives because it is more permeable than heartwood. Sapwood and heartwood are of similar strength.

## 4.5 KNOTS

*Knots* in logs are due to the presence of branches. Most branches originate at the pith, and while they remain alive, they grow combined with the trunk, as shown in Figure 5. When splitting firewood with an axe, it can be seen that wood fibres tend to "flow" around branches, producing grain disturbances some distance from the knot itself.

If branches die and fall off naturally, or if they removed in a pruning operation, the stubs become overgrown and the subsequent wood is clear of knots. Many radiata pine forests are manually pruned because the branches do not fall off naturally.

Radiata pine tends to have discrete whorls of branches at certain heights in the tree. Douglas-fir differs in that it has a much more random location of small branches which is a definite advantage for structural timber, giving less strength reduction from knots.

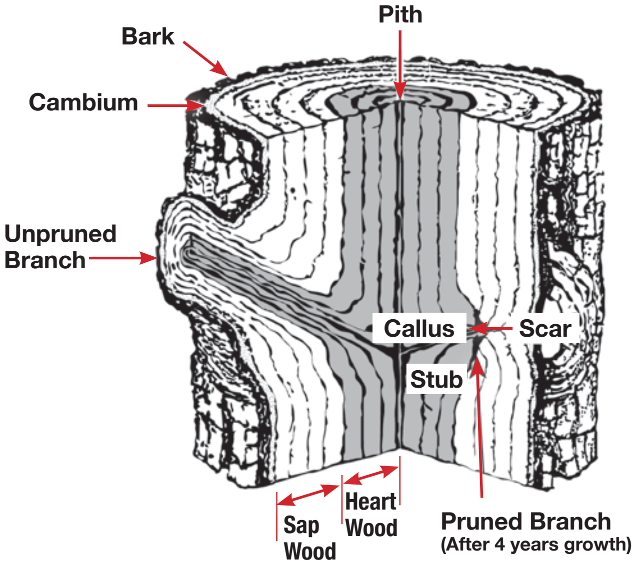



*Figure 5. Cut-away segment showing a pruned branch and an unpruned branch*

## 4.6 COREWOOD

*Corewood* refers to wood within about 5 to 10 growth rings from the centre of the tree, including the pith. It is sometimes referred to as *juvenile wood* because it was formed when the tree was very young. The corewood is less dense than the wood in the rest of the tree, and tends to have wide, low density growth rings that contain spiral grain with a propensity for twist. There is no clear definition of corewood and it cannot be identified visually except by counting growth rings from the pith. Boards cut from the centre of a log often have a large amount of corewood, leading to higher longitudinal shrinkage, more twisting, and less strength than wood from further out in the log.

Not all species are affected by the problem of corewood, but it is very significant in radiata pine. Douglas-fir exhibits more uniform properties within stems than radiata pine and therefore has less of a corewood problem.

## 4.7 REACTION WOOD

*Reaction wood* is abnormal woody material formed in the trunk of a tree, usually as a result of a leaning trunk. Reaction wood also occurs naturally in branches of trees.

In softwoods, reaction wood is called *compression wood*, and it is found on the lower side of a branch or an inclined trunk. The density of compression wood may be 30% to 40% greater than normal wood, and the cells are modified. After sawing, the presence of compression wood results in excessive longitudinal shrinkage which may cause significant warping when the wood dries. Compression wood is difficult to recognise visually, easier to identify in a log than in sawn timber, because the larger growth rings on the lower side of a leaning tree cause the pith to be away from the centre of the log, as shown for an extreme case in Figure 6.

In hardwoods, reaction wood is called *tension wood*, which occurs on the upper side of branches and leaning trunks, and can also cause problems in sawn timber.

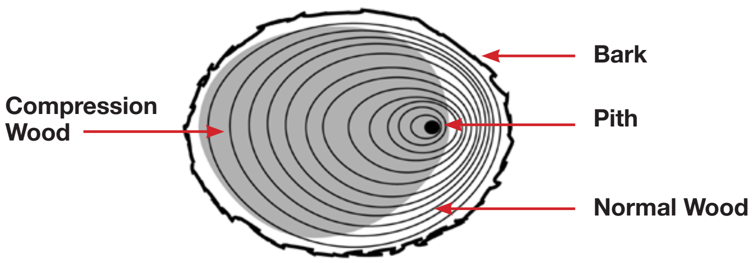



***Figure 6. Eccentric growth rings due to the formation of compression wood in a leaning tree.***

## 4.8 PITCH POCKETS

A *pitch pocket* is an opening between growth rings, which contains resin, or bark, or both. Pitch pockets are usually caused by surface damage to the bark of young trees. Pitch pockets containing resin can create appearance problems in timber because the pitch can slowly ooze out over a period of time, even if the surface is painted.

# 5. MOISTURE EFFECTS

Wood is derived from living material and interacts with the moisture in its environment. Changes in humidity and temperature cause fluctuations in wood moisture content and these affect its properties and dimensions. More problems in timber construction are attributable to inadequate detailing for moisture-related issues than anything to do with structural design. Designers must therefore consider how moisture affects the performance of timber components and structures, during manufacture, construction and in service.

To minimise shrinkage, swelling, warping or splitting of wood, the moisture content should be controlled at all stages. Changes in moisture content may also lead to problems with gluing, machining, and surface coating. Fungal and insect attack and metal corrosion are also affected by the amount of moisture in wood. To reduce the effect of changes in moisture content wood should be:

(a) Dried to the correct moisture content.

(b) Stored properly to avoid undue moisture change before and during manufacture.

(c) Manufactured under controlled conditions.

(d) Protected properly before use and while being put into use.

(e) Protected as necessary in the finished situation.

Any structure or component should incorporate appropriate allowances for moisture content control in the design, specification and detailing.

## 5.1 WATER AND WOOD

Wood in normal use always contains water. The water may be “bound”, ie. combined with the wood cell walls, or it may be “free” water within the cell cavities. When wet wood is dried the free water is lost first. This causes little change in wood properties other than reducing weight. But if drying is continued until all the free water is lost and the cell cavities are empty, further loss can only come from bound water. The loss of this bound water is accompanied by shrinkage and changes to properties such as strength and modulus of elasticity.

### MOISTURE CONTENT

Moisture content (m.c.) is a measure of the amount of water in a piece of wood and is defined as:

**Moisture content (%) = weight of water / weight of oven dry wood × 100**

This can be measured either indirectly with hand-held moisture meters or directly and most accurately by weighing samples before and after oven drying. Oven drying typically consists of leaving the wood sample in an oven at 105°C for 12 hours, or until there is no further loss of weight.

Several types of moisture meter are available. The most common is the electrical resistance type of moisture meter with two probes hammered into the wood. This is reasonably accurate, measuring moisture content to within 1.5% when the moisture content is below the fibre saturation point. Moisture meters with short probes are easier to use but they only measure moisture content near the surface whereas those with longer probes can measure much deeper in the timber. Some moisture meters are surface contact only. Radio frequency moisture meters are only accurate to about 3% but are very useful as a rapid indicator. Moisture meter readings need to be corrected for species, treatment and temperature effects, so they should be correctly calibrated.

**Example:** Oven drying method to obtain wood moisture content:

**A sample of wood weighs 5 kg. It is placed in an oven at 105°C until there is no loss in weight. It now weighs only 4 kg, 1 kg of water having been driven off. The original moisture content was:**

Moisture content $= (5 - 4) / 4 \times 100 = 25\%$

## GREEN (UNSEASONED) WOOD

Wood from newly felled trees is usually called “green” wood and has a high moisture content. The cell cavities contain water and the cell structure is swollen. The moisture content of green wood is often around 100%, but varies considerably between species, ranging from 45% to 200%. Low density species such as balsa and redwood have a low mass of wood in a given timber volume, so they can have moisture contents exceeding 200%. Heartwood generally has lower moisture content than sapwood.

## DRY WOOD

The term “dry” wood must be used carefully, because all wood in service contains some moisture. A specification referring to dry wood must be qualified with a specified range of moisture contents to ensure that allowances for any change in properties or dimensions are of the right magnitude.

## EQUILIBRIUM MOISTURE CONTENT

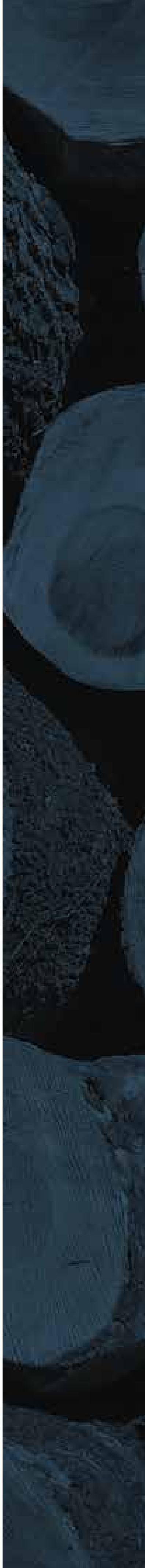
Timber in constant conditions of humidity and temperature will gain or lose moisture until it comes into equilibrium with the atmosphere. It is then said to have reached its *equilibrium moisture content* (e.m.c.) for those conditions. Because e.m.c. varies with chemical composition, different species and wood products may reach different moisture contents under similar conditions.

| Use category | Air conditioned or centrally-heated buildings | Intermittently heated buildings | Unheated buildings |
|---|---|---|---|
| Weatherboards, exterior joinery, finishing and framing, items outside the insulation | 14-18 | 14-18 | 14-18 |
| Flooring exposed to ground atmosphere | 10-14 | 12-18 | 14-18 |
| Interior joinery, and finish wall framing, flooring not exposed to ground atmosphere | 8-12 | 10-14 | 12-16 |

*Table 2. Suggested moisture content for finishing and framing timbers in New Zealand (percent)*

Table 2 gives the approximate e.m.c. and therefore the recommended moisture contents for timber in various environments in New Zealand. In exterior environments such as bridge beams, the e.m.c. may be as high as 20% to 24%. Piles beneath the soil water table and in marine structures should be considered to be saturated or “green.”

The general relationship for solid timber is given in Figure 7, which enables the e.m.c. to be calculated for any environment of known humidity and temperature. Timber in a low temperature, high humidity environment has high e.m.c., whereas timber in high temperature, low humidity conditions has a low e.m.c. For example, a glulam component destined for the Middle East may need to be below 8% moisture content.



Surface coatings reduce the rate of moisture movement into and out of wood and wood products, but they cannot entirely halt the process. Given sufficient time, wood ultimately comes into equilibrium with the average temperature and relative humidity of its environment, regardless of the surface coating. Consequently, if it is desired to minimise the effects of moisture content on wood properties, it is essential that the wood be dried to (and maintained at) a moisture content as close as possible to the e.m.c. of the final conditions of use. For dry indoor environments, this is best achieved by kiln drying the wood.

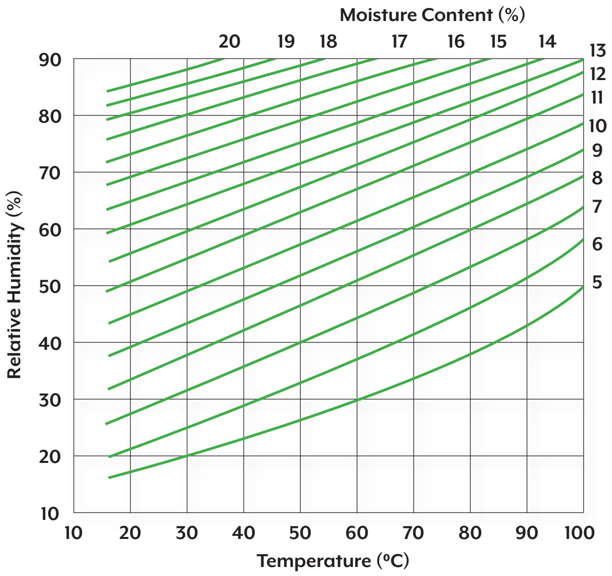



*Figure 7. Equilibrium moisture content as influenced by temperature and relative humidity.*

## DRYING

To reduce the moisture content of wood for given service conditions, timber needs to be dried. The two main methods used by the timber industry are:

- *Air drying* where timber is filleted in stacks and allowed to dry with the passage of air and wind, often exposed to the rain and natural weather conditions.
- *Kiln drying* using heat and air flow in a controlled cycle in a kiln.

In both cases the wood must be filleted in stacks with spacers between layers to allow passage of air.

These processes involve time and handling that can sometimes affect the delivery of timber orders. Air drying is rarely used because it can take several weeks or months depending on the time of the year, but it may be used for high value decorative timbers that are difficult to dry. Air drying usually results in moisture contents of 14% to 18%.

Conventional drying kilns can usually achieve much lower moisture content in a week, whereas special high temperature kilns are increasingly used for drying in 24 hours. Wood in kilns is often stacked with weights to keep the boards straight and prevent distortion during the drying process. Thinner wood takes less time to dry. Thin veneers used for plywood and LVL manufacture can be dried to 5% moisture content in less than 10 minutes.

## 5.2 SHRINKAGE AND SWELLING

### MOVEMENT OF WOOD

As the moisture content of wood reduces during drying, shrinkage commences after the cell walls start to lose bound water. This is called the fibre saturation point (FSP) and is usually about 30% moisture content, as listed in Table 3. Shrinkage of limber is usually expressed as the change in dimension from green (fibre saturation point) to 12% moisture content, divided by the green dimension, expressed as a percentage. Shrinkage and swelling of green wood due to moisture changes above the fibre saturation point is negligible. For moisture changes below the fibre saturation point, wood will swell as it gains moisture and shrink as it loses moisture as shown in Figure 8. The amount of movement is directly proportional to the change in moisture content and varies with species, density and the direction of the grain. Dense woods generally shrink and swell more than lighter woods.

| Species | % shrinkage, when drying from green to 12% m.c. | | Fibre saturation point (% m.c.) |
|---|---|---|---|
| | Tangential | Radial | |
| Radiata | 3.9 | 2.1 | 29 |
| Douglas fir | 4.9 | 2.8 | 27 |
| Macrocarpa | 3.2 | 1.8 | 25 |
| Redwood | 2.2 | 1.3 | 25 |
| Eucalyptus sp. | 6.0 | 3.5 | 30 |
| Kauri | 4.1 | 2.3 | 26 |
| Matai | 3.5 | 1.9 | 24 |
| Rimu | 4.2 | 3.0 | 27 |
| Beech, red | 7.1 | 3.3 | 24 |
| Tawa | 6.7 | 3.4 | 30 |

*Table 3. Shrinkage properties of some New Zealand timbers.*

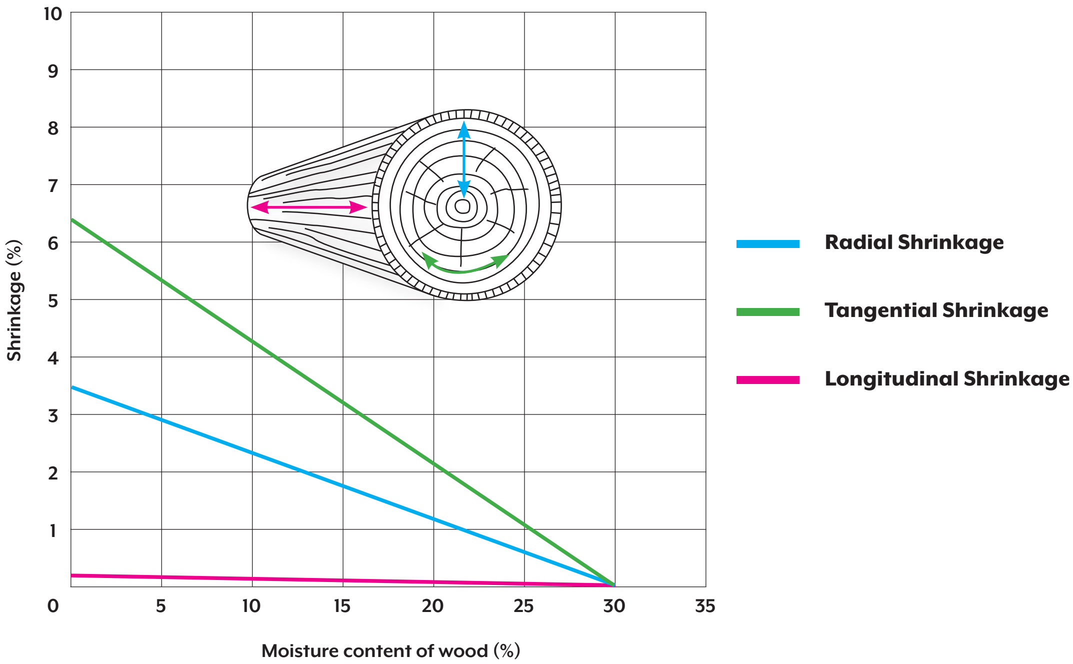
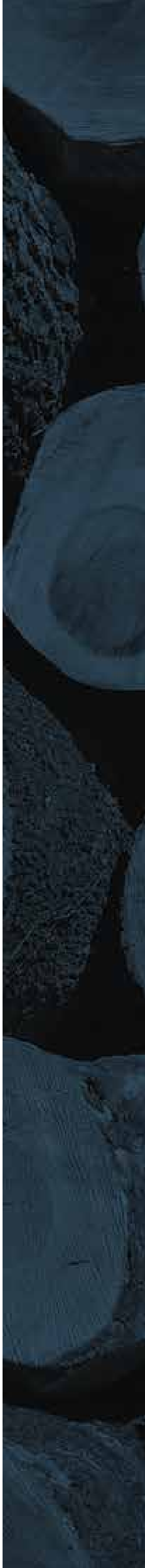



*Figure 8. Shrinkage at various directions to the grain.*



## TRANSVERSE SHRINKAGE

Typical values for transverse shrinkage (across the grain) are given in Table 3. Tangential shrinkage is always greater than radial shrinkage. This difference is the cause of much distortion and degrade in drying, such as:

- Cupping of flatsawn boards as shown in Figure 12
- Diamonding of square sections as shown in Figure 12
- Checking and splitting of poles
- Checking and splitting of large beams which enclose the pith

Limits are placed on distortion by timber grading rules (NZS 3631). Glulam, LVL, and finger-jointed timber are much more stable than single long lengths of timber because they contain smaller pieces of wood and the varying movements of adjacent pieces are averaged.

**Example:**
**If a piece of wood measures 150 mm wide in the green state, and 144 mm when dried to 12% moisture content, its width shrinkage is:**

$$\frac{150 - 144}{150} \times 100 = 4\%$$

## LONGITUDINAL SHRINKAGE

Longitudinal shrinkage (along the grain) of most timbers is about 0.1% when drying from green to 12% m.c. This is less than one tenth of the transverse shrinkage, so it can normally be ignored. For typical timber in service, the small seasonal variation in moisture content of 2 to 5% will result in only small changes in length which are usually inconsequential.

Longitudinal movement is only likely to be a problem where long members supporting critical elements are subject to differential movements producing visible deflections or undesirable stresses. Compression wood, and juvenile wood from the centre of the tree, may shrink more than normal wood and the resulting uneven longitudinal shrinkage can cause distortion or warp (crook, bow, twist) if moisture content is not controlled (Figure 15). Engineered wood products such as glulam and LVL are much less prone to distortion.

## CALCULATING MOISTURE MOVEMENT OF WOOD

### Transverse movement:

Designers, specifiers and builders have little or no control of the orientation of the radial and tangential components of structural timber. It is therefore appropriate to use an average value when calculating shrinkage or swelling of structural elements. Movement can be variable so accuracy to within less than a millimeter is probably not warranted. Using the shrinkage values in Table 3, the change of a given cross-sectional dimension can be calculated from:

$$\text{Dimensional change} = \frac{\text{\% shrinkage from Table 3}}{100} \times \frac{\text{m.c. change}}{\text{FSP} - 12} \times \text{initial dimension} \quad \text{[Equation 1]}$$

**Example using equation** [1]:
**Use the equation to calculate the shrinkage of a flat-sawn douglas fir board, 300mm wide, when it dries from 27% m.c. to 12% m.c (change of 8%):**

**From Table 3, the tangential shrinkage of douglas fir from green to 12% m.c. is 4.9% and the FSP is 27%.**

$$\text{Dimensional change} = \frac{4.9}{100} \times \frac{8}{27\text{-}12} \times 300\text{mm} = 7.8\text{mm}$$

**Simple rule for radiata pine:**

**Equation** [1] can be used to get a simple rule for a quick estimate of long term transverse moisture movement for radiata pine for a moisture content change of 1%. With the average transverse shrinkage of 3% from Table 3, and the fibre saturation point of 29%, **equation** [1]: gives

$$\text{Dimensional change} = \frac{3}{100} \times \frac{1}{29\text{-}12} \times \text{initial dimension}$$

$$= 0.00176 \times \%\ \text{m.c change} \times \text{initial dimension}$$

**Examples using the simple formula for radiata pine:**

**1. Consider a 100mm wide timber board drying from green (29%) to 12% m.c:**

**The m.c. change is 17 %, so the shrinkage = 0.00176 x 17 x 100mm = 3mm.**

**2. Consider a 250mm wide timber board going from air dry (20%) to 12% m.c:**

**The m.c. change is 8 %, so the shrinkage = 0.00176 x 8 x 250mm = 3.5mm**

**3. Consider a 150mm wide timber board going from kiln dry (10-14%) to 12% m.c:**

**The m.c. change is ±2%. Shrinkage = 0.00176 x 2 x 150mm = ±0.5mm. This shows that kiln dried wood is variable and may move one millimter or more as it equilibrates with the environment.**

### Longitudinal movement:

For almost all timbers, longitudinal movement can be estimated from:

**Change in length = 0.00005 x initial length x % m.c. change**

This may usually be neglected in design. Consider a 4.8 m long post of green timber, installed in a situation where the final e.m.c. is 12%. The shortening of the post for the change in moisture content of 30 - 12 = 8% is:

**0.00005 x 4800 x 18 = 4.3 mm**

If the adjacent supports are steel or masonry, there will be differential deflection of 4.3mm. Pith or corewood in the column could lead to larger movement. Simple precautions would be to specify that the column should be pith free, dried to 12% before installation, and protected from rewetting during construction. Glulam or LVL would be more appropriate for a critical member such as this.

## DISTORTION

Distortion of wood and wood products occurs in many different ways, mostly due to differential shrinkage during drying. Figure 15 shows the most common forms of distortion occurring in sawn timber.

## DIMENSIONAL STABILITY

It is not only the amount of moisture movement from green to dry that is important, but also the speed at which already dry timbers respond to changes in environmental conditions. Movement may be of either a long-term or short-term nature. Dimensional stability of heartwood of different species is given in Table 4. Long-term movement is typically associated with moisture content change as wood is exposed to dry summer conditions and later to wet winter conditions. The amount of movement is dependent on the wood's shrinkage value, fibre saturation point, and its e.m.c.

Short term movement is the response of wood to fluctuations such as those from alternating rainy and sunny conditions, depending on how quickly moisture moves through the wood. A timber that is stable in the short term is one that responds slowly to changes in environment. Values for short term stability in Table 4 range from 1.0 for red beech to 3.0 for tawa. This means that an article made from tawa would move three times as much as an equivalent red beech article when subjected to similar short-term atmospheric changes. Conversely, although red beech is 2.2 times more stable than radiata pine in the short term, its long term movement is three times as much. In other words, red beech may shrink a large amount on drying, but once dried and installed, it will tend to retain its dimensions.

| | Long-term movement | Short-term movement |
|---|---|---|
| Radiata | 2.0 | 2.2 |
| Douglas fir | 3.6* | 2.5 |
| Macrocarpa | 1.4 | 1.2 |
| Redwood | 1.6* | 2.1 |
| E. Regnans | 2.4 | 2.3 |
| E. Saligna | 2.9 | 1.9 |
| Kahikatea | 2.9* | 2.8 |
| Kauri | 3.0* | 2.8 |
| Matai | 2.6* | 1.5 |
| Rimu | 2.9* | 2.2 |
| Beech, red | 5.9* | 1.0 |
| Beech, silver | 4.0* | 1.9 |
| Tawa | 4.5* | 3.0 |

**Long-term movement is the percentage decrease in tangential dimension from equilibrium at 90% relative humidity to equilibrium at 60% relative humidity. Short-term movement is the tangential swelling from equilibrium at 60% humidity after 24 hours at 95% relative humidity.**

*Derived from previous data not in this form.

*Table 4. Dimensional stability (%) of some New Zealand timbers.*

## CALCULATING MOISTURE MOVEMENT OF PANEL PRODUCTS

For plywood, moisture movement can be related to the properties of the wood from which it was made. Transverse movement across the grain in the plane of the veneer is constrained by minimal longitudinal movement parallel to the grain in adjacent veneers crossing at right angles. Therefore, movement in the plane of the panel is only about double the longitudinal movement of timber. Swelling in plywood is recoverable on drying.

**Change in width or length of sheet = 0.0001 x initial dimension x % m.c. change.**

| Product | Likely moisture content ex factory | E.m.c.: Very dry conditions *(50% relative humidity, 20°C)* | E.m.c.: Very humid conditions *(90% relative humidity, 20°C)* | Linear expansion coefficient mm/%m.c. | Thickness swelling mm/%m.c. |
|---|---|---|---|---|---|
| Plywood | 10-14 | 8 | 19 | 0.0001 | 0.001 |
| Particle board | 16-14 | 10 | 17 | 0.0003 | |
| Bison board | 7-13 | 9 | 15 | 0.0006 | 0.01 |
| MDF hardboard | 7-13 | 7 | 12 | 0.0005 | 0.01 |
| Hardboard | | 6 | 12 | 0.0003 | |

*Table 5: Moisture content and movement properties of some panel products.*

For most other panel products the fibres are randomly oriented. The change in dimension can still be obtained by multiplying the initial dimension x % m.c. change x the coefficient from Table 5. Depending on the adhesive used, wood particle board and wood fibre based panels may swell permanently in the thickness and never recover the quite large movements that may occur, because of some loosening of the fibres.

## 5.3 MOVEMENT OF LARGE TIMBER COMPONENTS

For large timber components, even a small change in moisture content can result in significant movement that might affect detailing and connection requirements. On the other hand, changes in moisture content will be slow in large timber members.

The use of glulam or LVL has advantages in the control of moisture movement because:

Manufacturing is at a moisture content close to e.m.c. (gluing requires that timber be dry)

- Increased stability results from the random gluing together of pieces
- Glulam and LVL are handled and stored carefully because of their high value
- These products can be wrapped or coated with water repellents before delivery

Large solid sawn timber beams (such as a 300 x 100 mm sawn timber beam) may split on one face if they contain the pith of the tree, called “boxed pith”. There is no way of preventing this splitting. If appearance is important the beams should be selected carefully from previously dried stock, or they should be cut from the outer part of the log so that they are free of pith, or be made from engineered wood.

# 6. SAWN TIMBER

## 6.1 SAWMILLING

When a forest is logged, the branches are cut off and the logs are transported to processing facilities. For conversion into sawn timber, logs are taken to sawmills. Despite advanced technology, converting a round log into rectangular timber is rather inefficient, and only about half of the log volume becomes sawn timber. The remainder ends up as slabs, chips or sawdust, which may become feedstock for panel products or energy production.

## 6.2 LOG QUALITY

The quality of the logs is assessed visually and sonically. Additional information on log quality may be obtained from silvicultural records dealing with pruning, thinning, seedling quality etc. Logs for conversion into structural timber are assessed for quality with an estimate of the modulus of elasticity (MoE), made either in the forest or at the sawmill, with a device which measures the time taken for a sound wave to travel the length of the log, after one end is hit with an electronic hammer, as shown in Figure 9. Low stiffness logs will be sawn into appearance grade timber or chipped for manufacturing into panel products.

Modern sawmills are sophisticated industrial facilities, with much of the work done by computer-controlled machinery. Logs are often scanned and centred before sawing to ensure maximum yield of timber from each log.

*Figure 9. Use of an impact (sonic) device to sort logs.*

## 6.3  FLAT SAWN VS. QUARTER SAWN TIMBER

In the sawmill, the logs are sawn into timber.  There are many different possible patterns for cutting a log, with two possibilities shown in Figure 10.  The resulting timber is often described as “quarter-sawn” or “flat-sawn” as illustrated in Figure 11.  In quarter-sawn timber the annual rings form angles of 45° to 90° with the surface, whereas in flat sawn timber, they are at 0° to 45° with the surface.  Quarter sawn timber suffers much less distortion than flat sawn timber when it is dried.  It is also much less prone to surface checking if exposed to sunlight.

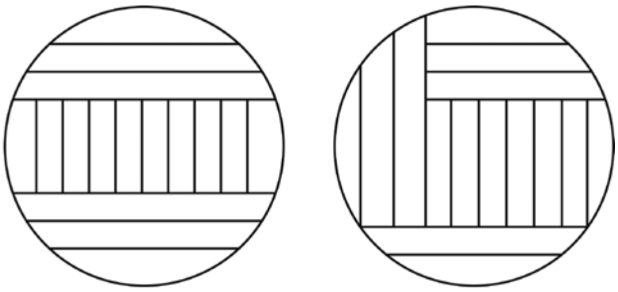


*Figure 10. Two of the many ways that logs can be converted into sawn timber.*

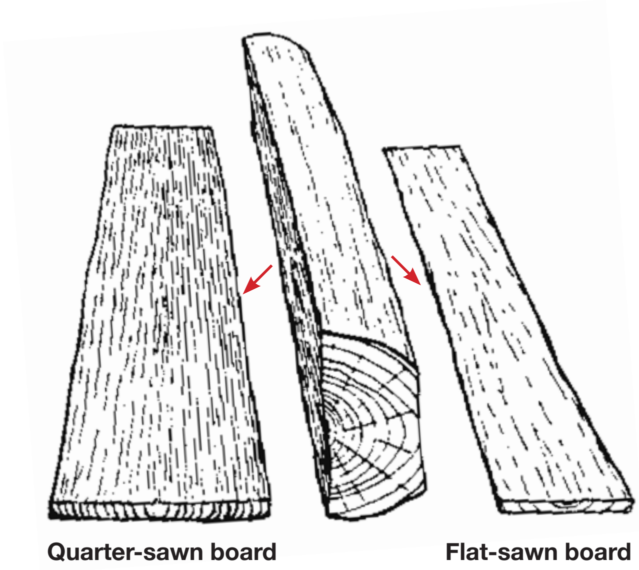



*Figure 11. Quarter-sawn and flat-sawn boards*

## 6.4  SEASONING

When logs are converted to sawn timber the moisture content of the wood is very high, maybe 100% of the weight of the dry wood.  The timber needs to be seasoned (dried) to reduce the moisture content before use.  This is done by air drying or kiln drying.  Changes in moisture content result in shrinkage and swelling of the wood which can be calculated.  Changes in dimension after installation can be minimised by seasoning the timber to near the equilibrium moisture content before use.  See Section 5 for methods of calculating shrinkage in different grain directions.

## 6.5  FEATURES OF SAWN TIMBER

Several important features are apparent in sawn timber.  These depend on how the tree grew, its species, and how it was sawn and dried.  In order of importance, the main features that affect strength and stiffness are:

- knots
- sloping grain
- corewood (or juvenile wood)
- compression wood
- splits, checks and shakes
- warp (or distortion)
- pitch pockets
- wane

Limitations on these features are the basis of visual grading rules.

## KNOTS

Knots appear in sawn timber as a result of the wood grain "flowing" into the branches in the living tree. The shape of a knot on a sawn surface depends upon the direction of the saw cut with respect to the axis of the branch. When a branch is sawn through at right angles to its length, a nearly circular knot results as shown in Figure 12(a). When the branch is sawn through lengthwise a "spike knot" appears as shown in Figure 12(b). Sawing diagonally produces an oval knot. A "dead knot" or an "encased knot" results when the tree has grown around a dead branch; these knots sometimes fall out leaving a hole right through the board. Most often, "live knots" or "inter-grown knots" result from sawing trees in which the branches were still alive. Douglas-fir differs from radiata pine in its branching as it does not form discrete whorls of branches in the living tree, resulting in a more random arrangement of small knots in the boards with less reduction in strength.

All types of knots will decrease most mechanical properties because:

- there is loss of load carrying cross section
- the fibres in the area of the knot are distorted, resulting in perpendicular-to-grain stresses
- checking or splitting often occurs around knots when the wood dries

Because sloping grain causes a greater reduction of tension strength than compression strength, knots also causes a greater reduction of tension strength than compression strength. For a simply supported beam, a knot will have the greatest strength-reducing effect when it is situated in the centre of the span on the lower side, where the tension stress is highest. Since knots also affect stiffness, they can decrease the buckling strength of columns.

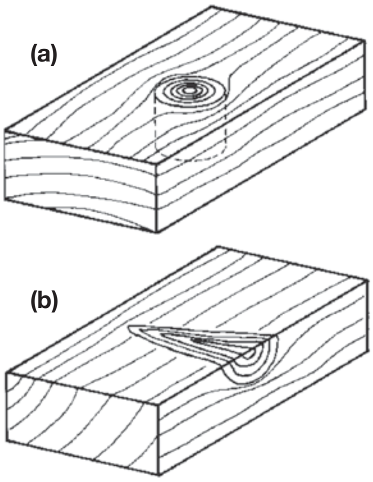



*Figure 12. Knots. (a) circular knot, (b) spike knot.*

## SLOPING GRAIN

Sloping grain lowers the strength of sawn timber. Sloping grain in a tree refers to the angle of the grain not being parallel to the longitudinal axis of the tree trunk, whereas sloping grain in wood refers to the grain not being parallel to the longitudinal axis of the wood member cut from the tree. Sloping grain may be local, or it may be over the whole cross section, due to several causes:

- the grain was disturbed locally in the growing tree due to a branch
- the board was sawn parallel to the pith of the tree, but the log had pronounced taper (resulting in "diagonal grain")
- the log had fibres growing in a spiral direction about the trunk of the tree instead of in a straight direction (called "spiral grain") as shown in Figure 13.

Slope of grain is not always visually detectable, although it may have significant effects on strength. In radiata pine there are often small brown longitudinal flecks in the wood which help to identify sloping grain.

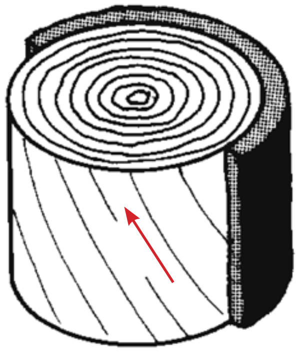


*Figure 13. Spiral grain in a tree.*

## COMPRESSION WOOD

"Compression wood" has been described earlier. It is weaker than normal wood, and is comparatively brittle. Unfortunately it is very difficult to identify compression wood in sawn timber, although a greater proportion of summerwood, and increased opacity may be present. Boards with some compression wood are likely to suffer greater distortion when the wood dries, in which case the boards will be downgraded for the distortion rather than for the compression wood itself.

## SPLITS, CHECKS AND SHAKES

Splits, checks and shakes are cracks or fissures parallel to the main axis of the tree, but they each have slightly different definitions:

- A split is a separation along the grain, forming a crack or fissure that extends through the piece of wood from one surface to another.
- A check is similar, except that the fissure does not extend all the way through the piece.
- A shake is a separation occurring between annual growth rings.

A shake and a check are shown in Figure 14. Splits and checks are usually the result of differential shrinkage during drying which often occurs because the end grain of a piece of wood will dry more quickly than the rest of the piece, and thus will shrink faster. The differential strain can cause splits or checks. Coating the end grain or drying at a slow rate can reduce this occurrence. Checks and splits can cause significant loss of shear strength. They also create cosmetic and durability problems, because an unbroken paint film cannot be maintained over a split or check. A pitch pocket is an opening between growth rings (i.e. a shake), which contains (or has previously contained) resin, or bark, or both.

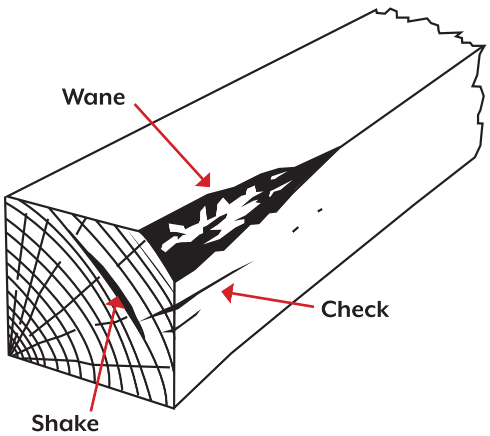



*Figure 14. Shake, Check and Wane.*

## WANE

Wane is a lack of wood at the corner of a board, as shown in Figure 14, usually caused by the sawmill cutting too close to the outside surface of the log. A small amount of wane is not a serious strength-reducing defect because the wood at the outside of the log is usually the strongest wood in the tree, so that boards with wane are often the strongest boards in a given population. Wane may be an unacceptable visual defect in some situations.

## WARP (DISTORTION)

If different parts of a cross section shrink at different rates, the result will be distortion of the board. This distortion is known as "warp". Warp can be due to several factors, all related to shrinkage when the wood is dried:

- Different rates of shrinkage in the radial and tangential directions of the cross section
- Higher longitudinal shrinkage on one side of the board, due to the local presence of corewood or compression wood
- Uneven drying, with one side of the board drying more quickly than the other
- Spiral grain in the board, resulting in twisting when the board dries

Warping can cause the sides of the board to deviate from plane surfaces. There are four main types of distortion referred to as warp, as shown in Figure 15:

- Bow
- Crook
- Cup
- Twist

Warp can cause an apparent decrease in strength, because straightening forces can add extra unexpected stresses. Warp is also inconvenient for building for many practical reasons. Warp is generally prevented by careful seasoning, restraining the timber in a straight position during drying.

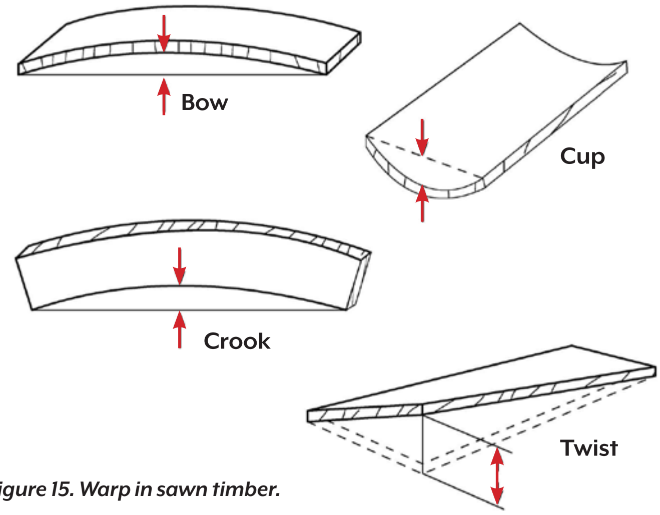



*Figure 15. Warp in sawn timber.*

# 7. MANUFACTURED TIMBER PRODUCTS

Trees are felled, limbed, cut into logs and transported to sawmills or other processing facilities where they are converted into sawn timber or other products.

## 7.1 ROUNDWOOD

*Roundwood* refers to naturally round wood such as posts and poles which are often used in structural applications. Roundwood is inexpensive because it requires very little processing, and poles are stronger than similar sizes of sawn timber. There are many advantages of using roundwood in applications such as foundations, retaining walls, farm buildings, pole houses, and many others.

## 7.2 SAWN TIMBER

*Sawn timber* refers to simple rectangular boards of timber which are sawn from a log in a sawmill. The most common sawn timber boards have a thickness of 45mm, with widths of 90, 140, 190, 240 or 290mm. Special orders may be requested for larger sizes, which will often be a higher price.

These dimensions are nominal sizes which depend on the moisture content of the wood. Shrinkage and swelling will result in slightly larger sizes in boards with a high moisture content and slightly smaller sizes in dry boards.

## 7.3 GLUED LAMINATED TIMBER

*Glued laminated timber (glulam)* can be manufactured in almost any size and shape by gluing sawn timber boards together. Curved glulam beams are more expensive than straight beams because the tighter the radius of curvature, the thinner the laminates, requiring additional machining and additional quantities of adhesive. Glulam is often manufactured from chemically treated timber for enhanced durability, especially for exposed outdoor applications.

## 7.4 LVL

*Laminated veneer lumber (LVL)* is a structural panel product manufactured from thin peeled veneers of wood (about 3mm thick), rather like thick plywood, but with all the grain running in the longitudinal direction. Long lengths are possible from a continuous manufacturing process. Structural LVL members such as beams and columns have high strength and stiffness because all the grain runs parallel to the main axis of the member. Some manufacturers can produce more expensive cross-banded LVL with two or more veneers rotated 90˚ to give increased stability and resistance to splitting.

## 7.5 CLT

*Cross laminated timber (CLT)* is made from sawn timber boards glued together in layers at 90° to each other as shown in Figure 16, rather like very thick plywood. CLT is manufactured in large panels several metres in each direction. The individual board thickness is usually between 10 mm and 40 mm. The most common layups are three-ply, five-ply, or seven-ply, so the finished thickness of typical panels is from about 40 mm (3 thin layers) to 300 mm (7 thicker layers).

Most CLT is used for pre-fabricated building systems, with pre-assembled panels for walls or floors. Most CLT panels are glued with one-component polyurethane adhesive, although some overseas manufacturers offer other adhesives or even non-glued panels where the boards are held together with nails or hardwood dowels.

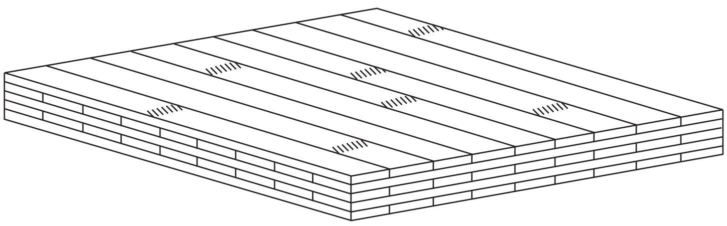


***Figure 16. Typical cross laminated timber (CLT) panel.***

## 7.6 PLYWOOD

*Plywood* is a panel product made up of thin layers (or plies) of peeled veneer (3mm thick), with the grain of adjacent layers at right angles. Typical panel sizes are 1.2m wide by 2.4m to 3.0m long. The thickness of structural plywood can range from about 7 mm to 30 mm. Plywood has several advantages as it has high strength, stiffness, and stability both in the length and width of the panel, and can be made highly durable if suitably treated. Structural plywood is often used for flooring, bracing, and other components such as I-beams and folded plate roofs.

## 7.7 OTHER PANEL PRODUCTS

There is a range of other wood-based panel products, sometimes used for flooring, linings, insulation, furniture, joinery and packaging. They have a number of advantages over solid wood in that they are easily worked, cheaper, more stable and have more consistent properties. On the other hand, they are often not durable, especially in wet conditions.

### STRAND BOARD

*Strand board* is a class of panel products made from wood flakes or strands rather than fibres or particles. These can be aligned in the manufacturing process to give *oriented strand board* (OSB) which has high strength and stiffness in one direction, with properties approaching those of plywood.

### PARTICLEBOARD

*Particleboard* is made from small wood chips or particles, bonded together with adhesive. It is commonly made from residues from processing solid wood. Particleboard has relatively low strength and stiffness compared with plywood. It is usually used for flooring, rather than primary structural purposes.

### HARDBOARD

*Hardboard* is a fibre board which depends on the natural bonding of the fibres without added adhesive. High pressure is used to achieve a high density material. It can be treated to produce tempered hardboard which is strong and moisture resistant.

### MEDIUM DENSITY FIBREBOARD

*Medium density fibreboard* (MDF) is a board with the bond between the fibre coming from added adhesive. MDF is used extensively in furniture and joinery, because it has superior strength to conventional particleboards and can be given a superior edge. MDF can be used for flooring, or as an interior lining material, but is not often used for structural purposes. Triboard is a proprietary product made of outer layers of MDF and an inner core of low grade wood particles.

### STRUCTURAL INSULATED PANELS

There is a range of products known as *Structural insulated panels* (SIPs) consisting of a structural skin either side of an insulated core. Wood-based structural insulated panels often consist of outer layers of oriented strand board (OSB) outside an insulated core of foamed plastic.

# 8. STRENGTH PROPERTIES OF SAWN TIMBER

## 8.1 RELATIONSHIP BETWEEN STRENGTH AND STIFFNESS

The relationship between stress and strain (force and deflection) of defect-free wood is shown schematically in Figure 17. Wood is much stronger parallel to grain than perpendicular to grain, by a factor of about 10 to 20. For this reason, structural members are designed to take advantage of the high strength parallel to the grain. When considering the strength of wood in different directions, it is convenient to consider the wood structure to consist of parallel hollow fibres rather like a bundle of drinking straws, as shown in Figure 18.

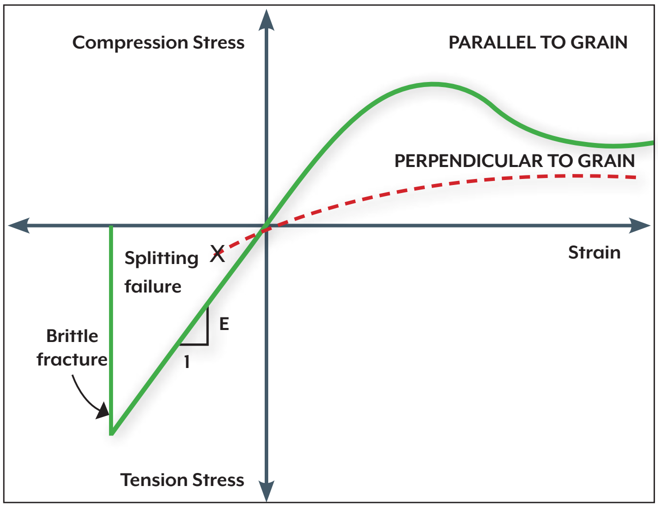



*Figure 17. Idealised stress-strain relationship for clear wood.*

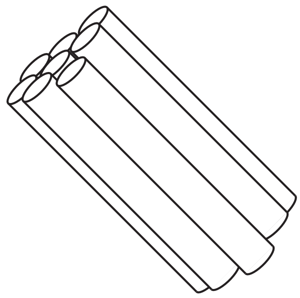


*Figure 18. Simplified wood structure consisting of parallel tubes.*

## 8.2 COMPRESSIVE STRENGTH

### PARALLEL TO GRAIN

When wood is stressed in compression parallel to the grain (Figure 19 (a)), each wood fibre acts as an individual hollow column, although the fibres give and receive support to neighbouring fibres. At failure, fibres buckle simultaneously producing a local failure visible on the wood surface, often called a compression crease. When wood is deformed in compression beyond its maximum load, it has the ability to maintain reduced strength in a non-linear range as shown in Figure 17.

### PERPENDICULAR TO GRAIN (BEARING STRENGTH)

Wood is weaker in compression perpendicular to grain because the cell walls do not offer much resistance to crushing. The ultimate compression strength perpendicular to grain (the bearing strength) is difficult to measure precisely, because of the continuously rising stress-strain curve shown in Figure 17 and because of the effect of unloaded adjacent areas shown in Figure 19 (b). Under severe loading, deformation continues until the wood substance is fully compressed, which is at about one third of the original volume.

The values of compression strength perpendicular to the grain, as presented in standards and manufacturers' documentation, are bearing capacities perpendicular to the grain at a certain level of deformation. The testing method for bearing strength perpendicular to the grain, as specified by AS/NZS 4063.1, states that the test deformation value is 2mm.

If the loaded surface is only part of the resisting member (as shown Figure 19 (b)) the fibres in unloaded areas assist those directly loaded, so small areas can develop higher unit stresses than larger areas. This is quantified by the Bearing Factor $k_7$ in Table 2.6 of NZS AS 1720.1.

A much more comprehensive coverage of bearing strength is given in Eurocode 5, which defines an effective contact area, 30mm wider than the actual contact area on each side, with an additional increase in strength depending on the wood material and the underlying support. This is described by Blass and Sandhaas (2017).

### ANGLE TO GRAIN

The compressive strength at an angle to the grain (Figure 19 (c)) is intermediate to the strengths parallel and perpendicular to the grain. Formulae such as Hankinson's formula are available to interpolate the strength at various grain angles.

The compression strength of wood is affected by wood defects, but the affect is often not very great because compression stresses can be transferred through many defects.

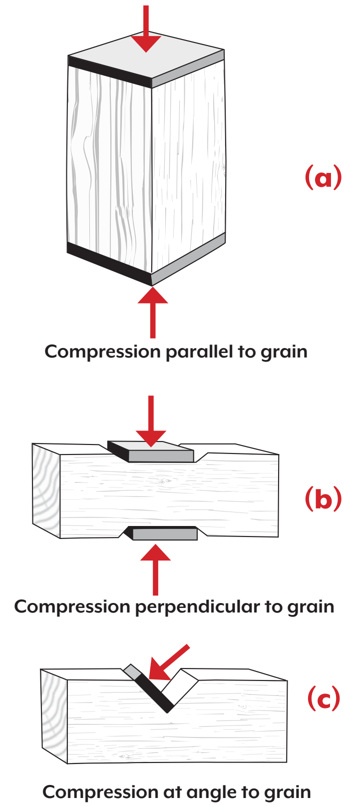



*Figure 19. Wood stressed in compression.*

## 8.3 TENSILE STRENGTH

Clear wood is very strong in tension parallel to grain (see Figures 17 and 20). However, tensile failure in wood is inherently brittle. If a member contains defects such as knots, holes, notches or cuts, not only is there a net loss of area, but there is also a stress-concentrating effect reducing tensile strength even further. The effect of defects is much greater in tension than in compression.

Wood is very much weaker in tension perpendicular to grain, where failure results in splitting, with separation between the wood fibres. It is good design practice to avoid stressing wood in tension perpendicular to grain. However, these stresses are unavoidable in some structures such as curved members in which case the stresses must be kept below acceptable limits.

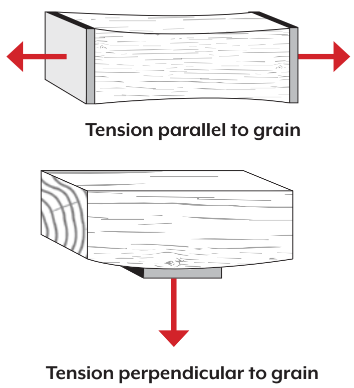



*Figure 20. Wood stressed in tension.*

## 8.4 BENDING STRENGTH

Bending induces both tensile and compressive stresses (see Figure 21). The bending strength of wood depends on the relative values of the tensile and compressive strengths, each of which can depend on the presence of defects in the wood. The bending behaviour and the bending strength are different in defect-free specimens compared with commercial timber with defects in the tensile zone.

In a clear wood beam, the tensile strength is much higher than the compressive strength. As load on the beam is increased, the bending behaviour becomes non-linear (at the proportional limit) after the wood in the compressive zone begins to crush (see Figures 22 and 23). Because the compressive behaviour of wood has residual non-linear strength as shown in Figure 17, there is now a redistribution of the stresses within the beam, leading to a drop in the neutral axis in order to maintain internal equilibrium. Stresses continue to increase until the extreme fibre stresses at the bottom of the beam reach the failure stress of the wood, at which point a brittle fracture occurs, as shown in Figure 22(c).

In a wood beam with defects in the tensile zone, the tensile strength of the wood is less than the compressive strength. Failure occurs when the extreme fibre stresses at the bottom of the beam reach the failure stress of the wood, before any crushing in the compressive zone and before any non-linear behaviour.

The *modulus of rupture* is the apparent failure stress, assuming linear elastic behaviour. It is calculated by dividing the bending moment at failure by the elastic section modulus. For wood with tensile defects (Figure 22(a)) the modulus of rupture is a good estimate of the failure stress in the tensile zone. For wood with no defects, the modulus of rupture has no physical meaning, but it provides a notional failure stress intermediate between the compression and tension strengths of the wood. The characteristic modulus of rupture is presented in NZS AS 1720.1 as the characteristic bending strength, $f'_b$ for design of timber beams.

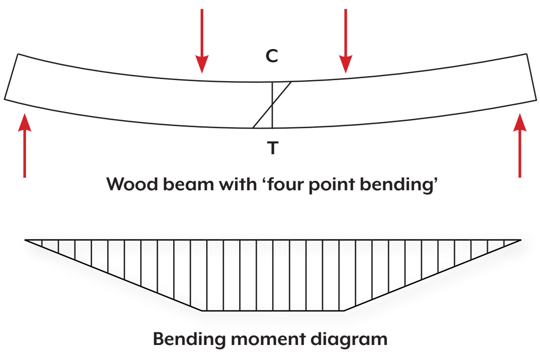



*Figure 21. Wood stressed in bending; top in compression (C), bottom in tension (T).*

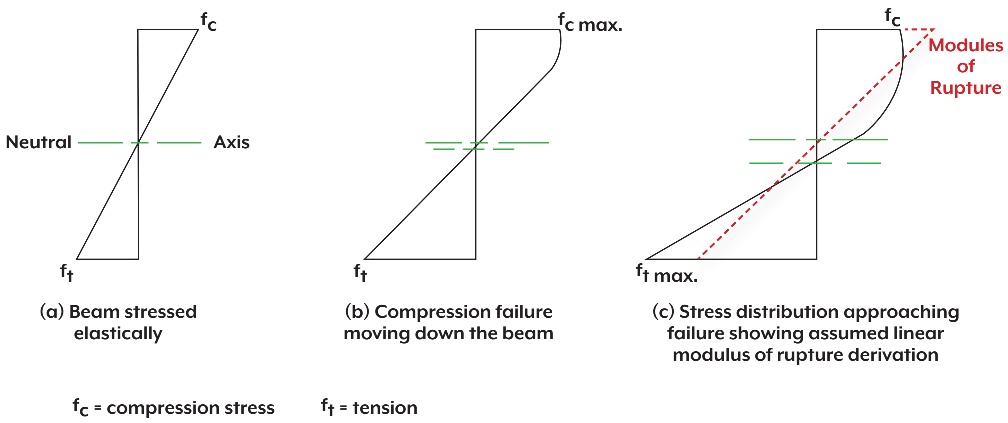



*Figure 22. Stress distribution in a beam at failure, depending on the ratio of tension to compression strength; (a) beam weaker in tension than compression, (b) beam about equal in tension and compression (c) beam stronger in tension (from FRI Bulletin 41).*

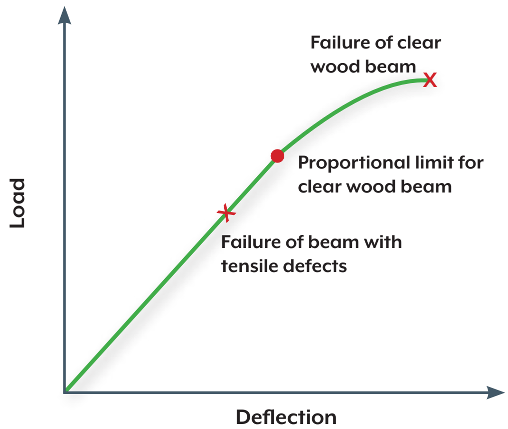



*Figure 23. Load deflection plot for wood in bending.*

## 8.5 SHEAR STRENGTH

There are 3 different shear strengths in wood; vertical shear, longitudinal shear and rolling shear, as shown in Figure 24. Wood is very strong when the shearing force and shearing plane are perpendicular to the fibres (vertical shear). It is much less strong in longitudinal shear, where the shearing force and shearing plane are parallel to the fibres. In a beam, longitudinal shear stress is maximum near the ends of the beam at the height of the neutral axis and it can be checked using conventional engineering methods. Shear failure will be a horizontal sliding parallel to the grain as shown in Figure 25. Any holes, notches or cuts which reduce the effective shear resisting area can cause stress concentrations and lead to premature shear failures. The characteristic longitudinal shear strength for structurally graded radiata pine and douglas fir beams is given in NZS AS 1720.1.

Shear strength is even less strong in rolling shear, where the shearing force is perpendicular to the fibres but the shearing plane is parallel to the fibres. This shear mode is not stressed in an ordinary wood beam, although it does occur in plywood, in CLT, and in some glued connections.

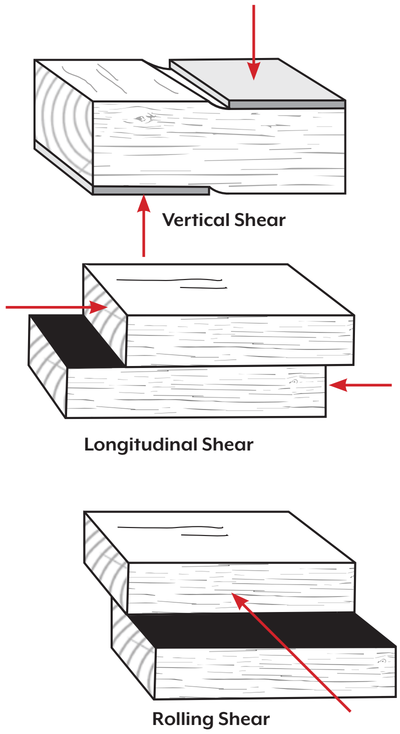



*Figure 24. Wood stressed in shear*

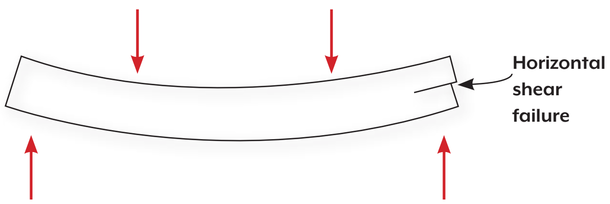
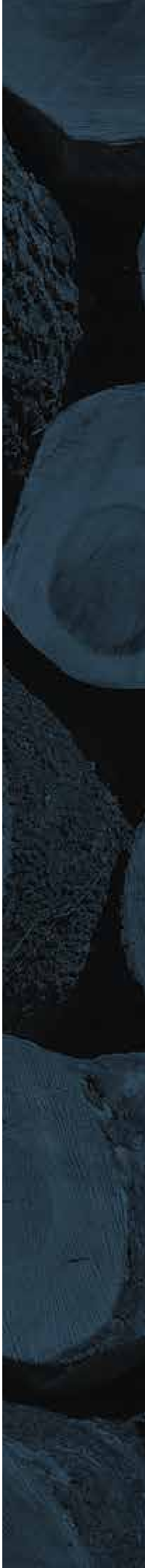



*Figure 25. Typical shear failure in a wood beam.*

## 8.6 TORSIONAL STRENGTH

Wood structural elements are seldom loaded in torsion. Calculations can be based on the relevant shear strengths and moduli. The shear modulus, G (sometimes referred to as the Modulus of Rigidity) of wood is not often measured, but is usually taken as E/15 where E is the longitudinal modulus of elasticity.



# 9. STATISTICAL VARIATION OF STRENGTH PROPERTIES

## 9.1 UNGRADED TIMBER

Any population of timber boards will have a range of strength and stiffness. Within a sample population of ungraded timber, the strongest boards may be up to five times stronger than the weakest boards. For graded timber, the variability between boards (and the shape of the statistical distribution) will depend on the accuracy of the grading method and the number of grades chosen by the producer. For example, variability will be less with an accurate grading method and a tightly defined set of grade classes, and vice versa.

It is important for designers to understand that when specifying timber of a particular grade, up to 5% of the delivered boards may be weaker than the code-specified strength, and up to half of the boards may have stiffness less than the code-specified MoE, depending on the shape of the distribution. This is because of the way design strength and stiffness values are defined.

Sawmillers can decide to offer single grades or combinations of grades, depending on their raw material. For example, weak boards can be "upgraded" by combining them with better material, to increase the 5th percentile strength or mean MoE of the whole population without any change in the wood properties of the weak boards. Such mixing may not be economic if it significantly reduces the assigned design values of the better material.

As an example of the strength distribution of a typical population of broken boards, Figure 26 shows a histogram of strength values, from the results of 100 randomly selected boards tested in bending. The plotted values show the number of boards in each 5 MPa grouping of strength. In this sample, the weakest board failed at 22 MPa and the strongest at 93 MPa, with a mean value of 51 MPa. It can be seen from the figure that the distribution is only roughly symmetrical.

Figure 27 shows the same data sorted from weakest to strongest on the x-axis, and plotted as a cumulative distribution function with probability F(x) from zero to 1.0 on the y-axis. Each data point represents one broken board. The 5th percentile value of 32 MPa is shown by the dotted vertical line, dropping from the point where the horizontal line from F(x)=0.05 meets the plotted data. This is the value which would be used as the characteristic strength for design using this population of boards.

Figure 28 shows a scatter-graph of the bending strength (modulus of rupture) and stiffness values for the same population of boards. The 5th percentile modulus of rupture and the average stiffness are shown as the design values which can be found in NZS AS 1720.1.

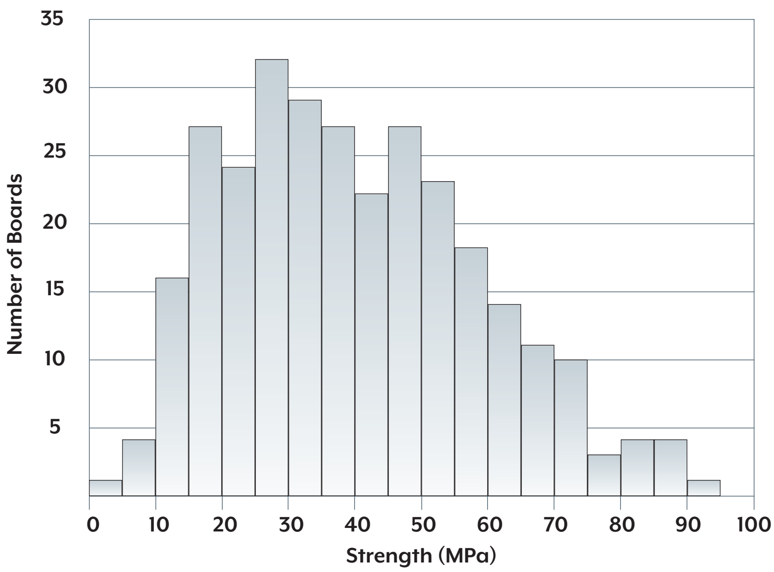



*Figure 26. Histogram of strength values.*

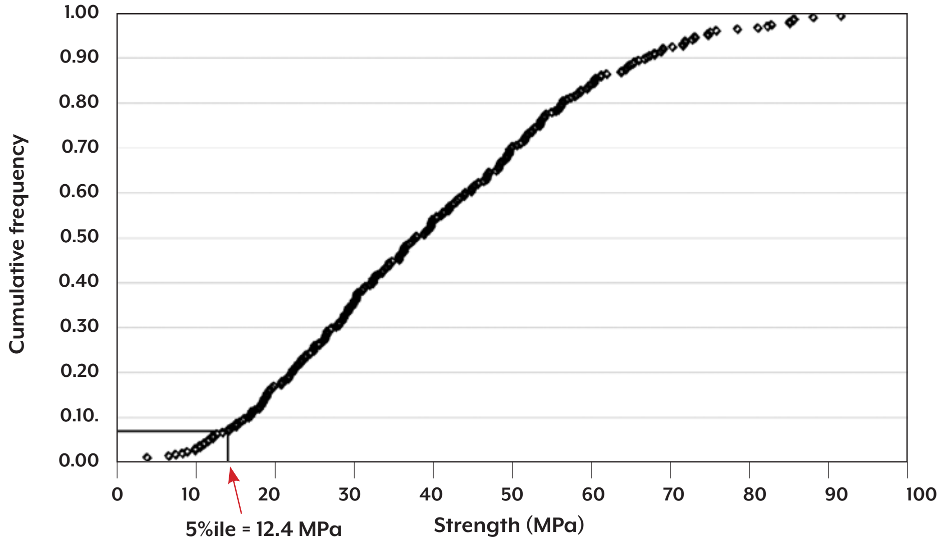



*Figure 27. Same data as in Figure 25 plotted as a cumulative distribution function.*

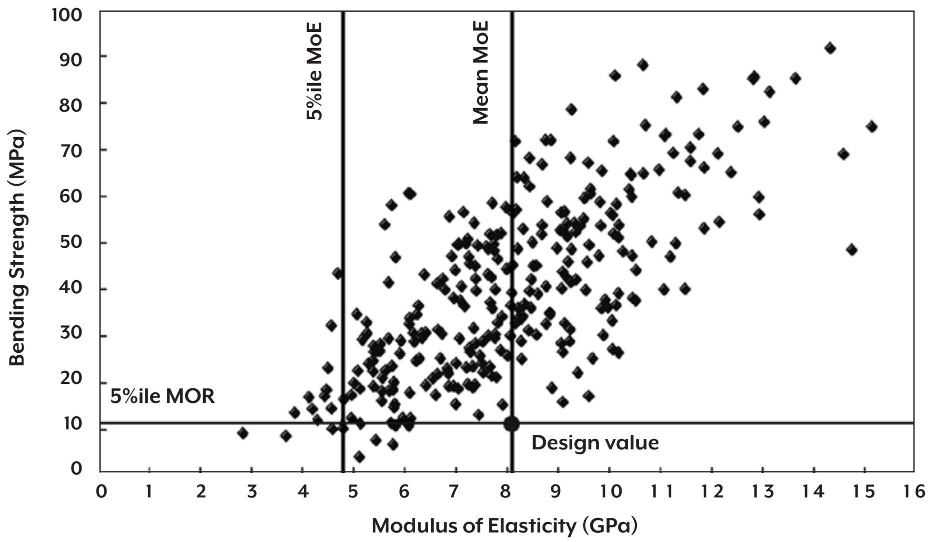



*Figure 28. Scatter-graph of bending strength and stiffness values for the same boards.*

## 9.2 GRADED TIMBER

The same principle can be used for plotting the distributions of timber after grading. Timber can be graded by either visual grading or by machine stress grading, with its properties verified and identified in accordance with NZS 3622. Verified timber is given the denomination 'SG' for Structurally Graded.

Figures 29 and 30 show the stiffness and strength, respectively, of a population of timber after machine stress grading into several verified grades, all plotted as cumulative distribution functions. It can be seen in Figure 27 that the grades have clear differences in the distribution of stiffness, which is not surprising because the grading was done by measuring the stiffness. The difference in strength between the grades (Figure 30) is much less than the difference in stiffness (Figure 29), especially at the 5th percentile level. It can be seen that very few boards from this population were stiff enough to be graded as SG12.

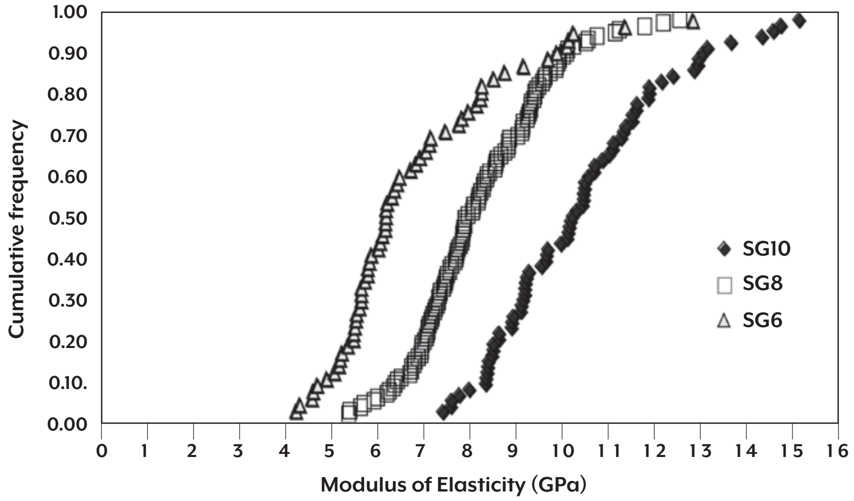



*Figure 29. Distributions of stiffness after sorting into three grades.*

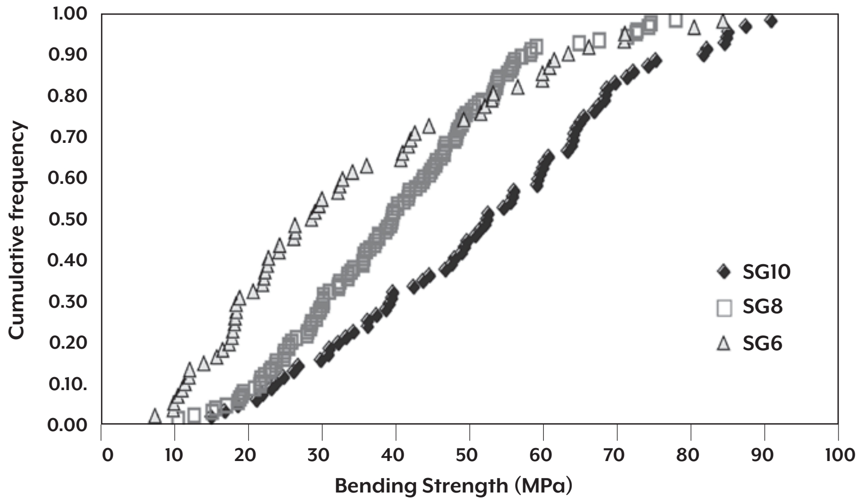



*Figure 30. Distributions of strength of the same three grades.*

## 9.3 ENGINEERED WOOD PRODUCTS

Engineered wood products (EWPs) tend to have much less variability in mechanical properties than sawn timber, because they have fewer significant defects.

For this reason there can be a larger difference in characteristic strengths between sawn timber and EWPs than the difference in mean strengths, as shown in Figure 31, for European grades GL30 glulam and C30 sawn timber. The variability may be even less in an engineered wood product manufactured from many layers, such as LVL.

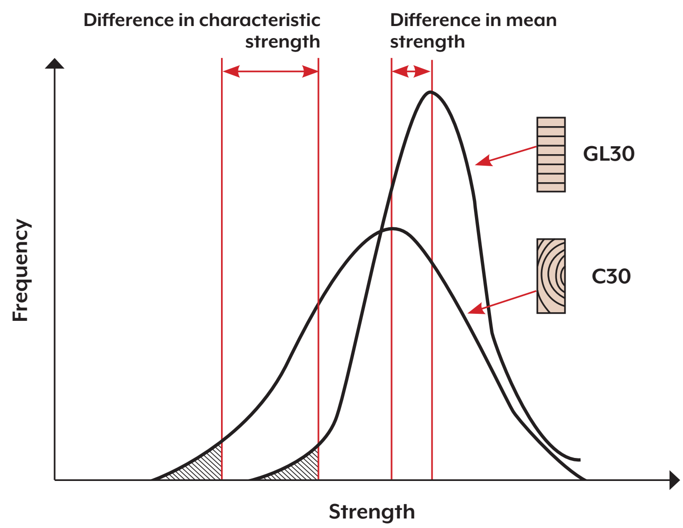



*Figure 31. Distribution functions for the strength of glulam beams and structural sawn timber*

# 10. OTHER FACTORS INFLUENCING STRENGTH PROPERTIES

## 10.1 MOISTURE CONTENT

The strength and stiffness of wood are higher in dry wood than in moist wood. The design properties for "dry" wood are usually given for wood with a moisture content of 15%, as shown in Tables 6 and 7. The design properties for "green" wood should be used for any wood with moisture content over 20%. As a rough rule of thumb, the bending strength and the compression strength both decrease by about 5% for each 1% increase in moisture content (ref TDG).

## 10.2 SIZE EFFECTS

When testing most brittle materials, including wood, the failure stress tends to decrease slightly as the size of the test specimen increases. With wood, this effect is most pronounced for brittle failure modes in tension, such as in large beams or tensile members. The reason for this size effect is that large members have a greater statistical probability of containing a critical defect.

This is one of the reasons why the results of small clear tests cannot be used directly for design of large members. Some timber design codes include a size factor to allow for this effect, but this is not necessary if verification of timber strength is done in the sizes which will be used for construction.

The impact of size is commonly considered on glue laminated timber (glulam) and laminated veneer lumber (LVL) structures. Characteristic bending strengths and tension strengths in NZS AS 1720.1 are to be multiplied by the volume/size reduction factor $k_v$ for this reason.

## 10.3 DURATION OF LOAD

Wood subjected to load for a long period of time tends to fail at lower loads than in short term testing. This effect is included in design codes by publishing the strength value for short term loading with factors to reduce the strength for long term or permanent loading.

The duration of load is allowed for in NZS AS 1720.1 through the use of the duration of load factor for strength, $k_1$.

## FATIGUE

Compared to other traditional structural materials, wood has good resistance to the effect of cyclic loading. Fatigue does not need to be considered in normal structural design.

## PRESERVATIVE TREATMENT

Chemicals used in preservative treatment affect the strength of wood very little, so no reduction in design stresses is required. The only exception is a small reduction in strength when wood is steamed as part of the treatment process. Fire retardant chemicals have some effect on strength, and North American codes specify a 10% reduction in design stresses. There is no similar consideration in NZS AS 1720.1, however where such products are used, designers should check to ensure that no reduction is needed.

## ELECTRICAL, THERMAL, ACOUSTIC PROPERTIES

### ELECTRICAL

The electrical resistance of wood is very high when it is dry, but this decreases by 0.3% moving from oven-dry to the fibre saturation point. Electric moisture meters utilise this property to measure moisture content in wood. The meters are inaccurate above the fibre saturation point (25-30%). Like many poor conductors, wood can be heated by subjecting it to a high-frequency radio electric field. This property is used to cure heat sensitive adhesives in the manufacture of glue laminated timber and some other wood products.

## THERMAL PROPERTIES

### Expansion

Like most materials, wood expands on heating, but compared to other structural materials the thermal expansion is very small. A compensating factor is that as the temperature rises the equilibrium moisture content reduces and the wood may dry out, causing shrinkage. Only in very long spans, such as in bridges or large floor areas is it necessary to consider thermal movement. However, differential thermal expansion may need to be considered when other materials are used in conjunction with wood.

Some wood-based panel products such as medium density fibreboard (MDF) have greater thermal expansion than solid wood. This may need to be allowed for with expansion joints.

### Conductivity

The thermal conductivity of wood is about 1/400 that of steel, making it an excellent natural insulator. This is due to the air pockets within its cellular structure. Lighter wood has bigger cavities and is a better insulator. Thermal conductivity also decreases with lower moisture content. Thermal conductivity is greater parallel than perpendicular to the grain, and is thus affected by structural irregularities such as checks and knots.

### Insulating construction

Timber wall and floor assemblies can be constructed with excellent thermal insulating properties. Materials such as fibreglass batts and building wraps can be built into timber assemblies to improve thermal performance.

## TEMPERATURE EFFECTS

Wood strength is affected by temperature, to a relatively small extent, compared with materials like steel. Whereas steel becomes brittle at low temperatures, wood becomes stronger. Wood strength reduces with increasing temperature, but design stresses for timber are safe for wood exposed to continual temperatures of up to 40°C with occasional exposures up to 50°C.

NZS AS 1720.1 considers that for most situations in New Zealand, the temperature will not impact design strengths. The temperature effect factor, $k_6$, is therefore set to 1 unless special conditions apply. Very dry wood (close to 0% moisture content, in very hot or cold environments) has been found to be more brittle than wood at normal moisture contents.

## ACOUSTIC PROPERTIES

Sound insulation refers to the ability of wood to reduce the intensity of sound passing through it. Wood has internal friction about 10 times that of steel, which means that it is more efficient for damping of vibrations. However good sound insulation also depends on other factors such as the barrier material having a high mass, and low rigidity, or containing air spaces and no rigid ties from one space to another. With careful design it is possible to obtain a timber structural unit with excellent sound insulation properties.

Sound absorption refers to the amount of incident sound on a surface which is not reflected by that surface. Sound absorption depends on the frequency, and is considerably higher for wood than materials such as concrete. See the WPMA Design Guide on Acoustic Design for more information.

# 11. GRADING OF STRUCTURAL TIMBER

This section describes grading systems for structural sawn timber. Methods of verifying the grades are described later.

There are three basic ways of obtaining material design stresses for different grades of timber:

1. Most designs will be carried out using verified timber.
2. A second option is to use non-verified timber which has been visually graded,
3. A third option is to carry out specific testing in accordance with AS/NZS 4063, as described below.

## 11.1 GRADING SYSTEMS

Grading refers to any system of classifying timber for specific end uses. Sawn timber will generally have large variability in strength and stiffness between individual pieces, so the pieces need to be sorted into a limited number of grades for convenience in distribution, merchandising and standardisation. Grading is essential to reduce the variability in timber properties for structural design.

Structural grades have assigned values of strength and stiffness, for use by designers of buildings and other structures. Other grades, such as appearance grades for cladding, furniture, finishing and other non-structural uses, do not have assigned design values. Structural grading can be done visually according to visible features, or mechanically using a device that measures the Modulus of Elasticity of the timber, or a combination of both.

Grading systems establish a number of strength classes, so that sawmillers can use whatever technique or equipment they wish to segregate their production into the different classes, with specified methods for verifying that the sorted timber meets the stated requirements.

Strength classes work well for structural designers because they can make all their calculations using a particular strength class, leaving the timber supplier with responsibility for providing verified timber with the specified properties.

## 11.2 STRUCTURAL GRADES

For many years, timber grading in New Zealand was done by visually grading a very small number of structural grades, with no verification of strength properties. Current structural grading requires testing for verification.

The current range of verified structural timber grades is shown in Table 6, (Table 2.1 from NZS AS 1720.1). These grades are applicable only to radiata pine and douglas fir grown in New Zealand, unless additional verification is carried out. See the section on Verification later in this guide.

For structural graded (SG) timber, the SG grade number refers to the short duration average modulus of elasticity assigned to that grade. For timber produced by visual grading but not verified, there is only one grade, No.1 Framing grade, with strength properties similar to SG6, as shown in Table 7 (Table 2.2 from NZS AS 1720.1).

## 11.3 METHODS OF GRADING STRUCTURAL TIMBER

In the grading process, every timber board is assessed to assign it to a particular grade. The two main methods of structural grading are visual grading and machine stress grading, but there are many other possible methods as mentioned below.

### VISUAL GRADING

Visual grading is a historic and widely practised way of segregating timber for different uses. Visual grading rules limit the sizes of knots and other visible features according to the reduction that they make in the properties of clear defect-free timber. Visual grading is not able to precisely predict the strength properties of timber. For example, Figure 32 shows the very poor correlation between knot size and bending strength in 90 x 45mm boards of radiata pine timber.

NZS AS 1720.1 allows for visual grading of un-verified No. 1 Framing grade and verified SG timber up to SG10. The main visual characteristic defining No. 1 Framing grade in NZS 3631 is that no knot or combination of knots should occupy more than one third of the cross section of any board.

NZS 3622 specifies verification methods for visually graded timber.

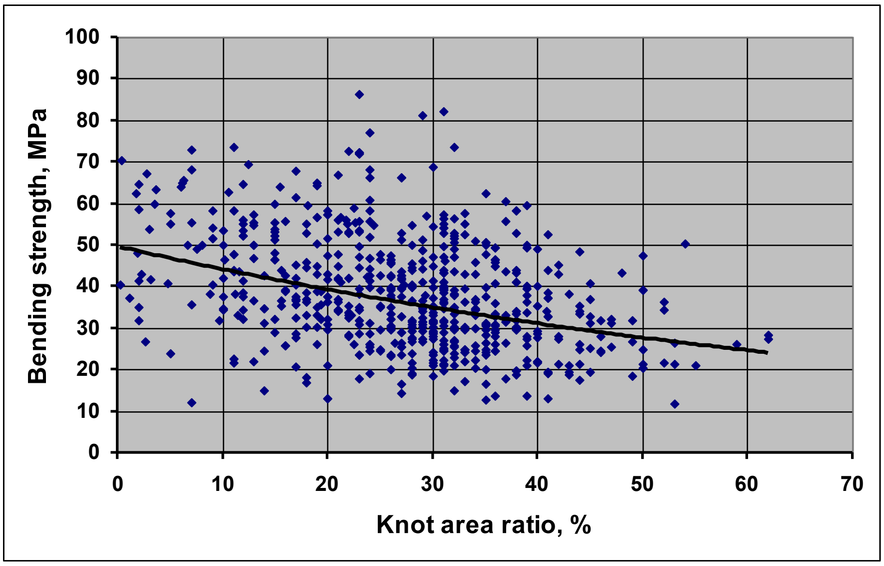



*Figure 32. Relationship between strength and knot area ratio in radiata pine timber.*

## MANUAL DEFLECTION GRADING

Testing for stiffness can be done very simply by bending a board on the flat over a convenient span, applying a weight at the centre, and measuring the deflection. This is known as the "Three Brick Test" and is convenient where there is some doubt about the properties of a particular piece of timber.

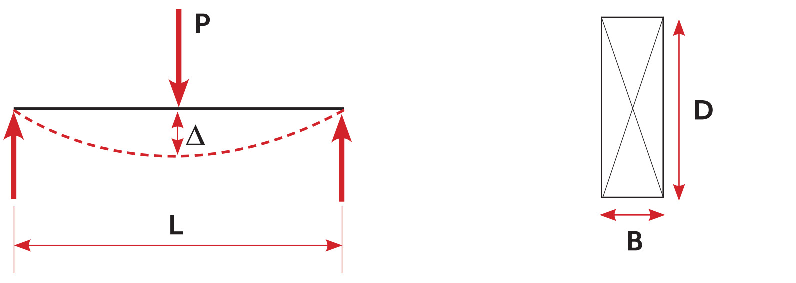
With reference to Figure 33, if the mid-span deflection Δ (mm) is measured under the application of a load P (N), over a span of length L (mm), the MoE (MPa or N/mm$^2$) can be calculated from the formula

$E = P L^3 / 48 \Delta I$

The moment of inertia I (mm$^4$) is calculated from

$I = B D^3/12$

where B (mm) is the breadth of the board and D (mm) is the depth of the board.




*(a) Test arrangement* *(b) Cross section of tested board*

*Figure 33. The "Three Brick Test" for manually obtaining the Modulus of Elasticity of a board.*

## MACHINE STRESS GRADING

Machine stress grading passes timber boards through a system of rollers, using the relationship between applied load and bending deflection to calculate the flat-wise flexural stiffness, or Modulus of Elasticity (MoE), of each board at several locations along its length.

Some stress grading machines apply a given load and measure the bending deflection, whereas other machines measure the load to impose a given deflection. In either case the only output is the MoE of the wood, using the formula given above. This may be single bending as shown in Figure 34 or double bending as shown in Figure 35.

## MARKING OF GRADED BOARDS

Most machine grading methods use coloured paint marks to indicate the grade of each board. This can be measured and marked every 100mm along the length, or continuously along the length in some machines, in accordance with Appendix A of NZS 3622. Brands, stamps or labels indicating the grade may also be used.

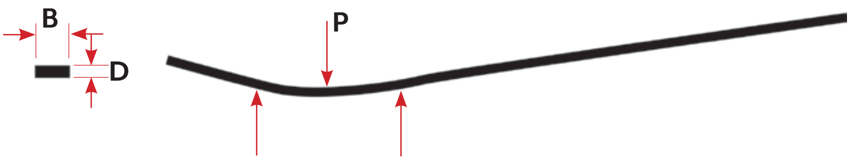



*Figure 34. Single bending stress grading machine.*

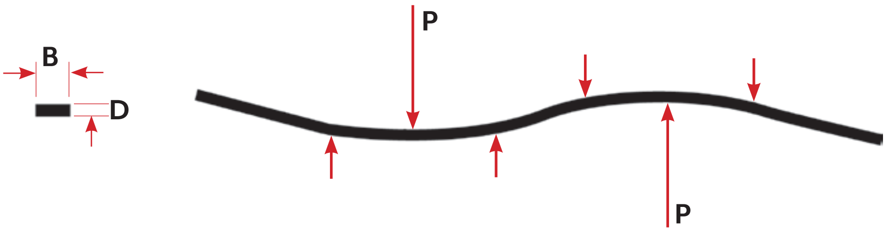



*Figure 35. Double bending stress grading machine.*

# 12. STRUCTURAL DESIGN PROPERTIES OF TIMBER

Information on sources of characteristic design values of strength and MoE for standardised stress grades of structural sawn timber, structural plywood, round timber, glue-laminated timber and structural laminated veneer lumber are given in Clause 2.2.1 of NZS AS 1720.1. The only values given in this guide are those for sawn timber.

## 12.1 SMALL CLEARS TESTING VS. IN-GRADE TESTING

There are two main types of testing to obtain wood properties, “in-grade testing” and “small clears testing”. These two test methods can give significantly different results for the strength of timber.

**“In-grade testing”** refers to testing of large representative samples of timber, in the actual sizes, grades and moisture content in which they will be used in construction, in accordance with AS/NZS 4063.

**“Small clears testing”** refers to tests on small defect-free specimens of clear wood in laboratory conditions.

Structural timber with defects behaves in a very different manner to clear wood. For example, clear wood is stronger in tension than in compression, but the reverse is true for sawn timber containing sloping grain or knots. The strength properties obtained from small clears testing are generally much higher than those obtained from in-grade testing, but the stiffness values are often about the same.

The main advantage of small clears testing is that the small test specimens are easily obtained and tested. Standard sizes for small clears tests are 20x20mm in British Standards and 50x50mm in American Standards. The test results are useful for comparing species, but a big disadvantage is the difficulty in predicting the lower strength of commercial size timber from the small clear test results.

In-grade testing requires much larger numbers of test specimens taken from commercial production, with correspondingly larger test equipment. The main advantage of in-grade testing is that the test results can be used directly to derive characteristic code values for structural design.

## 12.2 RADIATA PINE AND DOUGLAS FIR

For verified SG grades of New Zealand grown radiata pine and douglas fir, the characteristic design values for primary structural properties of strength and MoE are given in Table 6. These values have been obtained from in-grade testing.

Note that Table 6 and Table 7 give no values for the modulus of elasticity in compression perpendicular to the grain. According to Blass and Sandhaas (2017) this value is about 3% of the value in the parallel to grain direction.

The design density in Table 6 and Table 7 is the nominal density at 15% moisture content, to be used for calculation of fastener strength in accordance with Chapter 4 ofNZS AS 1720.1.

| New Zealand species | Moisture Content – Dry (m/c ≤ 15%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Stress Grade | Design density<br>kg/m$^3$ | Characteristic density<br>($\rho'$)<br>kg/m$^3$ | Bending<br>($f'_b$)<br>MPa | Compression parallel-to-grain<br>($f'_c$)<br>MPa | Tension parallel-to-grain<br>($f'_t$)<br>MPa | Tension perpendicular-to-grain<br>($f'_{tp}$)<br>MPa | Short duration average modulus of elasticity<br>($E'$)<br>MPa | Lower bound short duration average modulus of elasticity<br>($E_{lb}$)<br>MPa |
| Radiata pine & Douglas fir | SG 15 | 570 | 560 | 41.0 | 35.0 | 23.0 | 0.5 | 15200 | 11500 |
| | SG 12 | 540 | 530 | 28.0 | 25.0 | 14.0 | 0.5 | 12000 | 9000 |
| | SG 10 | 500 | 490 | 20.0 | 20.0 | 8.0 | 0.5 | 10000 | 7000 |
| | SG 8 | 450 | 440 | 14.0 | 18.0 | 6.0 | 0.4 | 8000 | 5000 |
| | SG 6 | 400 | 390 | 10.0 | 16.0 | 4.0 | 0.4 | 6000 | 4000 |

NOTES:

1. *Shear in beams for seasoned radiata pine shall be taken as $f'_s$ = 3.8 MPa. shear in beams for seasoned Douglas fir shall be taken as $f'_s$ = 3.0 MPa.*
2. *Compression perpendicular-to-grain for seasoned radiata pine and Douglas fir shall be taken as $f'_p$ = 4.5 MPa.*
3. *Short duration average modulus of rigidity shall be taken as $G' = E'/15$.*
4. *Grades shall be verified in accordance with NZS 3622.*
5. *Density is defined as (mass at 15% m/c) / (volume at 15% m/c).*
6. *The characteristic density is to be used for the design of connections using the detailed method.*

*Table 6. Characteristic Stresses for Verified Timber Grown in New Zealand (Table 2.1 in NZS AS 1720.1)*

## 12.3 OTHER EXOTIC SPECIES

For non-verified visual grades of all New Zealand grown species, the characteristic design values for primary structural properties of strength and MoE are given in Table 7.

This table applies to all native and exotic species grown in New Zealand unless the properties have been verified.

When designing with Australian grown species which are listed in AS 1720, the structural properties in AS 1720.2 should be used.

For imported timber species, designers must take care to identify characteristic values and the methods used to obtain these values.

| New Zealand species [1] | Moisture content – Dry (m/c ≤ 15%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Stress grade | Design density<br>kg/m$^3$ | Tension perpendicular-to-grain<br>($f'_{tp}$)<br>MPa | Bending<br>($f'_b$)<br>MPa | Compression parallel-to-grain<br>($f'_c$)<br>MPa | Tension parallel-to-grain<br>($f'_t$)<br>MPa | Short duration average modulus of elasticity<br>($E'$)<br>MPa | Lower bound short duration average modulus of elasticity<br>($E_{lb}$)<br>MPa |
| | No. 1 Framing [2] | 400 | 0.4 | 10.0 | 16.0 | 4.0 | 6000 | 4000 |

1. *This unverified grade is only available to timbers with an average density (at 15% moisture content) meeting or exceeding 400 kg/m$^3$.*
2. *No. 1 Framing is not verified and not subject to in-mill monitoring of strength and stiffness properties. No. 1 Framing shall be graded as a minimum to the requirements of NZS 3631.*

NOTES:

1. *Shear strength shall be taken as $f'_s$ = 3.0 MPa.*
2. *Compression perpendicular-to-grain shall be taken as $f'_p$ = 4.5 MPa.*
3. *Tension perpendicular-to-grain shall be taken as $f_{tp}$ = 0.4 MPa.*
4. *Modulus of rigidity shall be taken as G' = E'/15.*

*Table 7. Characteristic Stresses for Non-Verified Timber Grown in New Zealand (Table 2.2 in NZS AS 1720.1)*

# 13. VERIFICATION METHODS

Routine testing of random samples of stress graded timber is used to verify that the timber meets the specification of the required grade. The purpose of verifying timber is to ensure that the 5th percentile value of bending strength and the mean value of MoE are no less than the code-specified characteristic values for the desired grade.

Verification can be used for timber which has been visually graded, machine graded, or a combination of both. Most verification tests are carried out as bending tests on full-size specimens. If only the stiffness needs to be verified, non-destructive tests can be used and the tested boards can be returned to normal production. If strength needs to be verified, destructive testing will be necessary, breaking some or all of a sample of boards to obtain a statistical distribution of strength properties.

NZS 3622:2004 Verification of Timber Properties describes procedures for the initial evaluation and daily quality control of strength and stiffness. It applies to both visually graded and machine stress graded timber. The standard allows for continuous monitoring or non-continuous monitoring (batch monitoring) during sawmill production, after an initial evaluation of 30 boards to establish the stress properties of a reference sample. For continuous monitoring, it specifies a rate of sampling of one board in every 1000 for each size and grade.

In NZS 3622, the sawmiller has the option of breaking every board in a sample of boards or loading to a proof load equal to the characteristic strength.

The prescribed test method is testing on edge in bending in accordance with AS/NZS 4063 Characterization of Structural Timber. Part 1 Test Methods and Part 2 Determination of Characteristic Values. NZS 3622 can be used with any species of timber.

## 13.1 VERIFICATION REQUIREMENTS IN NZS AS 1720.1

Verification of timber is specified in Clauses 2.2.3 to 2.2.7 of the current drafy of NZS AS 1720.1, reproduced below in italics, with commentary clauses added:

### 2.2.3 VERIFIED TIMBER

***Verified timber may be produced by visual grading or by machine stress grading. In both cases the timber shall have its properties verified, and be identified, in accordance with the requirements of NZS 3622. Species other than radiata pine and douglas fir may also be verified to the characteristic values in Table 2.1 or other values in accordance with NZS 3622.***

This clause allows the use of any species of timber, provided that the strength properties are verified in accordance with NZS 3622, which requires testing in accordance with AS/NZS 4063, as described above.

### 2.2.4 VISUALLY GRADED TIMBER

***Visual grading shall only be permitted for the SG6, SG8 and SG10 grades, which, as a minimum, have been visually graded as No. 1 Framing to the requirements of NZS 3631 and verified in accordance with Clause 2.2.3.***

If timber is visually graded, then verified in accordance with NZS 3622 as meeting the requirements of SG6, SG8, or SG10, the strength properties are given in Table 6 This applies to all species of timber.

### 2.2.5 NON-VERIFIED TIMBER

***Non-verified timber has been visually graded as No. 1 Framing to the requirements of NZS 3631. Non-verified timber may be applied to volumes of sawn timber less than 20 m$^3$ at any one time. For volumes exceeding 20 m$^3$ (either produced in a single batch or continuously without changes to sawing or grading methods) the timber shall be verified in accordance with Clause 2.2.3.***

If timber is visually graded to the requirements of No.1 Framing grade, but not verified, the strength properties are given in Table 7. This applies to all species grown in New Zealand, meeting the density requirement of Note 1 in Table 7 (minimum test density of 400 kg/m$^3$ at 15% moisture content).

This clause only applies to volumes of sawn timber less than 20 $m^3$ produced at any one time. This is in order to limit the use of non-verified timber to small batches typical of a small milling operation for a special purpose, not commercial quantities.

Larger volumes need to be verified. If they are, then they become verified timber in accordance with 2.2.3 and can be designed in accordance with Table 6.

### 2.2.6 PROPERTIES OF TIMBER SPECIES NOT LISTED

***Timber of species and grades not listed in Table 2.1 may be assigned characteristic stresses. The characteristic stresses shall be determined in accordance with both parts of AS/NZS 4063. This approach may be applied to volumes of sawn timber less than 20 $m^3$ at any one time. For volumes exceeding 20 $m^3$ (either produced in a single batch or continuously without changes to sawing or grading methods) the timber shall either be verified in accordance with Clause 2.2.3 or produced as non-verified timber.***

Many New Zealand-grown timber species have properties that are well in excess of the characteristic strengths presented for non-verified timber in Table 2.2 of NZS AS 1720.1 (Table 7). Where designers want to take advantage of these higher strength properties, testing in accordance with AS/NZS 4063 can be performed to enable  a suitably qualified person, such as a Chartered Professional Engineer to undertakes a review of the proposed properties and issue a statement about the characteristic properties of the timber.

The New Zealand Farm Forestry Association has carried out in-grade testing of sawn timber from five species of trees, tested in accordance with AS/NZS 4063 after visual grading to the NZFFA No. 1 Structural Grade as defined on the website https://www.nzffa.org.nz/specialty-timber-market/brand-grades/structural-grading/#No-1-structural. The results of this testing are listed on the website https://www.nzffa.org.nz/specialty-timber-market/brand-grades/, reproduced (with minor rounding) in Table 8.

| Species | Modulus of elasticity (E') GPa | Bending strength ($f'_b$) MPa | Tension strength ($f'_t$) MPa | Shear strength ($f'_s$) MPa | Compression strength ($f'_c$) MPa |
|---|---|---|---|---|---|
| Farm totara | 7.4 | 20.5 | 10.6 | 4.4 | 30.2 |
| Lusitanica cypress | 9.1 | 27.2 | 9.6 | 3.6 | 19.5 |
| Lawson cypress | 8.5 | 29.7 | 13.9 | 3.4 | 23.4 |
| Macrocarpa | 6.1 | 16.1 | 5.8 | 2.7 | 23.9 |
| Redwood | 5.5 | 11.6 | 4.9 | 1.4 | 16.6 |

*Table 8. Characteristic design values for minor species, from test results:*

## 13.2 USING ALTERNATIVE SPECIES WITH NZS 3604

For house framing, NZS 3604 only allows verified SG grades of timber to be used, including SG6. Table 2.1 of NZS AS 1720.1 restricts SG grades to radiata pine and douglas fir. Hence, on first appearances, non-verified timber of other species cannot be used with NZS 3604.

However, Table 2.2 of NZS AS 1720.1 allows any New Zealand grown species to be used as non-verified timber with the listed properties, provided that the wood meets the average density requirement of 400kg/$m^3$ at 15% moisture content. The strength properties for No.1 Framing grade in Table 2.1 are almost identical to those for SG6 in Table 2.2

The apparent problem for the user of a small amount of alternative species is that even though non-verified timber has the same strength properties as SG6, it cannot be called SG6 because it has not been verified.

A solution to this problem is for the intended user to engage a Chartered Professional Engineer to give an expert opinion that No.1 Framing grade is structurally equivalent to SG6 for the species in question. This will then allow the timber to be used for house design in accordance with the SG6 tables in NZS 3604.

In most parts of house design, the property of most importance is MoE, not strength, so strength is not critical. If some low key verification is desired, it is relatively easy to manually measure the MoE of small volumes of timber using the Three Brick Test, as described above.

## 13.3 PROOF TESTING

For some special purposes it is desirable to produce proof-tested timber with a guaranteed minimum strength. In the process of proof testing, every board is loaded to the required stress level. Any sub-standard piece will break in the test and be discarded, so the boards are first carefully graded using other means in order to reduce unnecessary breakage and wastage. Proof testing machines can be designed to stress timber either in bending or in tension.

The question often arises; "Are the boards that almost break significantly weakened?". Studies have shown that if a quantity of timber is proof tested twice, the percentage which break on the second testing will be only one tenth the percentage that were broken on the first pass. Thus some damage occurs but the characteristic strength of the survivors will still be higher than the proof test stress level. Proof testing is allowed for in NZS 3622.

## 13.4. DESIGN VALUES FROM SMALL CLEAR TEST RESULTS

For any species of timber that is visually graded but not verified, another path for obtaining design values is to use mechanical properties from testing of small clear specimens, but this is difficult, especially for bending strength, because there is such a big difference between small clear test results and in-grade testing values.

For many applications the critical property is MoE, so high strength is often not essential. The mean value of MoE from small clears testing will be close to that obtained from in-grade testing.

FRI Bulletin 41 contains the results of many hundreds of test results from small clear testing of many different species. The two thousand test results for radiata pine show an average MoE of 8.7 GPa, allowing a comparison with the characteristic values for SG8, shown in Table 6.

- The characteristic compression strength in Table 6 is 18.0 MPa, which is 48% of the small clear average compression strength of 37.5 MPa.

- The characteristic bending strength in Table 6 is 14.0 MPa, which is only 16% of the small clear average bending strength of 88.2 MPa.

On the basis of this simple analysis for radiata pine, it might be possible to use similar ratios for timber of other species. In this case the characteristic in-grade compression strength for design would be half of the small clear compression strength, and the characteristic in-grade bending strength would be 15% of the small clear bending strength. This approach may be confirmed when more test results become available for other species.

# 14. DURABILITY OF TIMBER

The design of timber buildings must aim at preventing deterioration of timber by providing adequate protection or by using durable materials. Durability of timber is not covered in detail in this Design Guide. Refer to the new WPMA Design Guide on Durability.

As a very brief summary, durability against decay or insect attack is assessed in accordance with six Hazard Classes, H1 to H6. The hazard classes are described in terms of service exposure and biological hazard in Table 9. These hazard classes are generally the same as in Australia except that Australia does not have a split in the H1 and H3 classes

The New Zealand standards relating to durability of timber are focussed on levels of chemical treatment of radiata pine timber to achieve the hazard classes H1 to H6.

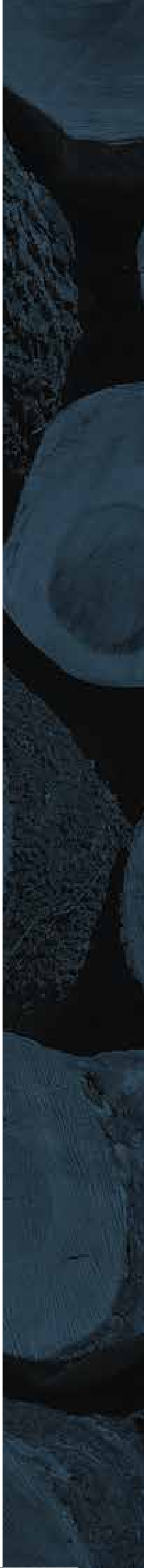
NZS 3602 specifies acceptable species and level of treatment for many different uses of wood in timber buildings. Chemical treatment is specified in NZS 3640. Both standards are under review at the time of publication.

Guidance on natural durability of sapwood and heartwood other species is given by Page and Singh (2014).

As an alternative to chemical treatment, decay of any wood can be prevented by keeping the long-term moisture content below about 18%. Building physics studies, such as a WUFI® hygrothermal computer analysis, can be used to predict the long-term moisture content of wood at any location in a building, depending on the expected weather prolife, the use of the building, and the weathertightness of the facade.

| Hazard class | Biological hazard | Service conditions | Typical uses |
|---|---|---|---|
| Untreated | Borer | Dry conditions, not exposed to weather or ground atmosphere. | Roof wall and floor framing, flooring, wall frames clad with masonry veneer. |
| H1.1 | Borer | Dry conditions. Not exposed to weather. | Roof wall and floor framing, sub floor framing, where dry use timber is installed wet, or dry rough sawn for interior dry use. |
| H1.2 | Borer, and short term decay fungi in a leaking wall situation | Not in contact with the ground. Protected from the weather but with a risk of moisture content conductive to decay as a result of moisture penetration of the building envelope.<br>Not in contact with the ground | Wall and roof framing in situations complying with NZBC E2/AS1. |
| H2 (Only Australia, not NZ.) | Termites and other borers | | Framing timber in Australia. |
| H3.1 | Decay fungi and borer | Periodic wetting in water shedding situations, such as exterior wall framing at risk to leaking cladding (greater than H1.2). Not in contact with the ground. | Cladding & trim, framing for exterior walls at serious risk of moisture penetration. Refer to E2/AS1. |
| H3.2 | Decay fungi and borer | Periodic wetting in situations not shedding water. Not in contact with the ground. | Exterior structural and decking and all H3.1 uses in farming and horticulture. |
| H4 | Decay fungi and borer | In water or in the ground, permanently wet. | Posts, fencing, bridge decks, landscaping. |
| H5 | Decay fungi and borer | In water or in the ground, permanently wet, and where 50 year durability is required for building purposes. | Piles, poles, foundations, retaining walls, line poles |
| H6 | Decay fungi and marine borer | In estuarine ground or immersed in seawater. | Marine timber & piles |

*Table 9. Hazard classes in New Zealand and Australia*



# 15. INFORMATION SHEETS FOR MINOR SPECIES

Information sheets for the minor species listed below are available on the NZ Wood website www.nzwood.co.nz. These data sheets give information on availability, durability, and mechanical properties, showing the results of small clear testing.

**EXOTIC SOFTWOODS**

Macrocarpa
Other cypresses

**EXOTIC HARDWOODS**

Eucalypts

**Native softwoods**

Rimu
Totara

**NATIVE HARDWOODS**

Red beech
Silver beech
Tawa

**Notes:**

Additional datasheets for kauri, matai and rewarewa are available from website of the National Association of Woodworkers New Zealand, www.naw.org.nz, but these datasheets do not list mechanical properties.

Additional information for 15 tree species is available on the website of the NZ Farm Forestry Association. https://www.nzffa.org.nz/specialty-timber-market/showcase/.

NZ Wood, www.nzwood.co.nz

New Zealand Farm Forestry Association, www.nzffa.org.nz

National Association of Woodworkers, https://naw.org.nz

# 16. FURTHER READING


Strength properties of small clear specimens of New Zealand grown timber. H.Bier and R.A.J.Britton. FRI Bulletin No. 41, Forest Research Insitute, 1999.

Density Conversions for Radiata Pine. M.J. Collins. FRI Bulletin No. 49. Forest Research Institute, 1983.

Blass, H.J. and C. Sandhaas (2017). Timber Engineering Principles for Design. KIT Publishing, Karlsruhe, Germany, 2017.

Page, D. and T.Singh. Durability of New Zealand Grown Timbers. NZ Journal of Forestry, February 2014, Vol. 58, No. 4.



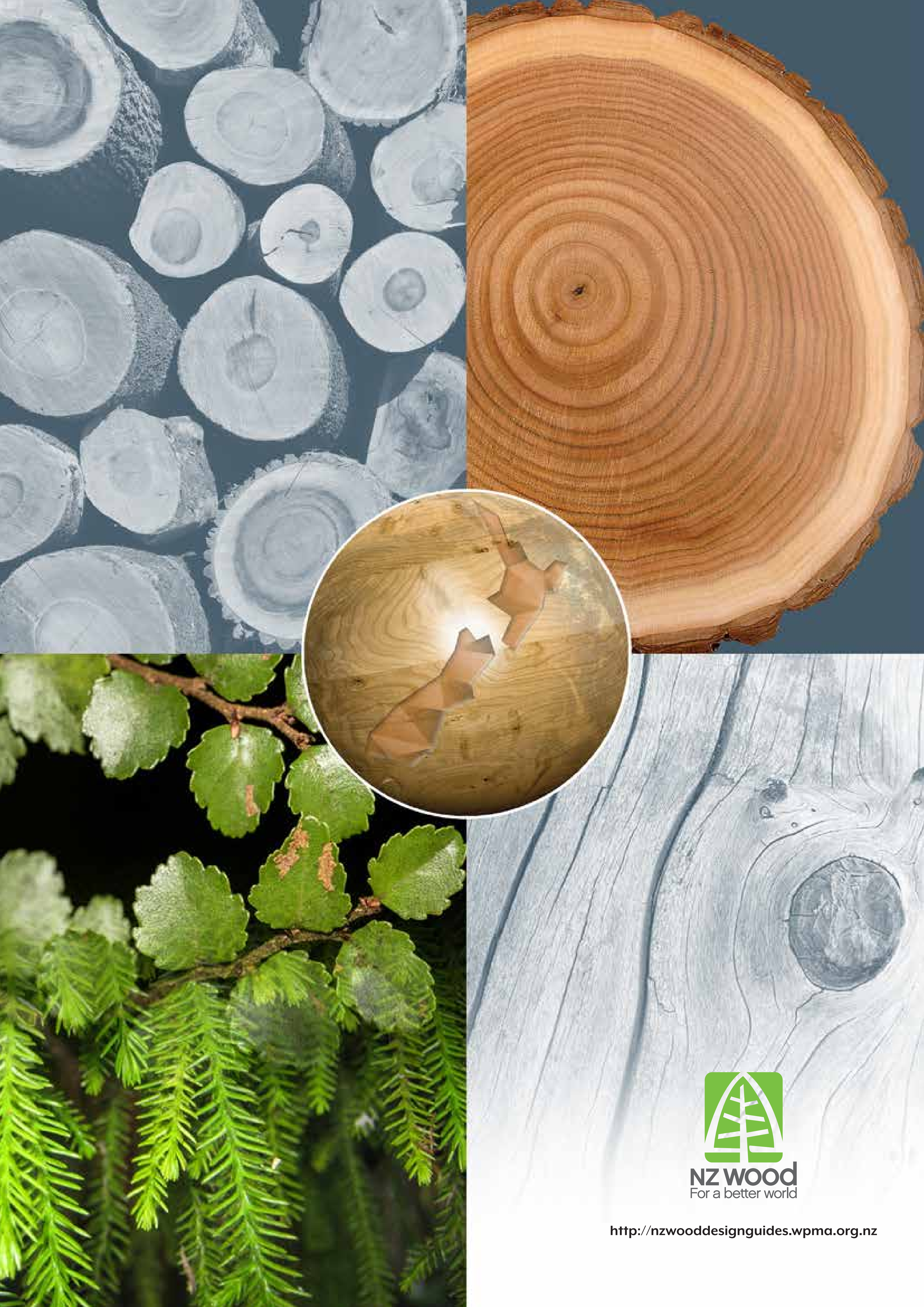






## ABOUT THE AUTHOR

**Dr. Andy Buchanan** is one of the pioneers of modern timber construction. With beginnings as a consulting engineer in Christchurch and now an Emeritus Professor at the University of Canterbury, and a Chartered Professional Engineer, Andy has worked for many years in the field of timber engineering, earthquake engineering and fire engineering converting cutting edge research results into industry solutions. He has been president of the New Zealand Timber Design Society, and is author of *Structural Design for Fire Safety* and the *New Zealand Timber Design Guide*.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