

INFORMATION SHEET

STRUCTURAL MATERIALS



SAWN TIMBER

GRADING SYSTEMS FOR STRUCTURAL TIMBER

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

Sawn timber will generally have large variability in strength and stiffness between individual pieces. Grading systems are essential to reduce the variability in properties of timber used for structural design. There are two distinct types of grading system used for structural timber:

- *Pre-sort* grading system, where the timber boards are segregated according to certain pre-established rules. Visual grading is the usual method of doing this. Design stresses are assigned after testing representative samples of the segregated populations.
- *Strength class* grading system where a number of strength categories are established, and sawmillers can use whatever technique or equipment they wish to segregate their production into the different classes, with specified methods available for verifying that the sorted timber meets the requirements.

The main advantage of a pre-sort system is simplicity. The major disadvantage of a pre-sort system is that it assumes that timber of similar appearance will have similar mechanical properties, and this assumption has been found to be invalid for most timbers. This has led to unexpectedly high deflections and other structural problems.

STRENGTH OF SAWN TIMBER

Published values for the strength of timber must be assessed with care, depending on how the numbers were obtained. There are two main types of testing to obtain wood properties which give significantly different results:

- In-grade testing refers to testing of large representative samples of timber, in the actual sizes, grades and moisture content which will be used in construction.
- Small clears testing refers to tests on small defect-free specimens of clear wood in laboratory conditions.

Structural timber with defects behaves in a 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 higher than those obtained from in-grade testing, but the stiffness values are 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 the British Standards and 50x50mm in the American Standards. The test results are useful for comparing one species with another but a big disadvantage is the great difficulty in predicting the lower strength of commercial sizes. 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 code values for structural purposes.

GRADING OF SAWN TIMBER

Grading systems

Grading refers to any system of classifying timber for specific end use. Every piece of timber is different, but for convenience in distribution and merchandising, a limited number of grades have to be formulated which will satisfy consumer needs.

There are four recognised general grade categories:

- *Appearance grades*, for cladding, furniture, finishing and other non-structural uses.
- *Cutting grades*, to produce short clear lengths for furniture and other speciality uses.
- *Structural grades*, where strength and stiffness are important, primarily for use in buildings.
- *Box grades*, for pallets, packaging and other uses.

Structural grades have design values assigned to them and are defined in terms of those mechanical properties, while the other categories do not have design values assigned to them. Grading of structural timber can be done visually according to its visible features, or mechanically using a device that measures some property of the timber, or a combination of both methods.

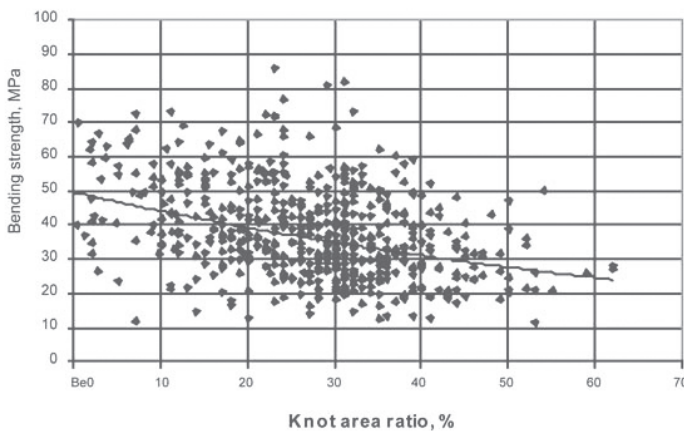
METHODS OF STRUCTURAL GRADING

In the process of grading timber, every board of timber is assessed in some way in order to assign it to a particular grade. The main two 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 an 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 clears (or defect-free) timber. For example, diagram 1 shows the relationship between knot size and bending strength in radiata pine and the poor correlation ($R^2 = 0.13$) illustrates one of the problems of using visual grading as a stand-alone method of predicting strength. NZS 3603 lists stresses for three visual grades for structural use; VSG10, VSG8, and No. 1 Framing grade. The main visual characteristic defining No. 1 Framing grade is that no knot or combination of knots should occupy more than one third of the cross section of the piece. VSG10 and VSG8 are verified structural grades which means that the producer has to verify the strength and stiffness of a certain number of boards to meet requirements of NZS 3622.

Diagram 1: Relationship between strength and knot area ratio in 90x45 mm timber



Machine grading

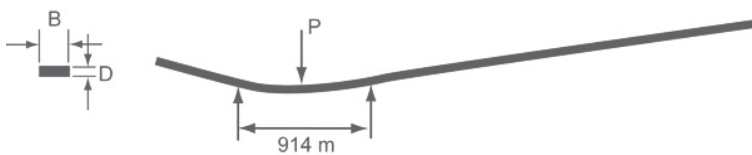
Machine stress grading uses a machine to assess the strength or the stiffness of each board. Four types of grading machines are used in New Zealand.

- Constant load plank graders.
- Constant deflection plank graders.
- Metriguard Continuous Lumber Tester.
- Joist grader.

Constant load plank graders

Constant load plank graders bend the timber on the flat, applying a constant load and measuring the deflection as shown in diagram 2. There are two makes: the Plessey Computermatic, and the Eldeco Dart.

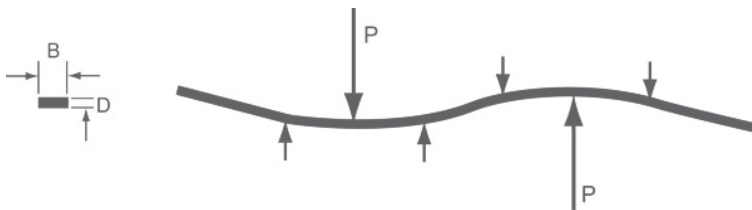
Diagram 2: Principle of operation of plank loading grading machines



Constant deflection plank graders

Constant deflection plank graders bend the timber on the flat, applying a constant deflection and measuring the load as shown in diagram 3. There are two makes: the Metriguard Continuous Lumber Tester, and the Cook-Bolinder Grader.

Diagram 3: Principle of operation of the Metriguard CLT machine



Joist grader

Joist graders measure stiffness and strength in bending as a joist. The E-Grader, made by Falcon Engineering, applies a load and measures the resulting deflection hence determines the long span stiffness as a joist. One stiffness reading per piece is taken. This machine is best used on large sizes and can be programmed to apply an appropriate proof load according to the grade indicated by the initial stiffness test.

Acoustic grader

Acoustic graders work by sending a sonic stress wave through the piece and computing the MoE. One stiffness reading per piece is taken. The A-grader is a brand of acoustic grader used in New Zealand.

All the machines described above use coloured paint marks to indicate the grade of each board, measured and marked every 100mm along its length in the case of the plank graders and continuously along the length in the case of the other two graders. For the plank type graders, the correlation between the local strength and the local measurement of MoE is sufficient not to require further visual grading. A subsequent visual grading to ensure strength is necessary in the case of the joist grader and the acoustic grader. The verification methods used for visually graded timber are also applied to machine-graded timber.

PROOF TESTING

For 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 substandard 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 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 breaks on the second testing will be one tenth the percentage that breaks 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.

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. Verification may be used for timber produced by any grading system, visual, machine, or a combination of both. Most verification tests are carried out as bending tests on full-size specimens since that is the easiest to do and bending is the most important property. 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 in order to obtain a statistical distribution of strength properties.

NZS 3622 specifies a rate of sampling of one board in every 1000 for each size and grade. The producer tests these samples and has the option of breaking every one, breaking a small fraction of them or loading them to a proof load equal to their characteristic strength.

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, measuring the deflection and calculating the modulus of elasticity. This is known as the “three brick test” and is convenient where there a question about the suitability of a particular piece of timber. Testing for strength requires more sophisticated equipment for applying and measuring loads.

The purpose of verifying timber is to ensure that the 5th percentile value of bending strength and the mean value of modulus of elasticity are no less than the code-specified values for the desired grade.

STATISTICAL PROPERTIES OF GRADED TIMBER

Any population of graded timber boards will have a range of strength and stiffness. The variability between boards (and the shape of the statistical distribution) will depend on the accuracy of the grading methods and the number of grades chosen by the producer. Variability will be less with an accurate grading method and a tightly defined set of grade classes, and vice versa. In any packet of graded boards, the strongest boards may be more than five times stronger than the weakest ones.

It is important for designers to understand that when specifying timber of a particular grade, up to 5% of the graded boards may be weaker than the code-specified strength, and up to half of the boards may have stiffness less than the code-specified E-value. In addition, up to 5% of the boards may have an E-value less than the “lower bound” E_b figure specified for the given grade.

Sawmillers can decide to offer single grades or combinations of grades, depending on their raw material and their access to grading machines. Weak boards can be “upgraded” by combining them with better material, to increase the 5th percentile strength or mean E-value 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 grade of the better material.

TYPICAL TEST RESULTS

The diagrams that follow are derived from a typical sample of 300 ungraded Radiata pine boards, 90x45mm, tested for strength and stiffness at Scion. Each board was non-destructively tested for modulus of elasticity (MOE) twice, in bending as a plank and in bending as a joist. The boards were then tested to destruction in bending as a joist.

Diagram 4 shows a histogram of strength values. The plotted values show the number of boards in each 5 MPa grouping of strength. In this sample, the weakest board failed at 4 MPa and the strongest at 91 MPa, with a mean value of 40 MPa. It can be seen that the distribution is not symmetrical, with a large tail at the strong end of the distribution.

Diagram 5 shows the same data after sorting from weakest to strongest, plotted as a cumulative distribution function. The bending strength on the x-axis is the modulus of rupture (MOR) for each board. The cumulative frequency $F(x)$ on the y-axis ranges from zero to 1.0. Each data point represents one broken board. The 5th percentile value of 12.4 MPa is shown by the vertical line dropping from the point where the horizontal line from $F(x)=0.05$ meets the plotted data. This value would be used as the *characteristic strength* if this population of boards was used for structural design.

Diagram 6 shows the scatter-graph of bending strength and stiffness for every board tested. The bending strength on the y-axis is the modulus of rupture for each board (same as the x-axis in previous figures). The x-axis shows the modulus of elasticity (MOE) in bending as a joist. The solid horizontal line is the 5th percentile strength value of 12.4 MPa, and the solid vertical line is the mean modulus of elasticity of 8.1 GPa. The intersection point is the design value which would be used in the design code for this sample of ungraded timber boards. The vertical dotted line is the 5th percentile MOE of 4.9 GPa, referred to in NZS 3603 as the “lower bound” value, E_{lb} .

Diagram 4: Histogram of bending strength values for 300 tested boards

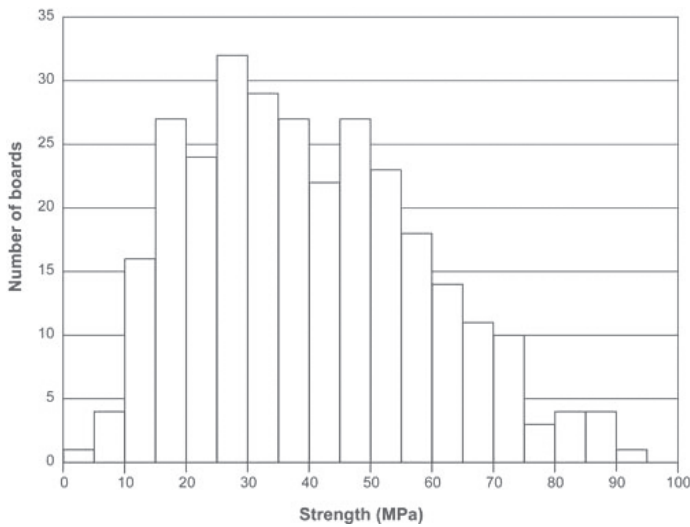
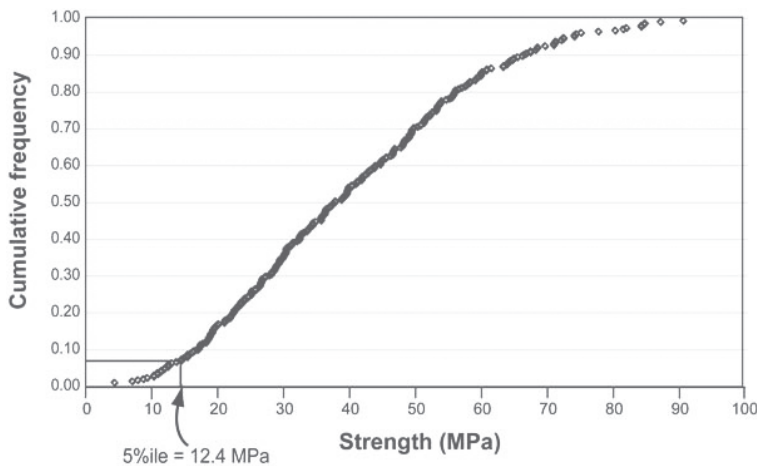


Diagram 5: Same data as diagram 4 plotted as a cumulative distribution function



RESULTS AFTER MACHINE STRESS GRADING

This approach can be used for plotting the distributions after grading. If the same population of timber is machine stress graded into three strength classes, diagrams 7 and 8 show the stiffness and bending strength, respectively, plotted as cumulative distribution functions. Of the whole population, 25% was graded as MSG10 or better, 40% as MSG8, 20% as MSG6, with 15% rejected. A comparison of diagrams 7 and 8 shows that the grades have greater separation in the distribution of stiffness than in the distribution of strength, which is not surprising because the grading was done by measuring stiffness. The difference in 5th percentile strength between the grades is not as large as the difference in mean strength.

Diagram 6: Scatter-graph of bending strength and stiffness values, for the same boards shown in diagrams 4 and 5

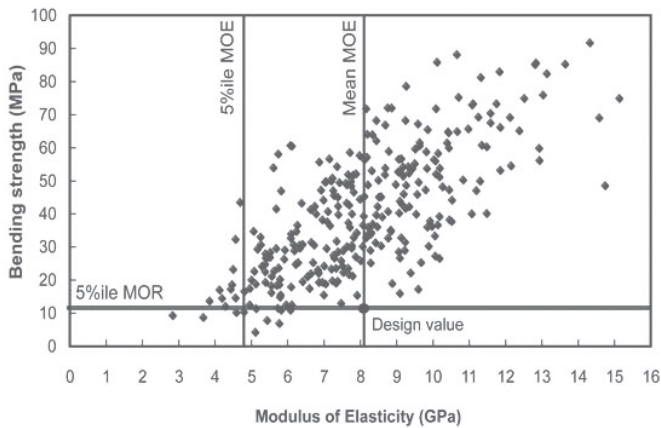


Diagram 7: Distributions of stiffness, after sorting into three MSG grades

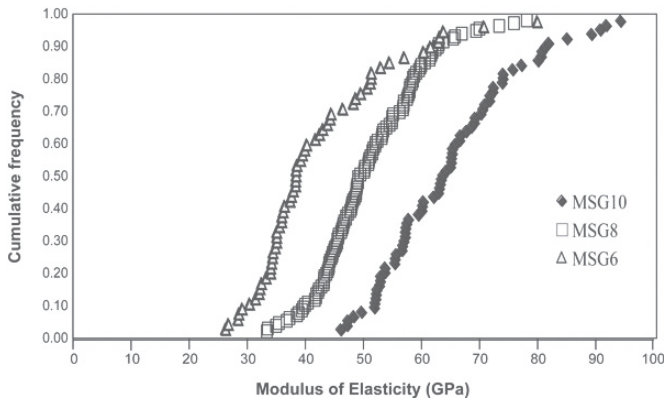


Diagram 8: Distributions of strength, of the same three MSG grades as shown in diagram 7

