Forest & Wood Products Australia
Level 4, 10 -16 Queen Street
Melbourne VIC 3000
Australia

T: +61 (0)3 9927 3200
F: +61 (0)3 9927 3288
E: info@fwpa.com.au
W: www.fwpa.com.au

Standards Coordination

By G N Boughton

Background and Guidance Document

AS/NZS 1748 Series 2011 (including AS/NZS 4490:2011)

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Part 1 - Introduction

1. Introduction

This document presents background and guidance information in support of the use of the following suite of Australian / New Zealand Standards:

- AS/NZS 1748.1:2011 Timber – Solid – Stress-graded for structural purposes, Part 1: General requirements
- AS/NZS 1748.2:2011 Timber – Solid – Stress-graded for structural purposes, Part 2: Qualification of grading method
- AS/NZS 4490:2011 Timber – Solid – Stress-graded for structural purposes – Verification of properties

Background information presents the basis for the Standards, and in some places can be quite technical. It is not necessary to understand all of the background to be able to use the Standards effectively. Information that is background only is included in Appendices A and B. A user guide for spreadsheets written to support the qualification analyses is also included as Appendix C.

1.1 Performance objectives

This suite of standards enables the stress-grading of structural timber using any grading method at all. It relies on the following principles for proving the performance of the stress-graded structural product:

- Stress-graded timber has performance requirements that are given as utility requirements in the relevant product standard, and structural properties that are listed under the stress-grade presented in AS 1720.1 or elsewhere. (It is possible to use this suite of standards to produce a generic stress-graded product where the properties are listed in AS 1720.1 or a product carrying a producer’s grade with properties specified by a producer.)
- The population of graded timber must have utility and structural properties that meet the requirements specified.
- The compliance is demonstrated by the verification process outlined in AS/NZS 4490:2011. This entails checking samples for compliance with utility requirements and with structural properties.
- The link between verification and compliance of all of the structural properties has been established in the qualification of the grading method.

The ultimate performance requirement of the timber is that it meets all of its required structural properties and its utility specification. Verification to AS/NZS 4490:2011 gives assurance that it meets its utility requirements and two of its structural properties. The steps undertaken in the qualification of grading method allow for confidence that having proved compliance of two of the structural properties, the untested structural properties also comply.

1.2 Steps in starting to use the suite of Standards

The use of the suite of Standards requires:

- A clear understanding of the nature of the population of ungraded timber.
- A working version of the specified grading method.
- A limited number of stress grades into which the ungraded timber will be sorted.

The grading method is valid only for the specified input resource material and for the specified grading method, so both of these must be well understood. It is likely that at the commencement of a new grading method, the range of resource types from which the timber will be produced may be well understood, but that the detail of the grading method may still be under development. In particular:

- The grading parameters will be well defined and understood.
- Algorithms for the combination of those grading parameters in order to make good sorting decisions for the particular resource handled by the mill may still be under development.
- Grade limits or thresholds for each of the grading parameters will only be able to be refined after there is a significant experience with production of the grades and feedback from the verification is available.

The process of qualification must be undertaken before commercial scale production commences, so it needs to be able to cope with the fact that some refinement to the grading system needs to happen once commercial production commences. However, it will require repetition of a number of qualification steps if grading parameters are added. Minor changes to the qualification analysis are required if grading parameters are removed or if algorithms for the combination of grading parameters are changed.

Prior to qualification, the following will be required:

- Description of the input resource listing the range of all factors that may affect the properties of the graded product. The standard list species or mix of species, forest region or log sorting regime used, other production processes that may influence properties (e.g. cutting patterns).
- Description of the grading method including technology used to measure any characteristics in the wood, any grading parameters produced, any algorithms used to estimate stress grades, and parameters and combinations of parameters used in applying the grade limits.
- Initial grade limits. However, it is recognized that prior to much production experience, these limits may be rough estimates.
- List of sizes that will be produced. List of stress-grades for which qualification is required. These will be any stress-grades for which the product will be stamped AS/NZS 1748.
- The ability to produce timber for testing using the proposed grading method (pilot production).

1.3 Continuing use of the suite of Standards

Once the grading method has been qualified and commercial production has commenced, changes to grading limits or thresholds are permitted in the use of the suite of standards without having to repeat the qualification. (Achievement of sufficient correlation between grading parameters and structural properties allows variation of the grade limits on key grading parameters in order to maintain the required structural properties.)

However, where the qualified grading method is changed by:

- introducing new grading parameters;
- removing grading parameters; or
- changing algorithms for combining grading parameters,

it is necessary to repeat Phase II of the qualification in order to demonstrate that the grading method used also has the correlations required to continue to discriminate timber with high structural properties from that with low structural properties.

Where new grade properties are introduced (for example by adding a new scanner to the machine), then the previous qualification would not have had data from that parameter at the time. In this case, a new sample of at least 200 run-of-mill pieces must be taken and the Phase II qualification testing and analysis repeated.

Where a grading parameter has been removed, provided there is sufficient correlation with one of the remaining grading parameters, the qualification is still valid.

Where an algorithm has been changed so that grading parameters are combined in a different way, then the data held from the previous qualification can be used with the new algorithm in order to repeat the correlation analysis only for the grading method that will be used in production in the future. Under these conditions, no new testing is required, but the Phase II analysis must be repeated so that the qualification report truly reflects the grading method used in production.

2. Introductory statistical concepts

In order to use the suite of Standards, an introductory level understanding of some statistical concepts is required. While this is strictly background information, it is recommended that all people planning to use the Standards check that they are familiar with the concepts outlined in this section.

2.1 Measures required for verification of structural timber

2.1.1 Statistical measures

A whole population has variability and its properties can be represented using a combination of statistical parameters. These are described in this section.

- The average represents the properties of the population near the middle of the range of values.
- The standard deviation gives a measure of the way the population is spread around the average. Both the average and the standard deviation have the same units as the property measured.
- The Coefficient of Variation is a non-dimensional measure of the variation about the average of a property.
- In describing the strength of timber products, it is normal to evaluate a 5%ile strength. This is the strength value which is estimated to have around 5% of the population weaker and around 95% of the population stronger. It is representative of the weakest pieces in the population.
- All of the above parameters are generally evaluated on a sample of the population and the true value of the population parameter may be a little different to the value evaluated from the sample. Hence the estimate based on a sample can be adjusted to give it a specified level of confidence. The level of confidence is expressed as a percentage. For example an average estimated to 75% confidence means that there is a 75% chance that the population average will be greater than the value estimated.

2.1.2 Average

The average is found by summing all of the values and dividing by the number of values. This is shown mathematically as *equation 1*.

$$\bar{X} = \frac{\sum X}{n} \qquad \textit{equation 1}$$

with $\bar{X}$ average value of the data set X = X_1, X_2, X_3, …
$\sum X$ sum of all individual X values ($X_1 + X_2 + X_3 + \ldots$)
n number of X values in the data

In msExcel, there is a function for average:

$\bar{X}$ = AVERAGE(x1:xn)

where x1 is the cell reference for the first cell in the list and xn is the cell reference for the last cell in the list

In assessing timber properties, there are a number of properties for which the average is important:

- The characteristic value of Modulus of Elasticity is based on the average MoE of the population.
- The average moisture content of a piece represents the moisture content in the piece.
- The average density of the timber in a population is the density value used.

The average of a series of measurements has the same units as the measurements and for a large number of measurements is generally a value near the middle of the data.

2.1.3 Standard deviation

The standard deviation is found mathematically using *equation 2*.

$$s_X = \sqrt{\frac{\sum(X-\bar{X})^2}{n}} \qquad \textit{equation 2}$$

with s_X the standard deviation of the data set X = X_1, X_2, X_3, …
$\bar{X}$ average value
$\sum(X-\bar{X})^2$ sum of squares of deviations from the average for all individual X values $(X_1-\bar{X})^2+(X_2-\bar{X})^2+(X_3-\bar{X})^2+$
n number of X values in the data

In msExcel, there is a function for standard deviation
s_X= STDEV(x1:xn)

where x1 is the cell reference for the first cell in the list and xn is the cell reference for the last cell in the list

2.1.4 Coefficient of variation

The Coefficient of Variation of the data is simply the standard deviation divided by the average as shown in *equation 3*.

$$V = \frac{s_X}{\bar{X}} \qquad \textit{equation 3}$$

A very simple example will illustrate the concept:
We will look at two data sets

Example 1: ***Coefficient of Variation (V)***

	Set A	**Set B**
Data	3 kN, 4 kN, 5 kN	2 kN, 3 kN, 4 kN, 5 kN, 6 kN
n	3	5
Average	4.00 kN	4.00 kN
Standard deviation	1.00 kN	1.58 kN
V	0.25	0.4

Both data sets have an average value of 4 kN. This can be seen as the data is symmetrical about 4 kN in both sets. However, Set A has a smaller range (3 to 5) compared with Set B (2 to 6). The larger spread of data leads to a higher standard deviation for Set B (1.58 kN) as compared with Set A (1.00 kN). This can also be

seen in the Coefficient of Variation (V), which also reflects the same relativity, but has no units. It is also useful in comparing less obvious cases in which the averages are not the same.

2.1.5 5%ile of a population

All strength properties used in verification of the timber, or in qualification of the grading method, are based on the 5%ile strength of the population. This is the strength value that divides the whole population of timber, so that 5% of the population would be less than this value and 95% more than this value. It is a strength value close to what is expected of the weakest pieces in the population.

There are a number of methods of evaluating the 5%ile value of some data. These are all given in AS/NZS 4063.2:

- Method 1 – Fit a log-normal distribution through the data and then calculate the 5%ile value of the distribution.
- Method 2 – Fit a 2 parameter Weibull distribution through the lowest data points in the record. (This method can only be used with more than 100 data points, so is not suitable for verification, and can rarely be used for qualification testing.)
- Method 3 – No statistical distribution is fitted through the data, it is ranked lowest to highest and the value corresponding to the lower 5%ile of all of the data points is found by interpolation.
- Method 4 – Also does not use a statistical distribution, and gives the 75% confidence estimate of the 5%ile directly. (It combines the estimation of the 5%ile value and the correction for sampling error in one operation.)

An example of the estimation of the 5%ile from data is given in *Example 2* after Section 2.2.

2.1.6 Sampling error

Wherever a sample is taken, the actual test values are a function of which particular pieces are taken. Hence each sample will produce a slightly different result. The actual population property may be higher or lower than the value calculated from the sample. Small samples may have a large discrepancy between the population property and the property derived from the sample, and larger samples have a smaller discrepancy. There is a relationship between the sample size and the discrepancy which is modelled by the analysis of model data. This has the form:

$$\text{Sampling error} = \text{sample property} \times \; k_s \frac{CoV}{\sqrt{n}} \qquad \textit{equation 4}$$

k_s is a sample error factor which is a statistical parameter dependent on the statistical method used in the analysis, the confidence level required and is different for a mean to a 5%ile.

V is the coefficient of variation of the property measured

n is the sample size

Sampling error can be either added to or subtracted from the sample property depending on whether an upper- or lower-bound is required. This form is used in

setting a Test Comparison Value in verification (where an upper bound is required so the sampling error is added) and in calculating a characteristic value (where a lower bound is required so the sampling error is subtracted).

For example, the lower bound estimate of a mean with 75% confidence is given in *equation 5*.

$$\bar{X}_{0.75} = X\left(1 - k_s \frac{CoV}{\sqrt{n}}\right) \qquad \textit{equation 5}$$

This means that we could expect that the true population average is greater than the calculated value $\bar{X}_{0.75}$

2.2 Methods of presenting data

Statistical data can be presented on a plot. There are a number of options for plotting data. The two most common are histograms and cumulative frequency distributions. This document uses the cumulative frequency distribution as the 5%ile of the distribution is more obvious.

2.2.1 Cumulative frequency distribution

The cumulative frequency distribution is a plot of the measured quantity against the cumulative probability of that measurement. It can be produced as follows:

- The data is ranked from lowest to highest.
- Each data point is given a cumulative probability based on its position in the ranked list. The probability of the i^{th} data point in the ranked list is:

$$pr = \frac{i-0.5}{n} \qquad \textit{equation 6}$$

with i = 1 for the first point in the ranked data, 2 for the second point, etc
n = the number of data points

An example of a cumulative frequency distribution of some data is provided in *Example 2*.

Example 2: Estimation of 5%ile and cumulative frequency distribution

The test data from a series of bending tests on a graded structural timber product is presented in Table 1. This shows the 50 test results from random position bending tests in accordance with AS/NZS 4063.1:2010.

- The left column contains the raw test data.
- The second column contains the ranking of all of that data with 1 as the smallest test value and 50 as the largest.
- The third column is the test data from the first column rearranged so that the entry in row 1 has rank 1, the entry in row 2 has rank 2 etc.
- The fourth column has the probability calculated from equation 6 with n = 50.
- The fifth column is the natural logarithm of the ranked test data

For the first row, the probability is $pr = \frac{1-0.5}{50} = \frac{0.5}{50} = 0.010$

For the second row, the probability is $pr = \frac{2-0.5}{50} = \frac{1.5}{50} = 0.030$

Table 1 Test data for *Example 2*

Test data (MPa)	Rank	Ranked data (MPa)	Probability	ln (ranked data)
66.45	45	13.81	0.01	2.625
35.12	18	18.46	0.03	2.916
49.16	32	21.52	0.05	3.069
63.07	43	22.80	0.07	3.127
46.85	28	23.13	0.09	3.141
76.58	46	23.30	0.11	3.148
57.66	40	24.60	0.13	3.203
48.87	31	24.91	0.15	3.215
80.61	48	25.39	0.17	3.234
39.85	21	25.91	0.19	3.255
25.39	9	26.62	0.21	3.282
24.60	7	27.03	0.23	3.297
62.37	42	27.83	0.25	3.326
22.80	4	29.75	0.27	3.393
54.45	35	30.60	0.29	3.421
44.39	27	33.13	0.31	3.500
39.19	20	34.88	0.33	3.552
56.58	38	35.12	0.35	3.559
41.12	24	37.93	0.37	3.636
47.48	29	39.19	0.39	3.668
40.03	22	39.85	0.41	3.685
27.83	13	40.03	0.43	3.690
25.91	10	40.89	0.45	3.711
49.45	33	41.12	0.47	3.716
57.39	39	43.37	0.49	3.770
18.46	2	43.95	0.51	3.783
94.27	50	44.39	0.53	3.793
23.13	5	46.85	0.55	3.847
43.95	26	47.48	0.57	3.860
56.17	37	47.84	0.59	3.868
29.75	14	48.87	0.61	3.889
30.60	15	49.16	0.63	3.895
93.78	49	49.45	0.65	3.901
34.88	17	52.55	0.67	3.962
61.21	41	54.45	0.69	3.997
52.55	34	55.01	0.71	4.008
26.62	11	56.17	0.73	4.028
79.92	47	56.58	0.75	4.036
33.13	16	57.39	0.77	4.050
13.81	1	57.66	0.79	4.055
24.91	8	61.21	0.81	4.114
21.52	3	62.37	0.83	4.133
55.01	36	63.07	0.85	4.144
47.84	30	64.10	0.87	4.160
40.89	23	66.45	0.89	4.196
43.37	25	76.58	0.91	4.338
64.10	44	79.92	0.93	4.381
27.03	12	80.61	0.95	4.390
23.30	6	93.78	0.97	4.541
37.93	19	94.27	0.99	4.546

Method 1 analysis in AS/NZS 4063.1 involves operating on all of the numbers in the fifth column (the natural logs of the test data). Using functions in msExcel:

$\bar{y}$ = AVERAGE(all data in fifth column) = 3.721
S_y=STDEV(all data in fifth column) = 0.439

The coefficient of variation of the data is
$$V_R = \sqrt{EXP(S_y{}^2) - 1} = \sqrt{EXP(0.439^2) - 1} = 0.461$$
The 5%ile of the data is
$$f_{05} = EXP(\bar{y} - 1.645 S_y) = EXP(3.721 - 1.645 \times 0.439) = 20.1$$

The characteristic value is $f_k = k_s f_{05} = \left(1 - 1.15 \times \frac{V_R}{\sqrt{n}}\right) \times 20.1$ = 18.6 MPa

For this case, $k_s = \left(1 - 1.15 \times \frac{0.461}{\sqrt{50}}\right)$ with $V_R = 0.461$ as calculated above

Method 2 analysis in AS/NZS 4063.1 is not possible as the data has only 50 points and Method 2 requires at least 100 points to provide enough data in the lower tail for a tail fit.

Method 3 analysis in AS/NZS 4063 involves operating on all of the numbers in the third column (the ranked test data). Using functions in msExcel:
$\bar{f}$ = AVERAGE(all data in third column) = 45.22 MPa
S = STDEV(all data in third column) = 19.18 MPa

The coefficient of variation of the data is
$$V_R = \frac{S}{\bar{f}} = \frac{19.18}{45.22} = 0.424$$

In order to find the 5%ile value from the data directly, the value in column 4 that is closest to 0.05 is selected. In this case, 0.05 is in the 3rd row, so the third lowest test value is used as the non-parametric 5%ile. This value is 21.52 MPa.

The characteristic value is $f_k = k_s f_{05} = \left(1 - 1.8 \times \frac{V_R}{\sqrt{n}}\right) \times 21.52$ = 20.0 MPa

For this case, $k_s = \left(1 - 1.15 \times \frac{0.424}{\sqrt{50}}\right)$ with $V_R = 0.424$ as calculated above

Method 4 analysis in AS/NZS 4063 also involves operating on all of the numbers in the third column (the ranked test data) but delivers an estimate of the characteristic value directly.
Here the sample size is 50, which is not an entry in Table B1 of AS/NZS 4063.1. However, a sample size of 28 corresponds to the 1st ranked data point and a sample size of 53 with the second. Interpolating between these two values gives:
Sample size 50 corresponds to rank = $1 + \frac{(50-28)}{(53-28)} = 1.88$
The characteristic value can be found by interpolating between the 1st and 2nd point in the data set:
Rank 1.88 corresponds to $13.81 + 0.88 \times (18.46 - 13.81) = 17.90$ MPa

This is the estimate of the characteristic value using this method.

Summary of Characteristic Values

The three different methods each produced slightly different estimates of the 5%ile of the population from which the sample had been taken:

Method 1 gave a 5%ile of the data of 20.1 MPa and a characteristic value of 18.6 MPa

Method 3 gave a 5%ile of the data of 21.5 MPa and a characteristic value of 20.0 MPa

Method 4 gave a characteristic value of 17.9 MPa

These are all within about 10% of each other. This range is representative of samples with 50 or fewer specimens.

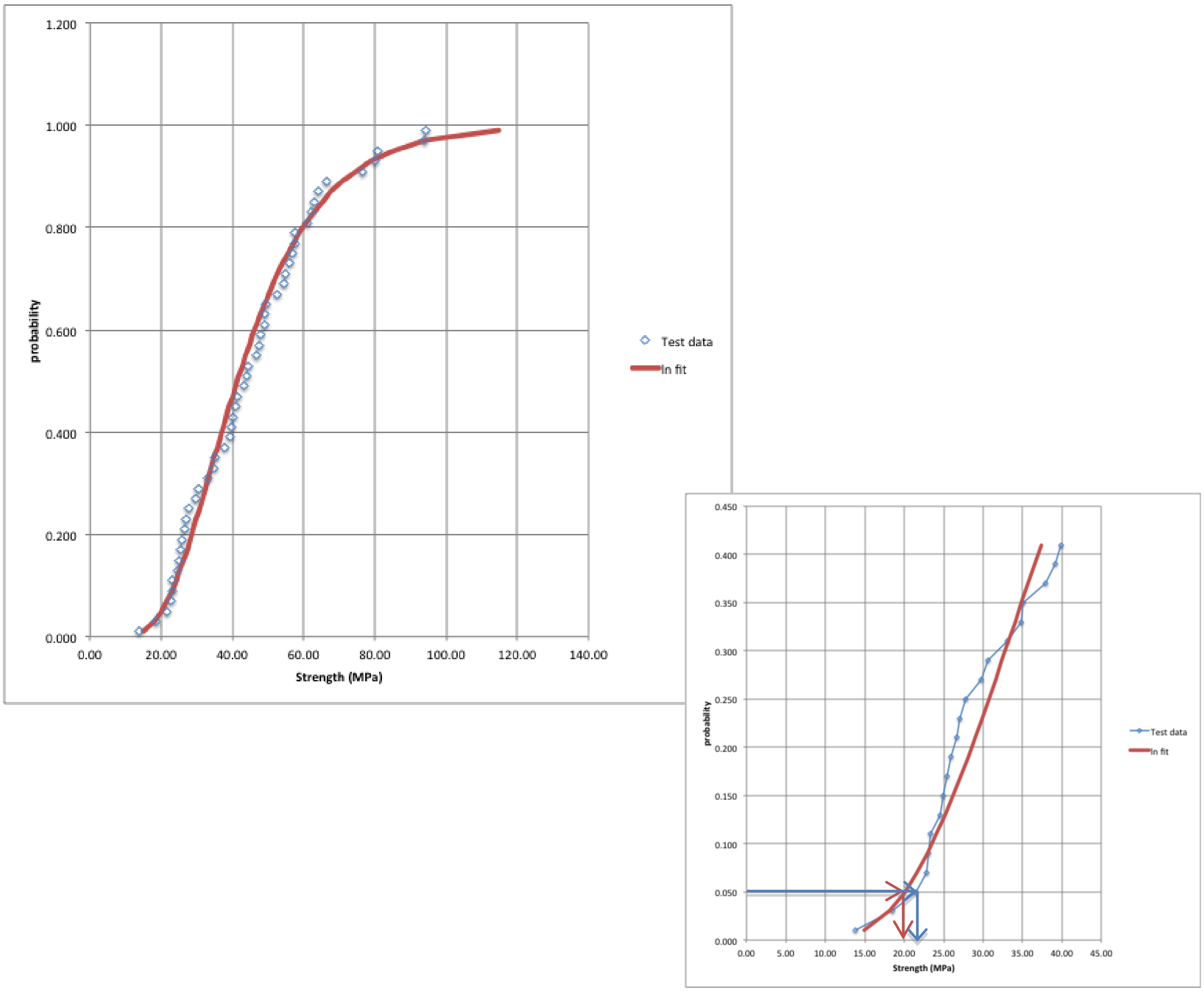


Figure 1 Cumulative frequency distribution
(inset shows the lower tail)

The data can be presented as shown in Figure 1 as a cumulative frequency distribution. In msExcel, this is achieved by plotting the ranked data from column 3 in Table 1 (on the X axis) and the probability from column 4 in Table 1 (on the Y axis). This gives all of the blue data points shown on the plot. The red line was obtained by fitting a log-normal distribution to that data. This uses the values of $\bar{y}$ and S_y from

Method 1 to develop the fitted log-normal curve. It shows that the fit is quite reasonable over the full range of the data as the red curve is never too far from the blue data points.

The inset to Figure 1 shows exactly the same data as the main diagram, but it focuses on the lower end of the distribution. This is where the 5%ile of the data is located. The 5%ile from the different methods can be illustrated on this plot:

- *Method 1* uses the distribution fitted through the data to obtain the 5%ile point from the distribution. Graphically, on the vertical (y) axis, 5% is located and a horizontal line drawn until it hits the red curve fitted by the distribution. Dropping down from that point to the horizontal (x) axis, gives the 5%ile strength of *Method 1* – 20.1 MPa. This is represented by the red arrows on Figure 1.
- *Method 2* was not used as there were not sufficient data points.
- *Method 3* uses the raw data which is the series of blue points on the plot. Graphically, the value 5% is located on the vertical (y) axis and the horizontal line is drawn until it hits either a blue data point or a straight line joining each pair of blue data points. Dropping from the point at which the horizontal line crosses the raw data to the horizontal (x) axis, gives the 5%ile strength using *Method 3* – 21.5 MPa. This is represented by the blue arrows on Figure 1.
- *Method 4* gave the characteristic value without calculating the 5%ile value, so cannot be shown on the plot.

2.3 Measures required for qualification

2.3.1 Characteristic values

These are values of properties said to characterize a population of timber. It is normally impossible to test every single piece in the population, so the population properties can't be measured directly, rather a sample is taken and tested. The analysis of the sample test data takes into account that while we present the properties as applying to the whole population, they have been found from a sample.

- For strength properties mentioned in the Standards and in this document, the characteristic value is an estimate of the 5%ile strength of the population.
- For Modulus of Elasticity (MoE) the characteristic value is an estimate of the average MoE. However, where there is a high variability of the MoE data, this value can be reduced further.

In both cases, the characteristic value is one that has come from a sample, so it represents an estimate. The accuracy of the estimate is represented by a confidence level. The analysis is one that gives a 75% confidence level. In other words, there is a 75% chance that the calculated characteristic value is less than the true population value (conservative). There is only a 25% chance that we have overestimated the population property (unconservative).

2.3.2 Coefficient of determination

The coefficient of determination with the symbol R^2 is a measure of the effectiveness of a relationship.

Example 3*: *Coefficient of determination

Figure 2 shows an example of two different notional data sets. In each case, there is a relationship between the grading parameter and the strength, but it is clearly a better relationship for Data 1 compared with Data 2.

- Data 1 R^2 = 0.984
- Data 2 R^2 = 0.612

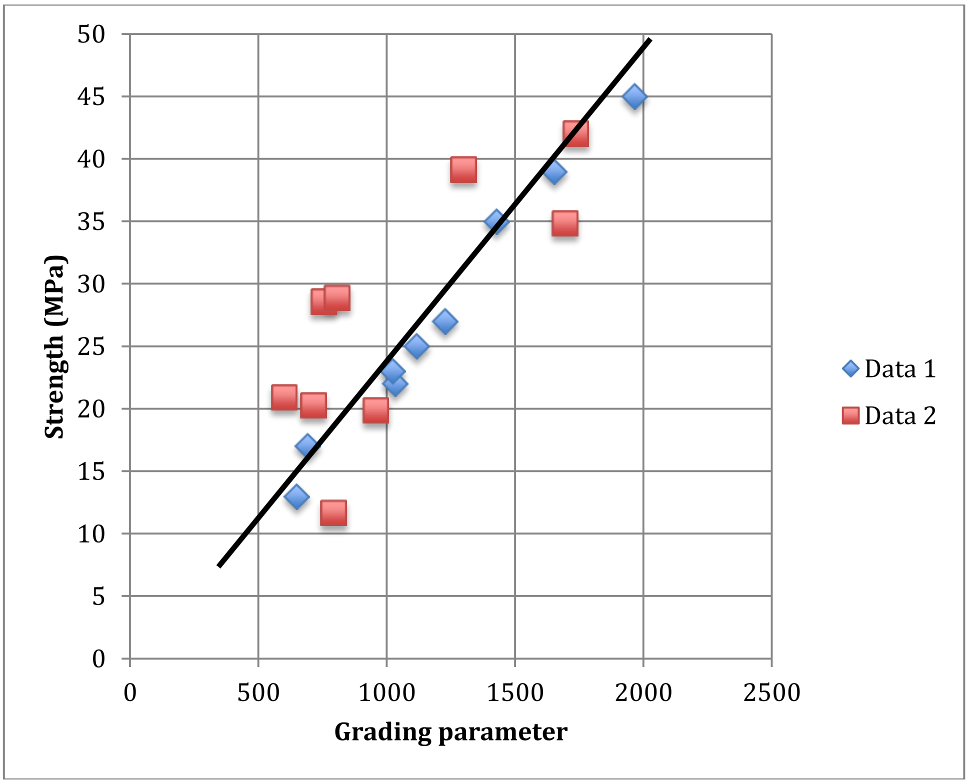


Figure 2 Illustration of coefficient of determination

In Figure 2, both data sets appear to follow a line shown in black on the plot of the data. Data 1 appears to be clustered closely to the line, and the relationship seems quite effective. The Grading parameter seems to be well related to the strength and the R^2 is close to 1. However, Data 2 has a much larger scatter around the line and the R^2 is much lower.

Technically, the meaning of coefficient of determination is the fraction of the variation in the Y values that can be "explained" by the X value. A value of 1 means that all of the variation in Y can be predicted using the X value and there is nothing that is unexplained. On the other hand a value of 0.612 means that 61.2% of the variation in the Y values can be explained by the relationship and the rest (38.8%) is an unexplained variation (random error).

In msExcel, there is a function for the correlation coefficient (R). The coefficient of determination can be found by squaring R.

R= CORREL(y1:yn,x1:xn)

R^2=(CORREL(y1:yn,x1:xn))^2

where x1 is the cell reference for the first cell in the list

xn is the cell reference for the last cell in the list for the parameter on the horizontal axis (the independent variable)
y1 is the cell reference for the first cell in the list
yn is the cell reference for the last cell in the list for the parameter on the vertical axis (the dependent variable).

The concepts presented here are all used in this document to explain measurements and analyses used in AS/NZS 1748:2011 and AS/NZS 4490:2011.

3. Strategy of stress grading by any method

The standard aims to be a performance based standard. There is no restriction on the method of grading, rather the requirement is that the timber produced must comply with its properties and specification. The strategy underpinning this document relies on the verification of properties of the timber as it is produced. This is classic output control:

- Where the timber produced has some tests performed that indicate it clearly meets or exceeds its tested properties, it is Verified and the production needs no adjustment.
- Where the timber does not meet its properties, it is Not Verified and production values must be adjusted to deliver a complying product.
- Between these two extremes, producers will monitor the output and ensure that if the properties are still safe, but decreasing, changes to production settings will arrest any deterioration in product properties.

In order to have confidence that a result of Verified means that all of the properties will comply, Phase I of qualification of grading establishes the relationships between the structural properties of the graded products. This Phase is outlined in Chapter 5 of this publication.

Also, in order to have confidence that the grading method can deliver products with appropriate V of properties and that changing grading parameters can give a change in the properties of the final products, Phase II of qualification establishes the relationships between grading parameters and the verification properties. This Phase of qualification is outlined in Chapter 6 of this publication.

The performance requirements are that all of the structural properties are met with each production unit and batch, and a combination of the verification testing and the property relationships established in qualification give confidence that the performance requirements are met by Verified timber.

A number of verification methods have been presented, so there is flexibility in selection of a verification method that matches the technical expertise in the production unit, the properties of the material and the number of grades produced. Each has a consistent level of confidence associated with Verification. The verification strategy is outlined in Chapter 10 of this publication and each method is explained in Chapters 12 to 16 of this publication.

3.1 Scope of AS/NZS 1748

The scope of the AS/NZS 1748 series is restricted to solid timber graded for use with the Australian and New Zealand timber design standards for general structures and for housing – AS 1720.1, NZS 3603, AS 1684 and NZS 3604.

The requirements for qualification have been based on reliability concepts that are compatible with the capacity factors for timber as used in the Australian and New Zealand design standards. They may or may not be compatible with reliability concepts that underpin timber design standards from other nations.

Solid timber is defined as timber that is free of joints, glues or reconstituted material. Again, the restriction of the scope of the standard to timber that does not have any joints, glue or reconstituted material simply reflects the fact that the acceptance criteria for qualification are based on known variability and statistical distributions for solid timber with naturally occurring growth characteristics. Mechanical joints and glues introduce other sources of variation of properties that have not been allowed for in the derivation of this standard.

- Mechanical fasteners can be introduced to lengths of timber, but the completed elements are assemblages. Their behaviour under load can be predicted using the timber design standards. However, the AS/NZS 1748 suite of standards has no requirements for mechanical fasteners, so the performance assemblage must be modelled using the behaviour of the mechanical connectors.
- Glues also introduce other sources of variation in performance which have not been included in the statistics that underpin both qualification and verification of timber properties. Glued timber products each have their own product standards that include requirements for glues and verification of glued products based on the redundancy within the glued product.

At present Standards Australia has approved a project to prepare a product standard for finger-jointed structural timber. This will be the appropriate product standard for glued structural timber.

3.2 Time of manufacture

In the Application clause of AS/NZS 1748.1, it indicates that the Standard is intended to apply to timber at the time of manufacture. Manufacture of structural timber can take a number of months, but the time of manufacture is normally taken to refer to the time at which the compliance mark was applied.

Appendix C of AS/NZS 1748.1 indicates the product identification requirements, and at that time, the producer is indicating compliance of the product with the requirements of the Standard. The identification of the manufacturer enables them to take responsibility for the product at that stage.

- Where a number of separate stages in the manufacture are undertaken, it is at the completion of the marking that the product is held to comply with the standard.
- Timber may change in some of its characteristics in time, particularly in response to environmental conditions.

Timber transport, storage and downstream processing all have the potential to change some aspects of the timber in a way that may affect its compliance with the standards.

- Exposure to moisture or to aggressive drying may mean that claims about moisture content of the product no longer apply.
- Some utility requirements, such as cross sectional dimensions, checking, splitting and straightness may also be affected by change in moisture content.
- Aggressive handling may introduce splits, cracks and fractures that may influence structural properties.

Part 2 Qualification

4. Qualification

Qualification involves two separate phases. Each is required in order to be able to demonstrate the performance objectives for solid stress-graded timber product using verification testing.

4.1 Phase I qualification

In verification only two properties are tested, and from the results of these tests it is inferred that all properties (including the untested ones) comply. This can only be reliably asserted where the relationships between all declared structural properties and the verified properties have been established. This is Phase I of the verification and it involves:

- Testing each of the properties of each grade that is to be qualified.
- Establishing the relationship between each property and the tested properties used in verification.
- Comparing the characteristic value of each property to the design characteristic properties to determine the indicator property target values that will be used in verification.

The outputs of Phase I testing are the indicator property target values that must be achieved for each grade in verification in order to have confidence that all of the properties have been achieved. Each grade is tested and analysed separately. Also, as the larger sized products may behave differently from the smaller sized products, this Phase requires testing of the most common small sized product and, where products larger than 140 mm are produced, they must also be sampled and tested separately. Phase I testing is explained in detail in Chapter 5 of this publication.

4.2 Phase II qualification

This phase of the qualification focuses on the link between grading parameters and timber properties. It does this for two reasons:

- Capacity factors presented for sawn structural products in Table 2.1 of AS 1720.1 are based on Coefficients of Variation of strength properties that are typically 35% to 45% for grades up to but not including MGP15, A17, F-17 and higher grades. For MGP15, A17, F-17 and higher grades, the assumed *V* is typically 20% to 30%. Where there is a sufficient correlation between the grading parameters and the verification properties it is possible to achieve enough separation in the grades to deliver products with these *V*s. However, where the correlation is not good enough then the separation between the grades is not as good and the larger overlap between the grades means that there will be a wide range of properties. If this is the case, the *V* of the products will be too high. Research has indicated that in order to achieve the appropriate *V*s the coefficients of determination must be:
  - For strength 0.4
  - For MoE 0.6

- Where there is a reasonable correlation, then it also indicates that at least one of the grading parameters can be used to control the process to increase the strength or MoE of the graded product. The grading parameters that have the highest coefficient of determination with strength will be the ones that should have thresholds adjusted to give a response in the event of deteriorating product strength or MoE as indicated by the verification process.

4.3 AS/NZS 1748.2 requirements for qualification

Clause 6.1 in AS/NZS 1748.2 indicates that the grading method used to produce timber that can be stamped "AS/NZS 1748" must be qualified in accordance with Clause 6.2. Qualification must be performed prior to the commencement of commercial production.

This part of the publication focuses on some general issues that must be addressed prior to commencing qualification.

4.3.1 Shared qualification

The note to Clause 6.1 in AS/NZS 1748.2 allows mills that use the same grading method to grade the same resource to pool the data and share the qualification. The consequences of this shared qualification are as follows:

- The burden of supply of material for qualification and the cost of testing is shared between more than one mill. This has a financial advantage.
- The grading method used by all of the shared mills must use the same types and combinations of equipment to measure the same collection of grading parameters.
- The species, general growing conditions, climatic conditions, and green sawing patterns and processes must be the same in all of the shared mills.
- Where a qualification is achieved, it is shared by all of the mills. Where it is not achieved it is likewise not achieved by all of the mills.
- The shared data for the Phase I and Phase II testing should be retained for future reference by all of the participating mills. The shared qualification is valid provided the same grading parameters are used. However, different thresholds or grade limits can be used in each of the qualified mills.
- Where a shared qualification is used and only one of the mills adds a new grading parameter, it must repeat the Phase II testing in order to assemble data to justify the current grading method. If it is the only one of the shared mills to add the extra grading parameter, this series of tests must be undertaken independently of the others in the sharing arrangement. This will not impact on the other mills in the arrangement.
- Where a shared qualification is used and only one of the mills removes a grading parameter, it may reprocess all of the shared data from Phase II testing without the grading parameter that has been removed. It retains this data as evidence of the qualification of its grading method. It is recognised that in time, the grading methods may diverge between the originally participating mills and that their retained data sets from Phase II testing will each be updated to reflect the grading parameters and algorithms used in each mill.

4.3.2 Grades and resources

The qualification is limited to the declared stress-grades. This is necessary as the ratio between the tested characteristic properties and the design characteristic properties is used in the qualification. This ratio will be different for different stress-grades. Further, the way in which the grades are sorted will differ if a different mix of grades is used.

A first step in the qualification process is to tabulate the list of products that will need to be included in the qualification. It is wise to list off not only those currently used, but also those that may be used in the future.

Careful consideration of the nature of the resource that will be an input to the process is also required. The material used for the qualification should represent as wide a range of the anticipated inputs as possible. This includes anticipated changes in the resource over time. For this discussion, the resource is the input to the grading process and it will include normal discussion of species and growth conditions for the logs, but also green sawing patterns, seasoning methods, and profiles used at the planer that may influence the character of the material arriving at the grading process.

4.3.3 Qualification of mechanical stress-grading to AS/NZS 1748:2006

Those productions that already have satisfied the initial evaluation and are currently grading to AS/NZS 1748:2006 are deemed to be qualified for that grading method. However, use of a different grading method will require the separate qualification of the new grading method.

Appendix A indicates that the deemed to qualify status is only conferred on existing grading operations. Where a new machine grading operation is commissioned, it must be subjected to the qualification requirements of the body of the standard.

4.3.4 Qualification requirements for any grading methods

There are four requirements for qualification of a grading method other than the deemed-to-have-qualified mechanical stress-grading method:

1. For all grades, and each size range, the characteristic values of all properties must be greater than the design characteristic value. This is demonstrated in Phase I testing, and is discussed in Chapter 5 of this publication.
2. The indicator properties are the ones that will be tested in verification testing and these have to be declared in the Phase I testing. Indicator target property values are set for each of the indicator properties from the Phase I test results. This process is also discussed in Chapter 5 of this publication.
3. The coefficients of determination for each of the grade parameters are calculated for each of the indicator properties. At least one grading parameter for each indicator value must have a value greater than the limits set in Clause 6.4.4.2 of AS/NZS 1748.2. This process is discussed in Chapter 6 of this publication.
4. An appropriate qualification report has to be prepared. The report is detailed in Clause 6.5 of AS/NZS 1748.2. It is discussed in Chapter 4.4 of this publication.

4.3.5 Grading parameters

A grading parameter is any measurement made in the course of sorting timber into stress-grades. It can also be a derived parameter from a combination of other grading parameters. Grading parameters usually have limits placed on them in order to allocate pieces of timber to a stress-grade.

A number of examples of grading parameters are provided to illustrate the flexibility of this concept:

***Example 4*: Grading parameters**

A grading system involves the in-line measurement of moisture content in the timber, acoustic modulus of elasticity, knot size and position to calculate Knot Area Ratio (KAR). The measurements on the timber are:

- Moisture content (profile, average, minimum and maximum);
- Average MoE; and
- KAR.

In addition, moisture content and MoE are combined to give a MoE at 12% mc, and MoE and KAR are combined in a non-linear algorithm to give an estimate of strength. Grade limits will be applied to KAR, MoE at 12% mc and estimated strength. Average moisture content will be monitored and limits applied to ensure that the graded timber meets the requirements for seasoned timber. The grading parameters declared in the report and covered in the Phase II testing will be:

- KAR;
- MoE at 12% mc;
- Estimated strength;
- MoE; and
- Average moisture content.

***Example 5*: Grading parameters and algorithms**

A grading system involves passing the timber through a machine that measures:

- Average MoE;
- Knot profile;
- Density profile; and
- Slope of grain profile.

All of these parameters are available as raw grading parameters and are combined to give an estimated strength and an estimated MoE profile. The limits are only applied to estimated strength and estimated MoE. In this case, all of the grading parameters measured and the two derived parameters – estimated strength and estimated MoE – will be declared as grading parameters in the report and covered in the Phase II testing:

- Estimated strength;
- Estimated local MoE;
- Average MoE;
- Knot size and position;
- Density; and
- Slope of grain.

4.4 Qualification report

The qualification report is evidence that qualification of the grading method has been completed. It should be kept up to date so that it always relates to the current grading method. This means that the qualification report is a “living document” and must be updated with each major change to the grading method.

4.4.1 Contents and structure of the qualification report

The required contents of the qualification report are detailed in AS/NZS 1748.2:2011 Clause 6.5 (a)-(m), as explained below.

(a) to (c) The grading method that has been qualified is described. This is the method currently used in the mill. Where the method has changed since the original qualification, this description must be kept up to date and the Phase II analysis repeated for the current grading method. The essential part of the grading method is a listing of all of the grading parameters used and methods for combining the basic grading parameters to give other grading parameters or grading indicators. Part of this process is the indication of the measured parameters that are used with limits to allocate timber to stress-grades in the grading process. Where grading parameters change at some later stage, this section of the report must be updated immediately so that the list is current. At the same time, the Phase II analysis is repeated to ensure that the report remains valid for the current grading method.

(d) The resource that is an input to the grading process is defined. This definition should be as wide as possible, and the material sampled for both Phases of the qualification should represent as wide a range as possible. This definition is more than just the definition of the log resource and includes any process upstream of the grading process.

(e) The outputs from the grading process are structural products and the intended stress-grades and size ranges must also be listed.

(f) to (j) The sampling, testing, and analysis of the Phase I testing are presented. The detail of this testing should not need to be revisited often in the operation of the grading system.

(k) The sampling, testing, and analysis of the Phase II testing are presented. Where new grading parameters are added, this section will need to be repeated, however, where parameters are removed or algorithms changed, no further testing is required but the analysis may have to be repeated. This section must remain current and aligned to sections (a) and (b).

5. Qualification Phase I testing and analysis

This Phase of the qualification process is detailed in Clause 6.3 of AS/NZS 1748.2. Random sampling and random position testing is used in this Phase to make the results directly comparable with the design characteristic values.

- The most valid sample is that which is drawn from normal production, however for some operations normal production cannot commence until qualification has been completed. In these cases, the sample for Phase I testing will need to be drawn from pilot production runs.
- Where the new grading method can be run in common with a previously qualified grading method, then it is possible to use the previously qualified grading method for producing a normal production run, but use the new grading method to classify the sampled timber for the qualification testing.

While there is no requirement for the repeat of Phase I testing, there are some advantages in regularly checking the compliance of the product with all of its properties. This is particularly valuable after some experience with the grading method has been accumulated, the limits have been refined and the ratios between the properties may be better defined. (Where it is felt that the test results of the Phase I qualification are not representative of the product, it may be expedient to repeat the Phase I testing quite quickly rather than operate for a long time with high indicator property target values.)

5.1 Phase I sampling

The requirements for Phase I sampling are presented in Clause 6.3.2 of AS/NZS 1748.2 The requirement is to determine the characteristic properties for each grade that will be qualified in a representative small size, and also, where wide boards are produced, in a representative wide size.

Grading information should be collected for each piece sampled. This is particularly important if the manufacturer is over-sampling in order to allow for refinement of grading limits in the Phase I testing. (See also 5.1.2 and 5.3.1 of this publication.)

5.1.1 Sizes

The standard classifies 140 mm wide pieces and smaller as small boards and pieces with the larger cross sectional dimension greater than 140 mm as wide boards. It has been found that the property relationships for wide boards can be different to those for narrow boards for some structural products. The Phase I sampling and testing is therefore performed on narrow boards and wide boards separately.

One of the highest volume products should be selected as the representative small size. In most cases, it will be the highest volume production size that is selected unless there is something unusual about that size. For example, if the highest volume size is not produced in all of the required stress grades, then a reasonably high volume size that is produced in all stress grades should be selected. Where there is no size that is produced in all of the required grades, then it is possible to draw all of the grades from some different but similar sizes. (e.g. if the lower grades are only produced in the 35 mm thick sections and the higher grades are only produced in 45 mm

thicknesses, then the lower grades could be qualified on 90x35 sections and the higher grades on 90x45.)

In addition, where wide boards are produced to AS/NZS 1748, it is also necessary to demonstrate the property relationships separately on a representative wide size. If the mill has no plans to produce sections with the largest cross sectional dimension larger than 140 mm, then there is no necessity to sample wide boards. The representative wide size is also selected as the size with a large annual production volume in the wide sizes.

5.1.2 Sample size

Each generic stress grade needs to be sampled for tests on bending strength and MoE, tension strength, compression strength and shear strength. For this, four separate samples of each grade are required, each with at least 50 pieces in it.

Where a product is to be qualified that has restricted use – e.g. battens or lintels that are clearly marked as bending only products – it is sufficient to demonstrate only those properties for which design characteristic values are declared. In each of these examples this may simply be bending strength, MoE and, for lintels, shear strength. This would only require one or two samples of 50+ pieces for these products.

While the standard calls for a sample size of 50 specimens per grade / size / property combination, it is prudent to sample more pieces than that for a number of reasons:

- Where there is a high level of certainty in the grading limits, then the sample size should be marginally more than 50 for each grade / size / property combination. In those cases, the sampled pieces should comply with the designated stress grade.
- However, often in a new grading process, there has not been a great deal of experience in setting and manipulating the grade limits for each stress-grade and grading parameter. In these cases, it may be necessary to adjust the grading limits to ensure that the grade properties are achieved. If this is the case, some of the specimens may be ruled out of the grade after the grade limits are adjusted, and in order to have 50 specimens left in the analysis, an allowance for some extra specimens should be made. A discussion of this issue is presented in Chapter 5.3.1 of this publication.
- The characteristic value is found by evaluating average MoE and 5%ile strength. These raw values are adjusted downward to allow for sampling error in the calculation of characteristic values. Larger sample sizes experience less reduction. The larger the sample size, the better is the estimate of characteristic value. Some producers may want to have a larger sample size to reduce the effect of sampling errors. In these cases, the benefit reduces with the sample size. There is little marginal value in sample sizes of more than 100.

Selection of sample size is a compromise between the cost of testing and the accuracy of the characteristic value reported. The cost of testing wider sizes is higher than that of the lower sizes, so often the sample sizes for wide boards are closer to the limit than for the narrow boards.

5.1.3 Random sample

The standard specifies that the sample be a random sample. This means that pieces are selected using a method that cannot introduce unintended bias. This invariably means an automated sampling method, as with manual sampling it is too easy to pass over a piece that does not look as though it would perform well.

Automated sampling would pull pieces out of production at regular intervals, for example every 100th piece in each grade would be sampled until the required number have been collected. In pilot production runs a much closer sampling interval would be used (e.g. every 10th piece).

If it is possible to sample over a number of shifts, then that increases the likelihood that the full range of the product will be sampled. The standard does not specify this, but it will make the sample more representative of the longer-term production. This ultimately benefits the producer as the data returned by the qualification have a much wider applicability.

5.1.4 Splitting the sample

Once the sample has been collected, it must be split into groups for testing for each property. The sample of each grade / size combination should be split as fairly as possible:

- Allocating pieces alternately to each property group in the order in which they were produced will mean that each production hour or shift will be equally represented in each property group and it will give the same range of production variants in each property group.
- If this is not possible, rank the sample by an important grading parameter, and split the sample alternately to the property groups. This will ensure that each property group contains the full range of grade parameters.
- Other methods for equitably splitting the sample can be devised, but they must not involve using a person or people to make a selection.

The equitable splitting of the sample into the property groups is very important as the ratios between the properties are used in the analysis of this data. The properties must therefore be comparable and this will only happen if the groups are comparable. Some extra effort before the testing to ensure that this is the case is much better than having to redo the tests because the groups were not well matched.

5.2 Phase I testing

For each grade / size / property combination, random position tests are performed in accordance with AS/NZS 4063.1. AS/NZS 4063.1 provides:

- Methods for allocation of a random test position using random numbers. Random numbers can easily be generated in msExcel using the RAND() function which generates a random number in the interval [0,1].
- Methods of test for bending strength, bending MoE, tension parallel to grain, compression parallel to grain, and bending shear strength.

The major axis bending MoE test configuration shown in the standard indicates that the deflection should be measured on the centre-line of the test piece but allows other

measurement methods if it can be demonstrated that they are conservative. The centre-line deflection method involves measurement on both sides and requires elaborate and sensitive equipment. Measurement on either the top face or bottom face of the specimen is conservative in all cases, as extra deformation equal to compression of the specimen perpendicular to the grain is added to the flexural deflection.

If the product is a designated single purpose product with bending around the minor axis (e.g. a batten product) then minor axis testing for both bending strength and MoE should be performed to simulate the use context of the member.

Also as mentioned in Section 5.1.2, restricted use products may require testing of only some of the properties, whereas products in generic stress-grades must be tested for all five of the listed primary properties – bending strength, bending MoE, tension parallel to grain, compression parallel to grain, and bending shear strength

For shear testing, note whether the failure is a shear failure or a bending failure for each specimen. (In the single span bending shear test in AS/NZS 4063.1, shear failures will have some part of the failure surface intersect an end of the specimen near the middle third of the end face.)

5.3 Phase I analysis of characteristic values

The analysis of the test data calls for the evaluation of characteristic value in accordance with AS/NZS 4063.2.

- For MoE, this involves the calculation of the average MoE and the 5%ile MoE using a single method of fitting a log-normal distribution through the test MoE data as shown in clause B.3.4 in AS/NZS 4063.2. The characteristic value can then be found using the factors in clause B.3.3 in AS/NZS 4063.2. Provided the V of the MoE test data is less than around 20%, the characteristic MoE will be related to the average MoE. Where the V of the data is higher than around 20%, the 5%ile MoE limits the characteristic MoE value.
- A number of different methods are used for evaluation of the 5%ile of strength data and the log-normal distribution (Method 1 in Appendix B of AS/NZS 4063.2) seems to give reasonable values for most structural products.

For shear strength evaluation, conservative estimates of the characteristic bending shear strength can be found using the following methods:

- Analyse all data as shear strength data regardless of the noted failure mode.
- Reject any data that is not a shear failure and analyse only the shear failure modes. The number of specimens (n) is the number of shear failures only. (This method is not advised for fewer than 10 shear failures.)

The requirement is that each characteristic property be greater or equal to the design characteristic value for the grade. Where the grading limits are well established, this should be easy to demonstrate, but where there has been limited experience with the grading method, then this series of tests can assist in refining the grading limits as shown in Section 5.3.1 of this publication.

5.3.1 Characteristic value where grading limits need to be revised

Where the characteristic value determined from the test result is less than the design characteristic value, it indicates that the grade parameters used were not appropriate for the grade. Often at the time of qualification, there has been limited experience in the use of the grading method and the grading limits need to be refined.

This is an appropriate step for this analysis where there have been sufficient specimens taken to allow adjustment of the grade limits to remove some of the data. (Note that once the new grade limits have been established, all sample groups must be truncated to the same limits.) The extra pieces that were sampled for this scenario should still leave more than 50 in each property group.

An appropriate procedure for the refinement of the grading parameters for a specific grade / size combination is as follows:

- The ratio between characteristic value from test data and the design characteristic value for each property is evaluated. The property with the lowest ratio is the limiting one.
- The lowest test values of the limiting property are examined and grading limits adjusted to remove sufficient pieces to cause the limiting property to have a characteristic strength greater than the design characteristic value (equivalent to giving a ratio of characteristic properties > 1.0).
- The same grading limits are applied to each property group and any pieces that fall below the revised grading limits are removed from the test data for that grade and included with another grade for which the grading parameters are appropriate. The characteristic values are re-evaluated for each property and each grade with the changed data set.
- If the ratio of the characteristic value from test to the design characteristic value is less than one for any property, then this process needs to be repeated. The process is continued until the ratio is greater than 1 for all properties.

Where the grading limits have not had the chance to be refined in production, the grading limits for each grade / size combination can be refined in this way until all properties for each grade / size combination are greater than their corresponding design characteristic value.

5.4 Phase I indicator property target values

The qualification aims to establish the basis for demonstrating the compliance of a product by verifying two basic properties. However, the objective of verification is to verify all of the structural properties. This will be achieved as long as the target values for the two properties that are tested are at an appropriate level to deliver the weakest of all of the properties. This is the crucial step that makes it possible.

In general:

- In sawn timber, Modulus of Elasticity is well correlated with the fibre density of the wood and while influenced a little by knots in the test span, it is not as well correlated with the size of knots. Both compression and shear strength are more correlated with wood fibre density than knot size, so MoE is a reasonable indicator of those properties. In studies of a number of grades of

commercial Australian structural timber, the compression and shear strength are better correlated with MoE than with bending strength.

- Both bending and tension strength are greatly influenced by presence of knots and other growth characteristics compared with the effect of wood fibre density. Tension strength is better correlated with bending strength than with MoE and likewise bending strength is better correlated with tension strength than with MoE.
- This leads to two lists of properties with reasonable correlations between the values in each group. List A is MoE, compression strength and shear strength, and List B is bending strength and tension strength.
- Verification requires the testing of one property from each group to verify that the grading is able to deliver compliant values for the properties that are affected by fibre density and for the properties that are affected by knot size and other growth characteristics.

The indicator properties are the ones used in verification. They are selected by the producer well before the qualification process. The two indicator properties selected are:

- Modulus of Elasticity as the indicator property that represents the List A properties. In production, an evaluation of the MoE will be undertaken as part of the normal verification testing of each batch. The compliance of compression strength parallel to grain and bending shear strength will be linked to the compliance of MoE.
- Either bending strength or tension strength must be chosen as the other indicator property. Whichever one is chosen will be linked with the other for the purposes of verification.

5.4.1 Steps to establishment of indicator property target values

The aim of the steps in this section of the Standard is to set the indicator property target values which will be used in verification to not only assure the compliance of the indicated property (which has been tested in verification), but the other properties linked to it (which have not been tested as part of the verification).

- In each list of properties (List A and List B), the property that is closest to the design characteristic value is found. This is the one that is most critical in the verification of that list.
- Where the critical property in the list is the indicator property, then the indicator property target value can be the design characteristic value.
- Where the critical property in the list is not the indicator property, then the target value for the indicator property must be higher than the design characteristic value to ensure that the property that is critical meets its design value.

Hence the steps are as follows:

- Find the ratio of the characteristic value from testing of each property to the characteristic value for design for the same property. (The characteristic value for design is in some cases a function of the size of the cross section. The appropriate value for the size tested is used.)

- For each property in List A, the property with the minimum ratio is found. This is the critical property in List A. The critical property in List B is also found.
- The upper confidence limit of the minimum ratio is found which allows for variations in the property due to the fact that the data was obtained on a sample. We can be quite confident that the minimum ratio will be less than this value.
- The upper confidence limit of the minimum ratio is used to establish the target value that must be achieved in verification testing.

These steps are detailed in Clause 6.3.6.2 of the standard, and the process is explained in the remaining parts of Section 5.4.2 of this report. This is involves some straightforward calculations, but the concepts are quite complex.

5.4.2 Ratio of characteristic values

This concept has already been introduced in Section 5.3. In that context, all of the characteristic values from test had to be higher than the design characteristic values, so the ratio had to be greater than 1.0. The same ratio is used a little differently here:

- For each tested property, the ratio of the characteristic value from test to the design characteristic value is found. (The appropriate value of characteristic value for design for the size tested is used.) By this stage all of these ratios are higher than 1.0.
- The indicator property has its ratio designated as $r_{i,A}$ for MoE or $r_{i,B}$ for the List B indicator property.

5.4.3 Minimum ratio of characteristic values

For each grouping of properties, the minimum value of the ratio is found. This property will be the critical property in the list:

- For the List A properties (MoE, compression strength parallel to grain, and bending shear strength), the minimum ratio is given by *equation 7*.

$$r_{m,A} = min\left(\frac{E_k}{E}, \frac{R_{k,c}}{f'_c}, \frac{R_{k,s}}{f'_s}\right) \qquad \textit{equation 7}$$

- For the List B properties (bending strength and tension strength parallel to grain), the minimum ratio is given by *equation 8*.

$$r_{m,B} = min\left(\frac{R_{k,b}}{f'_b}, \frac{R_{k,t}}{f'_t}\right) \qquad \textit{equation 8}$$

- The minimum in each list is the property that is closest to the design characteristic value and hence it is the one that is most at risk of non-conformance in the group. It is the one that needs to be protected in verification.

The property with the minimum ratio is the property that will normally be closest to its design value in production.

The suite of characteristic values for design may not always match the characteristics of every resource. Often the suite of properties in a stress-grade represent some compromise between the properties delivered by a range of resources and the properties most suitable for design. In a number of cases, they may have been derived

from some aggregated testing of a number of producers and / or production methods. It is rare that all properties from a testing program will have a uniform ratio to the design values.

Verification is easiest where the properties with the minimum ratio to design are also the properties tested in verification. In those cases, following the next steps will simply confirm that the indicator property target values are the characteristic values for design.

Where one or more of the properties with the minimum ratio to design is not the property tested in verification, then the next steps will work out the value of the indicator property that must be achieved in order to have confidence that the untested property which was found to be critical will be satisfactory.

5.4.4 Upper bound of minimum ratio of characteristic values

The calculations of the ratios of characteristic values and the minimum for each group are based on test results of a sample. As a result, the value returned as a characteristic value ratio by the tests may incorporate some sampling error. It is an estimate of the property of the whole population from which the sample was taken, but it may be slightly higher or lower than the true population value depending on which individual pieces were selected as the sample. In this step, this uncertainty is taken into account so that the value used as the indicator property target value is one that has a high level of confidence that it reflects the whole population, not just the pieces sampled.

The sampling error effect on the ratio can be estimated using *equation 4*. This can be added to a value to give an upper confidence limit, or subtracted from it to give a lower confidence limit. This is shown below for the r_m values calculated as the minimum ratio of characteristic values.

An estimate of the range of values that the population may have as the minimum ratio is therefore:

$$\left[r_{m,A}\left(1 - k_s\frac{CoV}{\sqrt{n}}\right), r_{m,A}\left(1 + k_s\frac{CoV}{\sqrt{n}}\right)\right] \text{ for the List A minimum ratio}$$

$$\left[r_{m,B}\left(1 - k_s\frac{CoV}{\sqrt{n}}\right), r_{m,B}\left(1 + k_s\frac{CoV}{\sqrt{n}}\right)\right] \text{ for the List B minimum ratio}$$

There is a high level of confidence that the minimum ratio will not be less than the upper bound in each of these ranges. It is this value that we need to use in setting the indicator property target value so that the target value is not affected by the sampling error.

The values of k_s are set to give a 75% confidence which is the value used in calculating characteristic values in accordance with AS/NZS4063.2. Different values are used for List A and for List B:

- The list A indicator property is MoE which is based on an average value and for it the upper 75% confidence limit is calculated using k_s = +0.70.
- The list B indicator property is based on a lower 5%ile and the upper 75% confidence limit is calculated using a k_s value that is a function of the statistical analysis method. The most common method used also has the lowest value of k_s and this is +1.17. It is appropriate for the log-normal

analysis method, but can also be conservatively used for other analysis methods.

In calculating the upper limit of the minimum ratio ($r_{m,u}$), the coefficient of variation used is the V of the property chosen as the indicator property from the Phase I testing and n is the number of test specimens used in the Phase I testing of that property.

Hence for List A:

$$r_{mu,A} = r_{m,A} \times \left(1 + 0.7\frac{V_E}{\sqrt{n}}\right) \qquad \textit{equation 9}$$

with $r_{m,A}$ calculated using *equation 7* above.
0.7 is the k_s value used in establishing characteristic values for MoE.
V_E as the V for the MoE values found from the MoE characteristic value.
n as the number of specimens tested to give the MoE characteristic value.

And for List B:

$$r_{mu,B} = r_{m,B} \times \left(1 + 1.17\frac{V_B}{\sqrt{n_B}}\right) \qquad \textit{equation 10}$$

with $r_{m,B}$ calculated using *equation 7* above.
1.17 is the k_s value used in establishing characteristic values for strength values. (This is appropriate as the List B property will either be bending or tension strength.
V_B as the V for the strength property used as the List B verification property as determined in testing for its characteristic value.
n as the number of specimens tested to give the characteristic value from testing for the List B verification property.

These two values are used in the final step of the Phase I analysis.

5.4.5 Setting indicator property target values

The two indicator properties will be used in verification of the properties of the grades in production. The target values are the values that will be put into any verification process as the values to be achieved in verification.

The lowest value that they can have is the relevant characteristic value for design, but they could have higher values in order to ensure even the weakest properties comply as indicated in Section 5.4.1.

In this case the indicator characteristic value for design is scaled by a value of:
$\frac{r_i}{r_{mu}}$, the ratio of the indicator property ratio (calculated as shown in Section 5.4.2) to the upper limit of the minimum ratio (calculated as shown in Section 5.4.4),
or 1.0, whichever is the higher.

The indicator property target value must be greater than or equal to the design value. It will be greater where the ratio for the critical property is less than the ratio for the indicator property. It is best illustrated with some examples as shown in Section 5.4.6.

5.4.6 Examples of calculation of indicator property target values

In this section there will be three examples to illustrate three different scenarios:

- Critical property is the indicator property.
- Critical property is not the indicator property, but target value is the design value.
- Critical property is not the indicator property and target value is larger than the design value.

Example 6*: *Phase I qualification

		List A			List B	
		MoE	Compr	Shear	Bend	Tens
	Design value	10,000	18	2.6	17	7.7
Test data	n	51	52	50	51	55
	V	0.18	0.24	0.27	0.42	0.39
	Characteristic Value from test	10,364	18.8	3.7	23.4	11.3
(a)	r	1.036	1.044	1.423	1.376	1.468
(b)	r_i	1.036			1.376	
(c)	r_m	1.036			1.376	
(d)	r_{mu}	1.055			1.471	
(e)	r_i/r_{mu}	0.983			0.936	
	Target Value	10000			17.0	

In this case, the design values and test results are as shown. The indicator properties have been selected as MoE and bending strength.

At step (a) the ratio is calculated as the test value divided by the design value

For MoE, $r = \frac{10364}{10000} = 1.036$ and for compression, $r = \frac{18.8}{18.0} = 1.044$

At step (b) the ratio for the indicator property is selected

For List A, this is the ratio for MoE, and for List B this is the ratio for bending strength

At step (c) the minimum of each value in the same list is selected.

For List A, this will be the minimum of 1.036, 1.044 and 1.423 i.e. 1.036

For both List A and List B, in this example, it is the indicator property value.

At step (d) the upper bound is calculated.

For List A, $r_{mu,A} = r_{m,A}\left(1 + 0.7\frac{V}{\sqrt{n}}\right) = 1.036\left(1 + 0.7\frac{0.18}{\sqrt{51}}\right) = 1.055$

For List B, $r_{mu,B} = r_{m,B}\left(1 + 1.17\frac{V}{\sqrt{n}}\right) = 1.376\left(1 + 1.17\frac{0.42}{\sqrt{51}}\right) = 1.471$

At step (e) the indicator property target value is found.

Firstly $\frac{r_i}{r_{mu,A}} = \frac{1.036}{1.055} = 0.983$ and for List B $\frac{r_i}{r_{mu,B}} = \frac{1.376}{1.471} = 0.936$

In each case, the maximum of this value and 1.0 is 1.0.

The Target Value is the Design Value times 1.0.

In this case, because the minimum ratio was for the same property as the one used as the indicator property, the Target Value was the Design Value. In other words, because the indicator properties were the ones in their group that were closest to the characteristic value for design, as long as their compliance had been demonstrated, then there was confidence that the other properties also complied.

Example 7: ***Phase I qualification***

		List A			List B	
		MoE	Compr	Shear	Bend	Tens
	Design value	10,000	18	2.6	17	7.7
Test data	n	51	52	50	51	55
	V	0.18	0.24	0.27	0.42	0.39
	Characteristic Value from test	10,364	18.4	3.5	24.1	10.5
(a)	r	1.036	1.022	1.346	1.418	1.364
(b)	r_i	1.036			1.418	
(c)	r_m	1.022			1.364	
(d)	r_{mu}	1.040			1.457	
(e)	r_i/r_{mu}	0.996			0.973	
	Target Value	10000			17.0	

In this case, the design values and test results are as shown. The indicator properties have been selected as MoE and bending strength.

At step (a) the ratio is calculated as the test value divided by the design value

For MoE, $r = \frac{10364}{10000} = 1.036$ and for compression, $r = \frac{18.4}{18.0} = 1.022$

At step (b) the ratio for the indicator property is selected

For List A, this is the ratio for MoE, and for List B this is the ratio for bending strength

At step (c) the minimum of each value in the same list is selected.

For List A, this will be the minimum of 1.036, 1.022 and 1.346 i.e. 1.022

For both List A and List B, in this example, the minimum value does not correspond to the indicator property value.

At step (d) the upper bound is calculated.

For List A, $r_{mu,A} = r_{m,A}\left(1 + 0.7\frac{V}{\sqrt{n}}\right) = 1.022\left(1 + 0.7\frac{0.18}{\sqrt{51}}\right) = 1.040$

For List B, $r_{mu,B} = r_{m,B}\left(1 + 1.17\frac{V}{\sqrt{n}}\right) = 1.364\left(1 + 1.17\frac{0.42}{\sqrt{51}}\right) = 1.457$

At step (e) the indicator property target value is found.

Firstly $\frac{r_i}{r_{mu,A}} = \frac{1.036}{1.040} = 0.996$ and for List B $\frac{r_i}{r_{mu,B}} = \frac{1.418}{1.457} = 0.973$

In each case, the maximum of this value and 1.0 is 1.0.

The Target Value is the Design Value times 1.0.

In this case, the ratio of test property to the design property was smallest for properties other than the indicator properties. However, the difference between the minimum ratio and the ratio for the indicator property was not significant. (It was smaller than the error due to the fact that a small sample had been tested.) The lack of statistically significant difference means there are no grounds to change the indicator property target values. As long as compliance with the indicator properties has been demonstrated , then compliance with the other properties can also be inferred as any discrepancy is within the accuracy of the analysis.

Example* 8: *Phase I qualification

		List A			List B	
		MoE	Compr	Shear	Bend	Tens
	Design value	10,000	18	2.6	17	7.7
Test data	n	51	52	50	51	55
	V	0.18	0.24	0.27	0.42	0.39
	Characteristic Value from test	10,804	18.7	3.7	26.7	10.1
(a)	r	1.080	1.039	1.423	1.571	1.312
(b)	r_i	1.080			1.571	
(c)	r_m	1.039			1.312	
(d)	r_{mu}	1.057			1.402	
(e)	r_i/r_{mu}	1.022			1.120	
	Target Value	10219			19.0	

In this case, the design values and test results are as shown. The indicator properties have been selected as MoE and bending strength.

At step (a) the ratio is calculated as the test value divided by the design value

For MoE, $r = \frac{10804}{10000} = 1.080$ and for compression, $r = \frac{18.7}{18.0} = 1.039$

At step (b) the ratio for the indicator property is selected

For List A, this is the ratio for MoE, and for List B this is the ratio for bending strength

At step (c) the minimum of each value in the same list is selected.

For List A, this will be the minimum of 1.080, 1.039 and 1.423 i.e. 1.039

For both List A and List B, in this example, the minimum value does not correspond to the indicator property value.

At step (d) the upper bound is calculated.

For List A, $r_{mu,A} = r_{m,A}\left(1 + 0.7\frac{V}{\sqrt{n}}\right) = 1.039\left(1 + 0.7\frac{0.18}{\sqrt{51}}\right) = 1.057$

For List B, $r_{mu,B} = r_{m,B}\left(1 + 1.17\frac{V}{\sqrt{n}}\right) = 1.312\left(1 + 1.17\frac{0.42}{\sqrt{51}}\right) = 1.402$

At step (e) the indicator property target value is found.

Firstly $\frac{r_i}{r_{mu,A}} = \frac{1.080}{1.057} = 1.022$ and for List B $\frac{r_i}{r_{mu,B}} = \frac{1.571}{1.402} = 1.120$
In each case, the maximum of this value and 1.0 is greater than 1.0.
The Target Value is larger than the Design Value.

Target Value for $E = 10{,}000 \times 1.022 = 10{,}220$ MPa
Target Value for bending strength = $17 \times 1.12 = 19.0$ MPa

In this case, the ratio of test property to the design property was smallest for properties other than the indicator properties. However, in this case, the difference between the minimum ratio and the ratio for the indicator property was statistically significant. (It was larger than the error due to the fact that a small sample had been tested.) The statistically significant difference means there are grounds to change the indicator property target values to protect the other properties. As long as compliance with the indicator properties has been demonstrated by exceeding the target value (higher than the design value), then compliance with the other properties can also be inferred because of the adjustment to the target value.

These calculations are applied to each stress-grade and each size tested.

- There may be different indicator property target values for each of the size groupings within a stress-grade. For example, the smaller size may have returned an indicator property target value of the design value for one grade (say 10.0 GPa for MoE of MGP10) but the larger size may have returned a value higher than the design value for the same grade (say 10.45 GPa for MoE of MGP10).
- The indicator property target values from the small sized specimen tests apply for all sizes with a wide face of 140 mm or less. The indicator property target values from the large sized specimen tests apply for all sizes with a wide face of more than 140 mm.
- Within a size range, the different grades may have indicator property target values with different trends. For example, the smaller size may have returned an indicator property target value of the design value for one grade (say 12.7 GPa for MoE of MGP12) but a value higher than the design value for another grade (say 10.45 GPa for MoE of MGP10).
- For each stress-grade, a separate series of tests must be completed in the Phase I qualification. It is not possible to extrapolate from one stress-grade to another. If a new stress-grade is introduced, a qualification for the new stress-grade must be completed to establish the new grade’s indicator property target values.

5.4.7 Use of indicator property target values

The indicator property target values are used in verification of properties. Regardless of the verification method chosen, some estimates of the production properties are compared with the indicator property target values. This gives confidence that all properties are verified.

Section 11 of this document gives more detail on the maintenance of the verification system and its relationship with the indicator properties. However, where verification

Method A, B, D or E is chosen, then the indicator property target values are used regularly in setting the acceptance criteria of the regular verification tests.

In the verification method described in Appendix A, the test results are compared with Test Comparison Values (TCVs) in order to determine the verification status. The TCVs are calculated based on the indicator property target values.

In the verification method described in Appendix B, which verifies List B properties, the proof stress is calculated from the indicator property target values.

In the verification method described in Appendix D, which verifies List A properties, the CUSUM parameters K, Y and Z are all calculated using the indicator property target value found for MoE.

In the verification method described in Appendix E, the target values referred to in NZS 3622 are to be taken as the indicator property target values.

Indicator property target values are specific to a single stress-grade, but apply to a size range.

- All sizes with wide face dimension of 140mm or less use the indicator property target values obtained from the smaller sized specimens of the stress-grade.
- All sizes with wide face dimension of more than 140mm use the indicator property target values obtained from the larger sized specimens of the stress-grade.

6. Qualification Phase II testing and analysis

This Phase of the qualification process is detailed in Clause 6.4 of AS/NZS 1748.2. The sampling and testing for this phase is completely different to that in Phase I. This is because its objective is completely different. In Phase I, the objective related to setting verification targets for each grade and each product range. In Phase II, the objective relates to the sensitivity of the indicator properties to the sorting given by all of the grading parameters. This step is necessary to have the confidence that the grading method can respond to changes indicated by the verification of the properties.

Verification of the product, as outlined in Section 10 of this document, provides assurance that the complying product meets its requirements. It provides a categorisation of the product of "Verified" if there is confidence that it meets its properties. Where this is not the case, the producer may have to adjust the grade limits of the grading method in order to deliver compliant product. Hence there needs to be a link between the grading parameters and the properties, in order for the feedback by verification to be implemented. The need for this requirement can be seen from a number of different perspectives:

- From a customer's perspective, the process of verification safeguards the properties of the product. This is only effective provided that there is a remedy for times in which the product fails to achieve a Verified status.
- From a producer's perspective, there should be a strong link between the indicator properties and at least some of the grading parameters. This will mean that they have a means of controlling the properties of the structural products.
- From a designer's perspective, there is a link between the efficiency of grade separation and the capacity factors given in AS 1720.1. Where the grading method is able to separate the grades without a large overlap between the properties of adjacent stress-grades, then the *V* of the properties will be appropriate for the values used in setting the capacity factors.

All of these perspectives can be addressed in ensuring that the grading method has a high enough coefficient of determination between the indicator properties and at least one of the grading parameters. The coefficient of determination is a measure of correlation:

- A high correlation means that the limits on at least one of the grading parameters can be adjusted to correct any deficiency in measured structural properties and thereby deliver the level of compliance expected by customers.
- A high correlation also means that producers can control the properties of the products they produce by varying the limits they impose on grading parameters. This enables them to balance potential liability for non-compliant products and profitability of manufacturing.
- Strong correlations mean that the range of properties in a stress grade is more limited, and this in turn gives a lower coefficient of variation. AS/NZS 1748.2 limits the coefficient of determination to a value that gives *V*s of products that meet the requirements of AS/NZS 4063.2 on which the capacity factors in AS 1720.1 were based.

Phase II of the qualification examines the correlations between indicator properties and each of the grading parameters in order to ensure that the product is controllable

and has appropriate *V*s for the standardised capacity factors. It involves only the grading parameters and the indicator properties and not any limits that may be in place to separate the various structural products.

- The sample is taken across the entire spectrum of input material. This is a run-of-mill sample.
- No attempt is made to separate the stress-grades.
- All pieces are tested at the location that the grading method indicates is the most critical on the length. This is biased position testing.

6.1 Phase II sampling

The requirements for Phase II sampling are presented in Clause 6.4.2 of AS/NZS 1748.2. Two separate Phase II evaluations are performed – one on the smaller sizes and one on the larger sizes. The Phase II sampling is:

- Drawn from all material processed by the grading method and not divided into stress-grades.
- Selected at random from all of the input material processed.
- Linked to the grading parameters collected in the grading process.
- Not sorted into stress-grades.

New sampling must be performed for the Phase II testing. The Phase I sample was taken at random from the graded material (output). The Phase II sample is selected at random from the ungraded (input) material.

6.1.1 Sizes

The same cross sectional dimensions used in the Phase I sampling are used in the Phase II sampling. Section 6.2.1 of this document outlines the selection of those cross sectional sizes. As before, where the wide face dimension of all products is 140 mm or less, then only the small sized cross section needs to be sampled. If any products with a wide face dimension of greater than 140 mm are produced, then both the small sized and the large sized cross sections need to be sampled.

6.1.2 Sample size

Clause 6.4.2 of AS/NZS 1748.2 requires that at least 200 specimens be collected in each of the one or two selected cross sectional sizes.

The aim of this sample is to include the full range of material passing through the mill, so the larger the sample the better. However, the results of the Phase II analysis are not as sensitive to the sample size as are the results of the Phase I analysis. Taking a few extra specimens in the sample may not give a significant improvement in the confidence in the result of the Phase II testing.

6.1.3 Random sample

The Standard specifies that the sample be a random sample. This means that pieces are selected using a method that cannot introduce unintended bias. This invariably means an automated sampling method, as with manual sampling it is too easy to pass over a piece that does not look as though it would perform well.

Automated sampling would pull pieces out of production at regular intervals, for example every 100th piece that passes through the grading machine would be sampled until the required number have been collected. In pilot production runs a much closer sampling interval would be used (e.g. every 10th piece).

If it is possible to sample over a number of shifts, then that increases the likelihood that the full range of the product will be sampled. The standard does not specify this, but it will make the sample more representative of the longer-term production. This ultimately benefits the producer as the data returned by the qualification have a much wider applicability.

Note that this sampling is only subtly different to the Phase I sampling. For example, if the sampling interval is every 100th piece:

- In the Phase I sampling, every 100th piece directed into each grade is taken as a sample of that grade.
- In the Phase II sampling, every 100th piece that passes through the grading process is taken, irrespective of the grade it is allocated.

The sample will in general contain material that would be included in each stress-grade produced and some fall down material that would be rejected from all stress-grades.

6.1.4 Data recorded in sampling

Each piece sampled must be accompanied by all of the grading parameters recorded for that piece. In particular:

- Any grading parameters that lead to a profile of the length of timber should be used to assess the stress-grade of each portion of the length.
- The location with the lowest indicated grade must be found by calculation from the recorded grading parameters.
- Raw grading parameters and calculated grading parameters must be collected for the location with the lowest indicated grade in each piece.

Grading parameters can be a single parameter for each piece; e.g. average MoE for the whole piece. The test location will have this value for that parameter. However, grading parameters with a single parameter for each piece must be combined with grading parameters that have a profile through the length of the piece in order to be able to satisfy the requirements for qualification.

Grading parameters can also represent a profile along the length of the piece; e.g. Knot Area Ratio (KAR), or local density. While KAR is a discontinuous function (it only has values where there are knots), the density is a continuous function as it varies throughout the length, but doesn't change much between adjacent locations. Grading parameters that have a profile can be used to indicate the lowest grade location on the piece.

Other grading parameters can be found by combining individual readings. Sometimes the algorithms that combine them can be quite complex, and in many cases, they are "hard wired" into the grading machine. An example of this type of grading parameter

may be Strength, which is a prediction of the strength of the timber at each location on the piece.

Figure 3 shows an illustration of some grading parameters based on the examples in the paragraphs above.

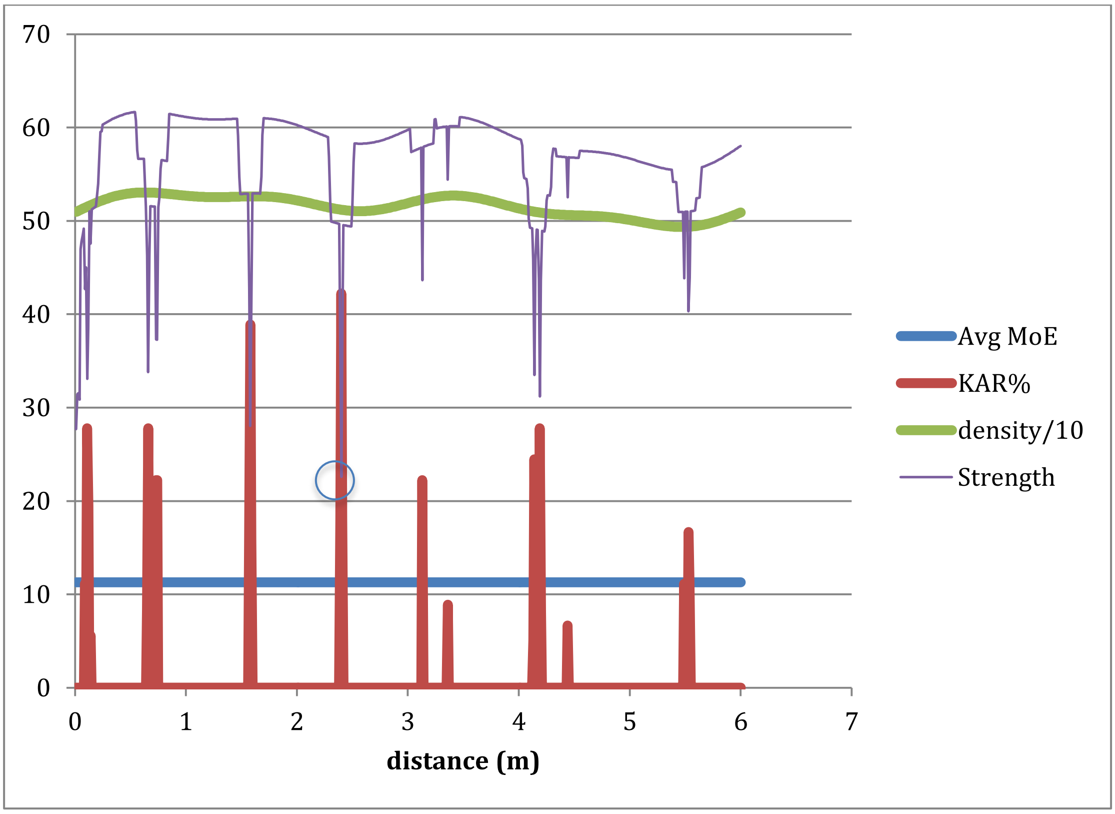


Figure 3 Grading parameters

Figure 3 shows that:

- The average MoE measured for the whole piece is a constant value of around 11.3 GPa.
- The KAR is a discontinuous function, with large jumps wherever there are knots.
- Density is a continuous function, with a gentle curve through the length of the piece and an average density of 513 kg/m^3. (The plot shows density divided by ten so that the scale is comparable with the other grading parameters.)
- Predicted strength is a complex function of all of the other grading parameters and it has its lowest value of around 22 MPa at about 2.3 m. This is the grade limiting location in the graded length.

The piece in Figure 3 would have the lowest indicated grade at 2.3 m and the grading parameters recorded for that location are:

- Average MoE 11.3 GPa
- KAR 42%
- Density 518 kg/m^3
- Predicted Strength 22 MPa

6.2 Phase II testing

The Phase II testing requires the indicator properties to be found on each piece.

- The List A indicator property is MoE which is a non-destructive test. It can be performed on the same specimen as the List B indicator property. It may be performed at a random location or at the same biased location used for the List B indicator property.
- The List B indicator property is either bending or tension strength and is a destructive test. This test should be performed last. It must be performed at the biased location selected by the normal grading method as the lowest grade location in the test piece.

With the exception of the test location, the testing method is the standard test method for the relevant properties in AS/NZS 4063.1. Biased position testing is required for this series of tests so that the ability of the grading method to predict the properties of the weakest point in the piece is under examination.

6.2.1 Test positions

The Phase II testing focuses on the properties at the weakest location in the piece. This is biased position testing. Here the biased position is that predicted by the grading method. There are a number of reasons that this has been chosen:

- Fit for purpose product will have an appropriately low risk of failure. Failures occur where the load effects exceed the resistance effects. Hence, the best place to focus on risk of failure is at the lowest resistance (or lowest strength) locations. Good grading systems have success in predicting the weakness of the graded timber.
- Correlations are better where the weakest point in the piece has been correctly identified. Hence grading methods that have greater success in identifying the weak locations in stress-graded timber will achieve higher coefficients of determination. They are also more likely to identify locations which may compromise safety in service.
- If test positions are manually identified by the testing officer, then there is opportunity for decisions to influence the outcome of the qualification. Leaving the decision on the test location to the grading method itself means that the testing authority has no influence at all on the results of the tests.

For MoE (a non-destructive test for the List A properties), the standard allows a different test location to be specified. It is not mandatory to use the random position, but if the producer chooses to do so, they may use a randomly selected test position for MoE. In many cases, this introduces another source of error into the correlation as the measured test MoE is a function of not only the properties of the timber, but also an arbitrary decision about the test location. If it is intended to perform random position MoE tests, it is probably wise to also perform biased position MoE tests as well so the tests with the best correlation can be selected. (Once the List B tests have been completed, the timber is broken and no further tests can be performed.)

6.3 Phase II analysis

The Phase II analysis is much simpler than the Phase I analysis:

- There are only two groups of data to analyse – the smaller cross-section data and if appropriate, the larger cross-section data.
- Each group is not subdivided further, the coefficient of determination is found for each grading parameter in turn against the strength of the List B property and also against the MoE from the test data.

6.3.1 Coefficients of determination

The coefficient of determination can be found using a msExcel formula

=(CORREL(Grading parameter data, test data))^2

The CORREL function returns the correlation coefficient (*R*) and by squaring it using ^2, the coefficient of determination (R^2) is found.

This value should be evaluated for each of the indicator properties used in verification (List A property – MoE) and (List B property – bending or tension strength) and comparing each with every grading parameter collected.

6.3.2 Limit on coefficient of determination for List A properties

While the List A property used in verification is MoE, it also models compliance of compression strength and bending shear strength. Hence, there is a need for control of these strength properties. AS/NZS 1748.2 Clause 6.4.4.2 requires R^2 between the MoE and at least one of the grading parameters be greater than or equal to 0.6.

MoE is an elastic property that can be estimated from non-destructive measurements using a number of different techniques. It is therefore possible for many different types of grading machines to deliver good estimates for this property and easily exceed the 0.6 minimum value of R^2.

This value was set on the basis of the performance of machine stress-graders that have been used in Australia and New Zealand over the past 30 years. In recent years, some parts of the market for machine-graded timber have indicated that they are keen to see this correlation improve. The current status quo for this relationship was adopted as the minimum acceptable requirement.

6.3.3 Limit on coefficient of determination for List B properties

The List B property used in verification is either bending strength or tension strength. These are important properties in avoiding collapses in timber structures and hence it is important that structural timber product is compatible with the basis of the selection of capacity factors in design. AS/NZS 1748.2 Clause 6.4.4.2 requires R^2 between the List B property and at least one of the grading parameters be greater than or equal to 0.4.

The List B property is much more difficult to estimate using non-destructive measurements compared with MoE. The use of a lower acceptance limit for this property is practical. In some resources, advanced grading methods must be used to obtain this value of R^2.

This value was set as the minimum value that gives V of List B properties that is compatible with the reliability models used to set capacity factors in the design standards. Appendix A has a paper that presents the processes for determination of the limiting R^2 values.

6.3.4 Strength- or stiffness-limited production

The R^2 limits indicated in Sections 6.3.2 and 6.3.3 provide V in the properties of barely complying product that are compatible with the capacity factors in the design standards. However, where the properties of the product always have a significant amount of conservatism, then there can be some leeway given to the minimum R^2 requirement. This is the case where production is either strength-limited or stiffness-limited.

Strength-limited production is one in which the List B test results are always closer to the indicator property target values than the List A test results. In other words, with this type of product, if there is a Not Verified batch it will always be because the List B test data was low. In this case, there is quite a lot of conservatism in the MoE results. This situation can arise where the resource is of low strength or where the stress-grade that is being produced has quite ambitious tension or bending strength requirements. In these cases, the conservatism in the MoE means that the grading method does not have to discriminate as effectively on the List A properties. The conservatism contributes to reliability in design so there can be a discount on the coefficient of determination needed for the MoE.

Stiffness-limited production is one in which the List A test results are always closer to the indicator property target values than the List B test results. In other words, with this type of product, if there is a Not Verified batch it will always be because the List A test data was low. In this case, there is quite a lot of conservatism in the bending and tension strength results. This situation can arise where the resource is of low stiffness or where the stress-grade that is being produced has quite ambitious MoE requirements. In these cases, the conservatism in the bending and tension strength means that the grading method does not have to discriminate as effectively on the List B properties. The conservatism contributes to reliability in design so there can be a discount on the coefficient of determination needed for the List B properties.

Appendix A contains a paper that presents the analyses that underpinned the discount in coefficient of determination for strength- or stiffness-limited production. It provides detail on the background to the limits presented in AS/NZS 1748.2:2011 Clause 6.4.4.2.

The ratio $r_{i,A}$ is the characteristic value of MoE from test divided by the characteristic value for design of MoE. Where a production is strength limited, this value will be high, and $r_{i,B}$ will be only just greater than 1. Hence $r_{i,A}$ / $r_{i,B}$ will be high and Clause 6.4.4.2(a) indicates that the limiting value of coefficient of determination (R^2) for MoE may be less than 0.6. However, if $r_{i,A}$ / $r_{i,B}$ is high then $r_{i,B}$ / $r_{i,A}$ will be low and the limiting value of coefficient of determination (R^2) for the List B property will remain at 0.4.

The ratio $r_{i,B}$ is the characteristic value of the List B indicator property from test divided by the characteristic value for design of the List B indicator property. Where a production is stiffness limited, this value will be high, and $r_{i,A}$ will be only just greater than 1. Hence $r_{i,B}$ / $r_{i,A}$ will be high and Clause 6.4.4.2(a) indicates that the limiting value of coefficient of determination (R^2) for the List B property may be less than 0.4. However, if $r_{i,B}$ / $r_{i,A}$ is high then $r_{i,A}$ / $r_{i,B}$ will be low and the limiting value of coefficient of determination (R^2) for MoE will remain at 0.6.

The values of $r_{i,A}$ and $r_{i,B}$ were found in the Phase I testing which pertains to individual stress-grades, but the Phase II testing is based on run-of-mill sampling with all stress-grades included. Hence the values of $r_{i,A}$ and $r_{i,B}$ used here are found by averaging the values found in Phase I for all stress-grades in the appropriate size. It is quite possible that one grade only may be stiffness limited, and the average of the ratios is not unusual, which means that there is no discount on R^2. It may also be the case that a discount is available on the small sizes but not on the larger sizes (or vice versa).

The value of k_r allows for sampling error. Again, because the values of $r_{i,A}$ and $r_{i,B}$ were found from tests on small samples, the results may be affected by sampling error. The inclusion of k_r in the calculation means that the discount is based on a high level of confidence that the production is strength- or stiffness-limited after allowing for sampling error.

6.4 Optional responsiveness study

AS/NZS 1748.2:2011 Clause 6.4.4.3 includes a reference to an informative appendix that gives a responsiveness study using the data already collected in the Phase II sampling and testing. No further testing needs to be done in order to complete this analysis. It can come from an extension of the analysis of the Phase II testing.

6.4.1 Benefit of responsiveness calculations

Many grading methods that are qualified using this standard involve measurement of a significant number of grading parameters. Some of these parameters measure things that have a strong link with MoE and others measure things that have a strong link with the List B properties.

In production, a manufacturer will need to adjust some of the grade limits on the grading parameters from time-to-time to ensure that all products comply with their properties. For example, if the verification process has signalled that the List B properties are slipping and the production needs to be tightened in order to preserve compliance with those properties, then the manufacturer will adjust the limits on the grading parameters that are best linked with the List B properties.

The responsiveness study indicates the relative strength of the link between each grading parameter and the two indicator properties. Higher responsiveness means that there is a greater effect on the indicator property for a proportional change in that grading parameter.

6.4.2 Grouping of test data and calculation of responsiveness

The Phase II test data for each size is grouped into four separate groups. Each grouping is done separately for each grading parameter. Thus if there are six grading parameters, the grouping must be done separately for each one, six times.

For each cross section size, there are at least 200 pieces of timber with a number of grading parameter measurements and a corresponding MoE and List B strength test value. For each grading parameter:

- The data for each piece is ranked using a single grading parameter, *G*. It is ranked from the lowest value of *G* to the highest value of *G*.
- The data is split into four roughly equal sized groups. If there are *n* pieces, then each group will have roughly *n*/4. The groups are formed from the ranked grading parameters. The lowest group has all of the pieces with lowest values of *G*. The next group has all of the pieces with low values of *G*. The next group has all of the pieces with high values of *G*. The final group has all of the pieces with highest values of *G*.
- In each of the four groups, the average value of *G*, the characteristic value of MoE, and the characteristic value of List B property are found. The characteristic values are found for the 50 or so pieces using the techniques given in AS/NZS 4063.2:2010 or as summarised in section 2.3.1.
- At this stage, for each grading parameter, the data is summarised by four groups each with a value of average *G*, characteristic MoE and characteristic List B property. The natural logarithms of each of these parameters is calculated – in msExcel this is the LN(*x*) function.
- The responsiveness for List A is half of the value of the slope of the line of best fit through the natural logarithms of MoE vs natural logarithms of *G*. The responsiveness for List B is half of the value of the slope of the line of best fit through the natural logarithms of List B strength vs natural logarithms of *G*.

6.4.3 Use of responsiveness values

The responsiveness values can be used by manufacturers to rank the grading parameters in order of effectiveness of their limits delivering changes to properties in verification.

- Where verification indicates a problem in achieving the List A properties, then tightening of grade limits for parameters that have high responsiveness to MoE will deliver the most effect on future manufacturing operations.
- Where verification indicates a problem in achieving the List B properties, then tightening of grade limits for parameters that have high responsiveness to List B properties will deliver the most effect on future manufacturing operations.

6.5 Examples – Phase II analysis

In this section, the data from a Phase II analysis will be illustrated for just one grading parameter. In this case, the grading parameter is an estimate of the local MoE at the test location.

Two hundred pieces of timber were drawn from a number of runs and were selected as every 200th board that entered the grading machine, regardless of the grade

awarded. The grading machine was used to detect the lowest strength location on the piece and this was used as the test location for both MoE and bending strength (the List B property to be used in verification).

Figure 4 shows the test MoE data plotted against Grading parameter 1 for each of the 200 pieces tested.

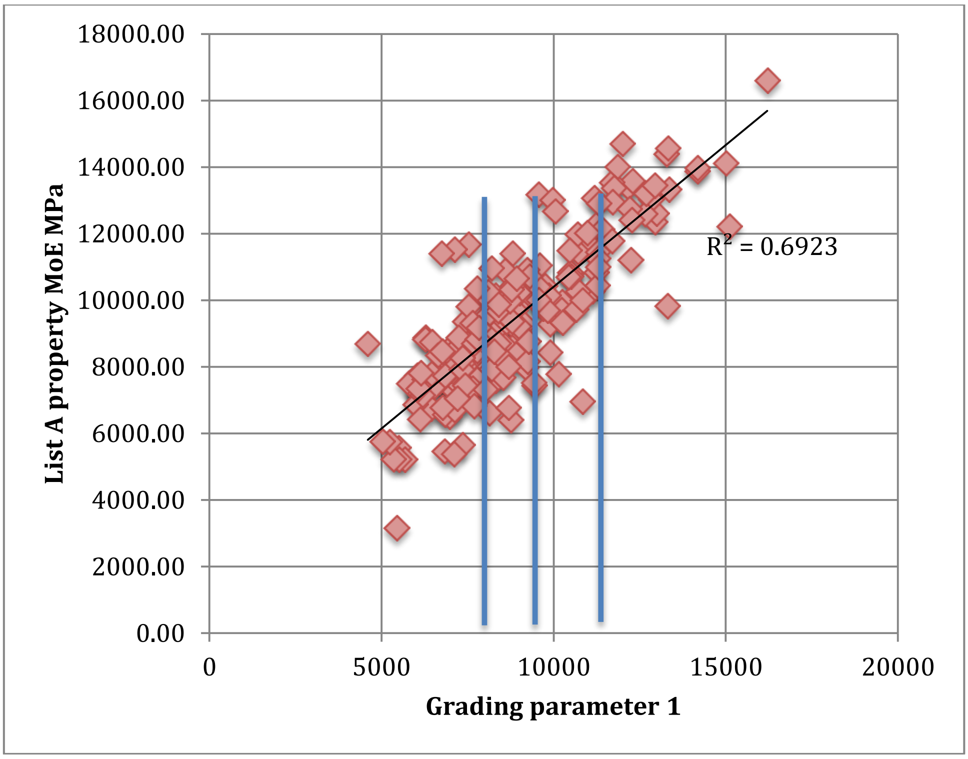


Figure 4 Correlation MoE vs Grading parameter

Figure 4 shows a reasonable correlation between List A property and Grading parameter 1 with R^2 = 0.692. This is higher than the 0.6 limit required. Other grading parameters used in this grading gave slightly higher coefficients of determination against MoE. The highest was R^2 = 0.762.

Figure 5 shows the same grading parameter but plotted against the test bending strength data for each piece. The correlation is not as good as that for MoE against Grading parameter 1, but the coefficient of determination (R^2 = 0.430) was still in excess of the 0.4 required in the qualification. In this example no other grading parameters had as high a coefficient of determination against bending strength as this one.

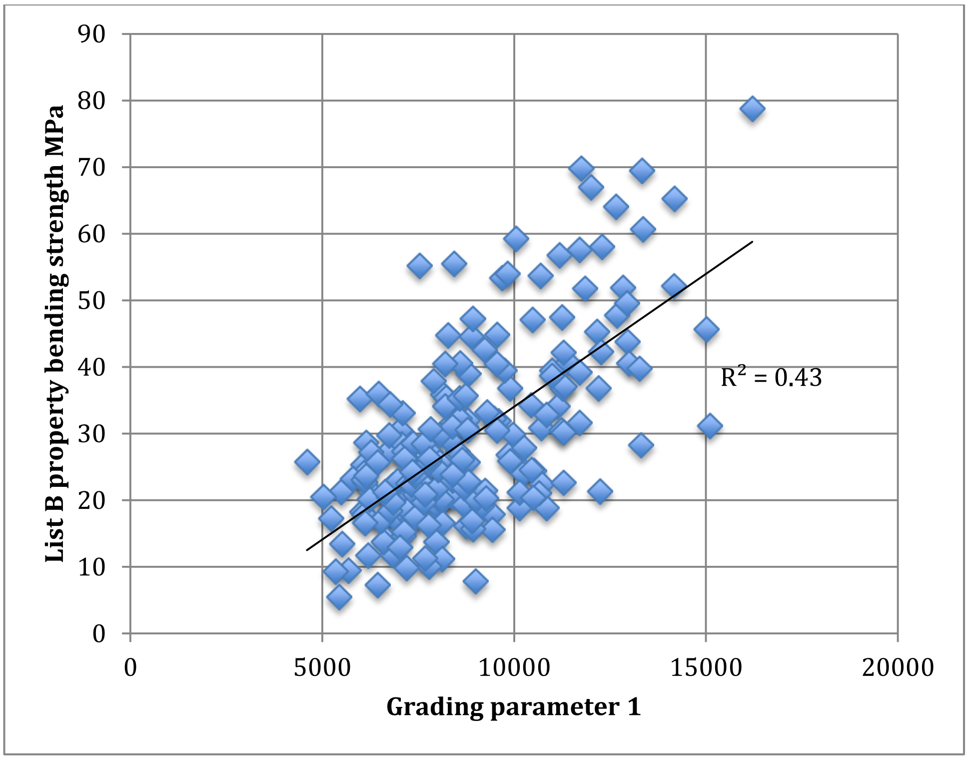


Figure 5 Correlation List B strength vs Grading parameter

In order to establish the limiting values of R^2 for qualification, the data from the Phase I tests must be used. The salient data for the same size cross section is reproduced in Table 2 below.

Table 2 Characteristic values, ratios and *V*

	Characteristic values		Ratios		Coefficient of Variation	
	MoE	f'_b	$r_{i,A}$	$r_{i,B}$	$V\,E$	$V\,f'_b$
MGP10	10259	27.7	1.026	1.632	21%	43%
MGP12	12872	35.8	1.014	1.280	17%	42%
MGP15	16049	52.3	1.049	1.274	14%	35%
average			1.029	1.395	0.173	0.400

The ratios were found by dividing the test value by the characteristic value for design. E.g. for MGP10, $r_{i,A} = \frac{10259}{10000} = 1.026$ and $r_{i,B} = \frac{27.7}{17} = 1.632$

The average of all of the grades gave $r_{i,A} = 1.029$ and $r_{i,B} = 1.395$

This appears to be stiffness-limited in production as the $r_{i,A}$ value is significantly less than the $r_{i,B}$ value.

The averages of the *V*s for the List A properties and the List B properties must also be found and this is shown in the last two columns of the data.

$$k_r = 1 - 0.37(0.08 + V_A + V_B) = 1 - 0.37(0.08 + 0.173 + 0.400) = 0.758$$

For MoE (List A property)
The limit is the smaller of 0.6 and $1.6 - k_r \frac{r_{i,A}}{r_{i,B}} = 1.6 - 0.758 \frac{1.029}{1.395} = 1.041$
i.e. 0.6

For bending strength (List B property)
The limit is the smaller of 0.4 and $1.4 - k_r \frac{r_{i,B}}{r_{i,A}} = 1.4 - 0.758 \frac{1.395}{1.029} = 0.372$
i.e. 0.372

A small discount on the R^2 for the List B property was available as the product was stiffness limited in production.

For MoE, R^2 from Phase II testing (0.762) was higher than the requirement (0.6).
For List B property, R^2 from Phase II testing (0.430) was higher than the requirement (0.372).

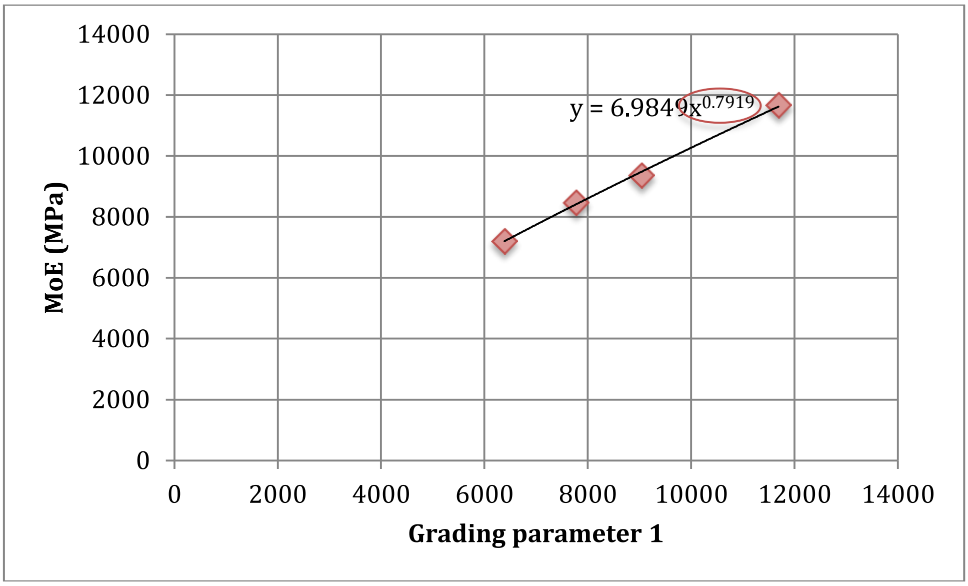
The requirements for qualification in Clause 6.4.4.2 of AS/NZS 1748.2:2011 have been satisfied.

Responsiveness
The same data plotted in Figures 4 and 5 has been used to illustrate the calculation of responsiveness. The data was divided into four equal sized groups by ranking the data according to Grading parameter 1. The groups are shown separated by the vertical lines in Figure 4.

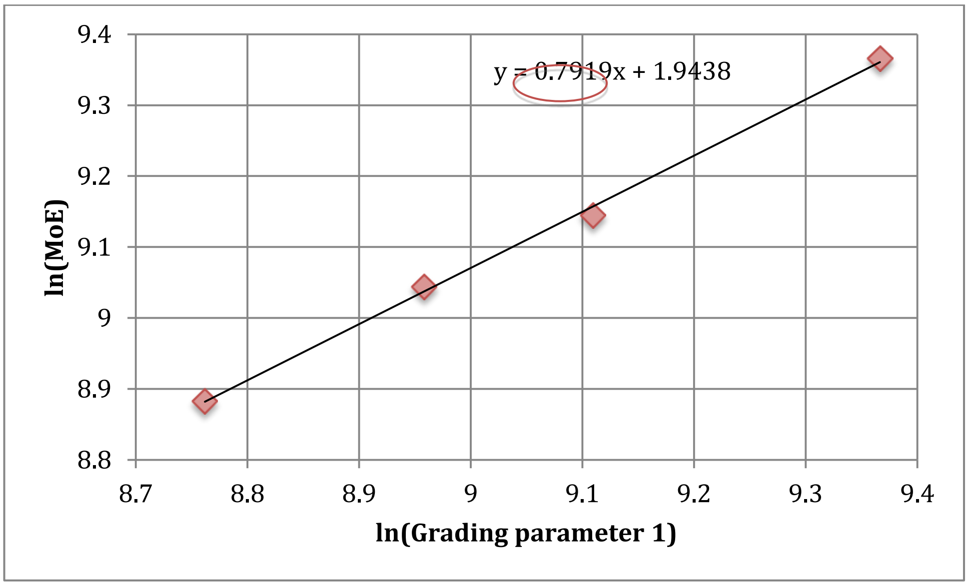
Responsiveness of MoE
The characteristic MoE of each of the 50 pieces in these four groups was calculated. This is shown plotted in Figure 6(a) against the average value of Grading parameter 1 for each of the groups. A power law trend line has been fitted through the four points.

The same data is shown plotted as the logarithm of the data in Figure 6(b) and here a straight line plot has been fitted through the data. The slope of the straight line in the logarithm plot, Figure 6(b), 0.7919, is the same value as the exponent of the power law shown in Figure 6(a).

In this case, the Responsiveness is half of 0.7919 = 0.396. This means that if the Grading parameter 1 grade limit or threshold for a product is increased by 1%, then we could expect an increase of 0.396% in the characteristic MoE of the product.



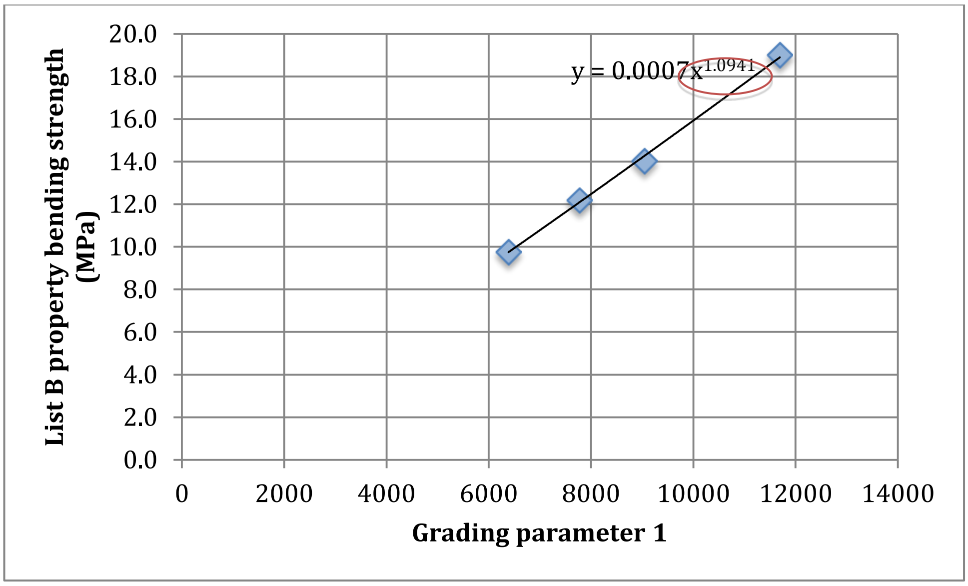
(a) MoE vs grading parameter 1



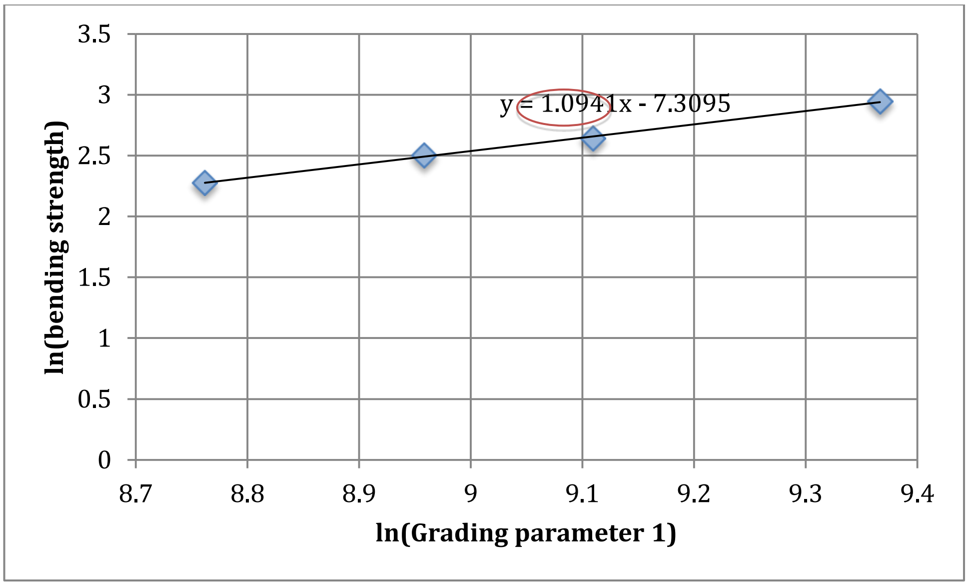
(b) ln(MoE) vs ln(grading parameter 1)

Figure 6 Responsiveness MoE to Grading parameter 1

Exactly the same four groupings are used to establish the responsiveness of the List B property with the same grading parameter. The characteristic strength of the List B property is found for each of the four equal sized groups and it is shown plotted against the average Grading parameter value for each of the groups in Figure 7(a). Again Figure 7(a) shows the power law fitted through the data, and Figure 7(b) shows a straight line through the logarithms of the same data. The slope of the straight line in the logarithm plot is the same value as the exponent of the raw data plot (1.0941).



(a) bending strength vs grading parameter 1



(b) ln(bending strength) vs ln(grading parameter 1)

Figure 7 Responsiveness List B strength to Grading parameter 1

In this case, the Responsiveness is half of 1.0941 = 0.547. This means that if the Grading parameter 1 grade limit or threshold for a product is increased by 1%, then we could expect an increase of 0.547% in the characteristic bending strength of the product.

Part 3 Operation

7. Changing grade limits (thresholds)

In normal operation of the grading method, grade limits or thresholds may be adjusted in response to results of verification testing. This is a normal operational requirement and is not a requirement of the Standard. Technically, the grading method is not changed, however, some parameters that are used in that grading method have been changed.

AS/NZS 1748 only has requirements where the grading method has changed. A Note under AS/NZS 1748.2 Clause 6.2.3 confirms that grade limits may be varied at any time without affecting the qualification, and hence the requirement that the grading method must be qualified.

The Standard requires that complying product has satisfied the requirements of verification. This is discussed in Section 10 of this document.

1. Where timber has been classified as “verified” by the verification, then it is deemed to have complied.
2. Where timber has been classified as “conditionally verified” in the verification, then provided the conditions set out in AS/NZS 4490 and any set by the manufacturer have been met, it is also deemed to have complied.
3. Where timber has been classified as “conditionally verified” in the verification, and the conditions set out in AS/NZS 4490 or any set by the manufacturer have not been met, then the timber cannot be marked as complying with AS/NZS 1748.
4. Where timber has been classified as “not verified” by the verification, then the timber cannot be marked as complying with AS/NZS 1748.

Where the timber does not comply with AS/NZS 1748, as in points 3 and 4 above, then it cannot be marked as complying. In order to be marked as complying, it must be reprocessed, and it is likely that tighter production limits will be needed. The production limits are changed by altering limits on individual grading parameters. As indicated in Section 6.4 of this document, the responsiveness data from qualification may assist producers in deciding which grading parameters to change, and by how much.

7.1 Tightening grade limits

Grade limits should always be tightened in response to “not verified” results in verification. However, most producers would want to avoid having to re-run material which should be a consequence of a “not verified” result, so they would want to tighten the grade limits before a “not verified” result is achieved.

- Many producers would want to tighten grade limits when a “conditionally verified” result is returned in verification.
- In some cases, the limits may be tightened after a “verified” result is achieved, but there has been a big drop in properties so that it is only just “verified” and if the reduction continued would return a “not verified” result next time.

The decision to tighten grade limits is at the discretion of a manufacturer, but the manufacturer does not have any option about “not verified” timber – it does not comply with the standard and so cannot be marked as complying with it.

7.2 Relaxing grade limits

While there are clear signals that grade limits need to be tightened from time-to-time in production, there are no clear signals that they should be relaxed. However, it is quite appropriate to relax grade limits as long as the relaxation does not mean that the product properties decrease to the point that it is no longer “verified”.

In general, the grade limits could be considered for relaxation if the product achieves its verification status with a considerable margin and very consistently.

Again, the decision to relax grade limits is at the discretion of a manufacturer.

8. Changing grading method

Where the grading method is changed, then qualification must be updated. The requirements for this can be traced through the documents as follows:

- AS/NZS 1748.1 Clause 6.1 requires that the timber has to be graded using a grading method that is qualified. If the qualification is not current then the timber is not being produced using a qualified grading method and therefore can no longer be regarded as complying with the standard and so cannot be marked as complying.
- AS/NZS 1748.2 Clause 6.1 requires qualification to address all of the requirements of Clause 6.2.
- AS/NZS 1748.2 Clause 6.2 requires testing of the finished product without any reference to the grading parameters in Phase I testing, and testing of the grading parameters themselves in Phase II testing.
- AS/NZS 1748.2 Clause 6.2.3 specifies some confirmation requirements when relatively minor changes are made to the grading method.
- AS/NZS 1748.2 Clause 6.5 lists the requirements of the qualification report. This is has a requirement for specific measurement technology and for the wood resource and stress-grades for which the qualification applies to be listed.

8.1 New stress-grades

A qualification is required for each stress-grade that is to be produced. This is necessary to set the indicator property target values that will be used in verification of the product. Hence if a new stress-grade is introduced, then a substantial part of the qualification must be repeated for that stress-grade.

Where the new stress-grade is a new product in addition to a number of other already qualified stress-grades taken from an unchanged resource, it is appropriate to simply perform the Phase I qualification for that stress-grade. The Phase II part of the qualification will be unchanged for this, as the data for the timber represented by the new stress-grade would already have been included in the run-of-mill sample taken from the production. For example, if MGP10, MGP12, and MGP15 had been qualified with a given grading method, and it was planned to introduce an F5 product at the bottom end of the stiffness-limited grading operation, then it would be necessary to perform the Phase I tests on the F5 product, but not to repeat the Phase II tests.

Where new stress-grades are introduced for the first time, then the full qualification (both Phase I and Phase II) is required. For example, if an overseas mill had been producing a range of products for a different market and wanted to start producing and marketing MGP10 and MGP12 products, then as there has not already been a qualification to AS/NZS 1748.2 for the production of the existing products, there has not already been the Phase II testing on the grading method for this resource. Phase I testing of the MGP10 and MGP12 products is required, and Phase II testing is required as well to enable a full qualification report to be issued.

8.2 New wood resource

The input resource to the grading method is described in the qualification report. The qualification only pertains to production from the resource from which the sample was drawn. As indicated in Section 4.3.2, it was suggested that the material sampled for the qualification should represent all of the variants anticipated in future production. This prevents frustration at having to repeat part of the qualification because a new resource has been introduced.

Where the resource no longer reflects the one on which the method was qualified, then the qualification is no longer valid, and must be repeated. For example, if the qualification was undertaken on a mixture of species, but a new species becomes available, then the wood resource has changed appreciably and either the qualification must be repeated on the new species, or testing must be undertaken to demonstrate that the behaviour of the species mix with the new species is the same as the species mix that was qualified. Where possible, the samples taken for qualification should include all of the species that are likely to be used in future production so that this is not an issue.

However, if the qualification had been performed on a mixture of species, but the composition of the species mixture changes, say from a 50:50 mix to a 70:30 mix, then unless there is reason to believe that the new mix will have a different behaviour, there is no need to repeat the qualification. All aspects of the resource were represented in the samples that were taken at the time of the original qualification.

Some resource changes are more subtle, but can still have a profound impact on the performance of the products in service. For example, if a product was qualified on the basis of material cut away from the core of the log, then if subsequently the cutting pattern is changed so that it is always cut from the core, then the relationships between the properties under the new cutting pattern may have changed considerably. Again, if there is a possibility that production may be drawn from both the core wood and the wood away from the core, then both should be included in the qualification sample to allow flexibility in later production.

The logs processed by a single mill may be sourced from a number of different areas. In some areas, the logs may have quite different characteristics compared with logs drawn from other areas. These differences may be caused by different climates, different soil types or different silvicultural practices. Provided the original qualification samples represented the range of different log types encountered by the mill, there should not be a problem as the areas from which logs are drawn change in normal production. However, if subsequent to the original qualification, a new area is introduced and there is reason to believe that the character of the wood from that area is quite different to the character of the timber on which the qualification was based, this problem can be treated as if a new species has been introduced. Either the qualification must be repeated on the new resource, or testing must be undertaken to demonstrate that the behaviour of the new timber mix with the new resource is the same as the resource mix that was qualified.

Where new species or resources are introduced, it is suggested that extra samples are taken from the new species or resource and the Phase I and Phase II testing is completed on them. However, in analysis, it is wise to augment the existing data with

new data. In this way, the qualification can apply to the full range of resources represented by the old and the new data.

8.3 New grading technology

Where new grading technology is introduced to a grading method, then it has to be qualified as the grading method has changed appreciably.

New grading technology will change the way in which the input material is sorted. (It is likely that the new technology will have been justified on the basis of better recovery or more reliable properties in the graded product. Either way, the way in which a given parcel of timber is sorted must be different in order to justify the improvement.) This means that the relationships between the properties may be different, and if that is the case, the indicator property target values will be different.

Where the introduction of new grading technology is simply an addition to the existing qualified grading method, it can be viewed as an extra grading sensor and the changes required are detailed in Section 8.4.

Where the new grading technology replaces part of the qualified grading method, and the grading parameters are effectively unchanged, then the new grading technology has not materially changed the grading method and the existing qualification remains unchanged. The qualification report should be amended to reflect the new technology. For example if the sensor for visual assessment of knot size is changed to a better model, no new grading parameters are introduced, but the performance of an existing parameter could be expected to improve.

However, if the introduction of the new technology changes the number or type of grading parameters that are used to sort the timber into stress-grades, then effectively a new grading method has been created and this requires a new qualification. For example, where an existing Mechanical grading machine is replaced by a new scanning system, the grading method has changed and a new qualification is required.

8.4 Adding an extra grading sensor

Where a grading method has a new grading sensor added, then there may be a requirement to repeat part of the qualification.

In some cases, the new grading sensor may not be used in performing the grading sort based on structural properties. Here there is no necessity to repeat any part of the qualification of grading method. An example of this may be the introduction of a moisture meter which is designed to ensure compliance with AS/NZS 1748.1 Clause 6.2.1 Moisture Content. If it was designed to reject pieces that may cause violation of the moisture content classification of the product, but not used to assign the stress-grade, then there would be no need to repeat any part of the qualification.

In other cases, the grading sensor will be included in the allocation of timber to stress-grades. Here the Part II testing has not incorporated any data from the new grading sensor, so it will be necessary to repeat the Phase II sampling and testing to generate some data for the correlations with the new grading parameter. An example of this

may be the introduction of a moisture meter which is designed to correct the measured average MoE to MoE at 12% moisture content. The grade allocation will use MoE at 12% moisture content as a grading parameter. Here the moisture meter is a new sensor that is used in an algorithm to find one of the sorting parameters, so new correlations must be found between the indicator properties and the moisture content and the MoE at 12% moisture content.

In the worst case, the introduction of a new sensor used in grading will mean that the Phase II sampling, testing and analysis as detailed in AS/NZS 1748.2 Clause 6.4 will need to be repeated.

8.5 Removal of a grading sensor

Removal of a grading sensor also changes the way in which the grading performs and new relationships between the various parameters must be evaluated. However in this case, no extra information is required.

The analysis of the Part II qualification test data can be repeated without the grading parameter that has been removed. This will not require any new test data. All of the previous data can be used again, but without the data from the sensor that has been removed.

The qualification report can reflect the current production grading method without performing any new tests. A desk-top study will regenerate the grading data without the grading parameter that comes from the sensor that has been removed.

In some cases, the sensor that was removed was not involved in the stress-grading decisions. In these cases, no change to the qualification report is required. For example, a grading method may have a sensor that measures local MoE, but in the grading method used, there were no limits placed on this measurement or any derived from it to allocate timber to a stress-grade. If this is the case, then the qualification report does not require change.

In the worst case, the removal of a grading sensor will mean that the Phase II analysis will need to be repeated.

8.6 New combination algorithm

Combination algorithms are used to combine a number of individual grading parameters into a composite parameter. Here the measurements from a number of sensors are combined to give a single indicator of timber properties. By changing the way in which the data is combined, the grading method can be adapted to deliver an improved discrimination. The new combined algorithm can be applied to the existing data without obtaining any more from the grading machine.

For example, if a combination algorithm took data from density measurements, average MoE measurements, knot type, size and position measurements and combined it to deliver a predicted strength profile, but in developments of the machine, the way in which they were combined was modified by the manufacturer, then the qualification could be updated in the following way:

- The raw data from the original grading runs would be re-run through the grading machine simulator with the new combination algorithm. This would generate new grading profiles on each piece used in the Phase II testing.
- The test location gives the value of the new combined grading parameter at the test location.
- The new suite of combined grading parameter values are used in the Phase II analysis to derive the correlation coefficients and if required, the responsiveness factors.

9. Maintenance of Grading method and Qualification

It follows from AS/NZS 1748.1 Clause 6.1 that the grading method in use must be qualified. Hence if any change at all is made to the grading method, it must be accompanied by an update to the qualification report to indicate that the grading method is qualified.

The continuing improvement and evolution of the grading method must be supported by a number of revisions to the qualification report that demonstrate that the grading method has satisfied the qualification requirements at all stages.

No changes in the qualification report are required where grade limits or thresholds are changed.

9.1 Updating the qualification report

Section 8 of this report indicated that many small changes in grading method only require small changes in the qualification report.

Referring to the list of items to be included in the qualification report in AS/NZS 1748.2 Clause 6.5:

a) The qualification report contains a detailed description of the grading method and so if changes are made to the grading method, this description must be updated.
b) The list of grading parameters must also be updated as new ones are added or removed, or combination parameters are changed.
c) Here the main interest is which grading parameters are associated with the limits, not so much the limits themselves. None the less, by tracking the way in which the limits change over time, it can show the stability of the grading system.
d) Where the changes in the wood resource from time-to-time are included in the range of material sampled in the original qualification, then no changes are needed here. However, if there are changes in this part of the report, then the changes should be accompanied by extra test data.
e) to j) These items refer to Phase I qualification. Where it is repeated, then these sections will change.
f) and k) These items refer to Phase II qualification. Where some aspect of the Phase II qualification has been repeated, then these sections will require some modification.

9.2 Strategy for implementation of changes to the grading method

Changes to the grading method should be encouraged to keep production methods improving with experience and with technological developments in grading technology. However, in some cases, meeting the qualification requirements may impose a delay on the developments. This section examines some different change scenarios.

9.2.1 Minor replacement of grading sensors

Wherever a grading sensor is replaced either with an identical unit or an improved unit, provided the grading parameter returned by the unit is a measure of the same property, then there is no need for requalification. Most sensor replacements can be performed without any impact on the current qualification.

Where a grading sensor is replaced by a superior one that gives a number of different grading parameters, then in order to make use of the new grading parameters, a stepped introduction process is required. (See Section 9.2.2)

9.2.2 Major changes to grading method

Where a change is made to a grading method that warrants a repeat of at least part of the qualification method, there will be some delays between the installation of the change and the commercial implementation of the new grading method.

In most cases, the grading machine can collect information from the new configuration but use the previous configuration for commercial grading. Most manufacturers are happy to run the old and new systems in parallel for a while and gain confidence that the new system would make similar decisions to the old system before the new system goes “live”. Repeating part of the qualification formalises this process:

- While the old system is commercially grading timber, new samples can be taken for the part of qualification that needs to be repeated. The grading data for these samples will be taken from the data collected by the new system.
- Qualification testing and analysis can be performed on the new test sample.
- If the results of the new analysis will confirm that the new system is as good or as better than the old system, then the manufacturer has the information that confirms the success of the modification at the same time as the qualification of the new system is completed.
- The new system can go “live” as soon as the qualification report is updated. Commercial grading decisions are made on the information delivered by the new grading system.

In some cases, the new grading system cannot function in parallel with the old grading system. For example, where a sensor has been replaced with one that records some extra grading parameters, then only the information from the new sensor is available as the old sensor has been removed to install it.

In these cases, it may be possible to ignore some of the new information from the new sensor in making commercial grading decisions until its performance has been demonstrated in qualification.

In other cases, the commercial grading must be performed on the new system as soon as it is installed, in which case, the repeat of the necessary parts of the qualification must be fast-tracked to deliver a new qualification report as soon as possible after the installation of the new equipment to enable recommencement of commercial grading. In planning these types of upgrades, effort should be made to enable parallel production to avoid any delays while the new system is being commissioned, debugged and qualified.

9.2.3 New Grading methods

Where a new grading method is to be installed, it is advisable to plan for the old (previously qualified) system to be able to operate on the timber at the same time. This is possible if there is enough room on the production line for the timber to pass through both the old and the new grading technologies for a period. If this is the case, then the commercial grading can continue to be based on the old system, while the new one is tested commissioned, debugged and qualified. The techniques outlined in Section 9.2.2 can be used.

Where the old grading method must be removed completely before the new grading method can be installed, then this requires a major shut-down of the production. Some suggestions for expediting the change over include:

- Well in advance of the installation of the new system, sample sufficient timber for the qualification of the new system (allowing for extra Phase I specimens for adjustment of grade thresholds). Run all of the sampled timber through the new grading system at another site (for example a pilot machine at the machine manufacturer's facility). These are the qualification samples and are sent to the test facility.
- Also run a further 200 pieces through the pilot machine and retain the grading records for these pieces. This will be a comparison sample and is returned to the manufacturer,
- Having obtained all of the new grading information on the new system on the qualification sample, the qualification testing is completed.
- The qualification analysis can be completed and the qualification report prepared on the basis of the pilot machine.
- Just prior to the removal of the old system, run a batch of timber through the old grading system and save it without sorting and docking so that it can be re-run through the new grading system. Save all grading parameters and grading decisions for this batch.
- Once the new system is installed, carefully re-run some of the saved batch of timber from the old system. This batch will be used to commission and debug the new system. The grade marks from the old system should be used on this batch until the commissioning process is complete.
- Once commissioning is complete, then the comparison sample should be run through the new machine and the data from the new grading machine and the data from the pilot machine can be compared directly with the new machine. Where the data matches, then the qualification report can reflect that the new machine is identical to the pilot machine. Where it does not match, the new machine should be adjusted to give the same data as the pilot machine on which the qualification was based. The new machine can now be regarded as qualified.
- With the new machine qualified, the remainder of the saved batch can be run with the grading decisions based on the data from the new (now qualified) grading machine. This process should be carefully monitored so that individual pieces for which the two grading processes give different results are checked by the manufacturer to confirm that the new grading process gives reasonable grading outcomes.
- The new grading process can be refined by changing grade limits in response to verification data on new batches of timber.

9.3 Revising grade limits

While a perfect grading method will not require any revision of grade limits, because all grading methods are based on measurements and prediction algorithms, both of which incorporate some errors, there may be a need to tighten or relax grade limits in response to changes in the properties of the input material.

Section 7 presents detail on changing the grade limits. These changes are made in response to results of the verification of products. As indicated in that section, the Standard has no requirements for revising grade limits, but in practice, this will be required from time-to-time to ensure that all products meet the requirement for verification in spite of normal changes in resource material.

Manufacturers may wish to keep records of grade limits used and this will enable them to build a database of the success or otherwise of each change of grade limits. The accumulation of this data helps develop an understanding of the sensitivities of the grading method and also serves to guide future decisions about grade limits. With experience, manufacturers may be able to anticipate the limits required for particular types of resource that are fed into the grading machines.

9.4 Repetition of qualification testing

The Standard does not require a repetition of qualification testing. However, there may be some commercial advantages to the re-evaluation of indicator property target values:

- The indicator property target values are used in verification, and where they are higher than the characteristic value for design, they mean that the grade limits have to be tighter than those where the target values are the characteristic values for design.
- Time pressures with the initial qualification often mean that the samples are drawn over a few weeks and may not represent the full range of resource variations within a year. Second and subsequent qualifications can incorporate sampling over a complete year and may better represent the full range of resources used in the manufacture.
- As each series of tests is completed, there is even more information available on which to base the calculations and the effects of sampling errors are reduced. The qualification data has improved quality.

9.4.1 Decision to repeat qualification testing

Setting the time interval between qualifications is a commercial decision. Some of the factors that may influence this are:

- Current values of indicator property target values. High values make it more commercially attractive to repeat the qualification.
- Scale of production. High volume operations have more to gain by small improvements in efficiency in grading.
- Plans for refinement of grading method. It makes sense to plan repetition of qualification to coincide with changes to the grading method that may warrant repetition of the qualification anyway.

9.4.2 Sampling and testing for repetition qualification testing

Because time constraints are less critical for the repeated qualification testing, it is possible to sample over a full year of production and to make sure that all resources are represented and all species are sampled.

Random sampling over a long period can provide a representative sample, but in many cases, a stratified sampling regime can ensure that each type of resource is included in the sample. Stratified sampling follows the following process:

- Identify all of the groups that need to be included in the sample that represents the full range of resource handled in production. Where possible, estimate the percentage of annual production normally associated with each of these groups.
- Use the estimated percentages to calculate the number of specimens required in each group. From the planned number of batches of each group, calculate the number of specimens required per batch. To achieve this target, it is often necessary to apply a factor that allows for the fact that reality rarely adheres to our plans. (Something around 2 seems appropriate, and if too much timber is sampled, the sample can be sorted, the correct number of pieces sent for test and the excess returned to production.)
- Whenever one of the groups is in production, sampling is undertaken at the pre-determined rate. The samples are kept separate from production and are allowed to accumulate over the year.

At the end of the sampling period, the sample should be re-run through the grading method prior to sorting and testing. In this way, if there has been any change in the sample while it was in storage, the test result will be linked to the assessment of the material immediately prior to the test. Also, if there have been changes to the grading method, it is the most current version of the method that is the subject of the qualification.

Splitting the sample and testing for qualification were discussed in Sections 5.1 and 5.2 respectively. Where more specimens than required have been sampled, the excess can be removed using the splitting techniques described in Section 5.1.4. This can be used for both the Phase I sample and the Phase II sample.

9.4.3 Analysis for repetition qualification testing

The analysis for the repetition qualification testing is conducted in the same way as the original analysis. This is detailed for Phase I in Sections 5.3 and 5.4, and for Phase II in Sections 6.3 and 6.4.

In analysing data for a repeated qualification, there is the option of performing an independent analysis, or aggregating all of the qualification data collected to date and analysing it as a large sample. The second option increases the size of the data set and therefore reduces the sampling error.

Part 4 Verification

10. Strategy of verification

Verification is the process by which the product is checked against its target values to ensure that it has a performance that is compatible with all of the design parameters for the product. This includes all of its stress-grade properties.

Verification works by monitoring two properties only: MoE and either bending strength or tension strength. There is assurance that the other properties are maintained by the use of the indicator property target value. As indicated in Section 5.4, this value was derived to give confidence that the linked non-tested properties would exceed their design value if the test data on the indicator property were greater than the indicator property target value.

Different methods of verification are given in Appendices to AS/NZS 4490. These have a common target level of confidence that is in line with international standards for establishment of characteristic values for populations from sample testing:

- For strength properties the target level of confidence is 75%
- For MoE, the target level of confidence is 50%

The confidence is achieved by a mixture of:

- Conservatism
- Test data from samples

Figure 8 illustrates the principle.

- If a verification option is selected that uses a lot of test data, then little conservatism is needed to deliver the required confidence in the population properties. This is equivalent to selecting a verification strategy near to the left of the plot in Figure 8.
- On the other hand if a verification option that uses few specimens, then much conservatism is needed to deliver the required confidence in the population properties. This option is equivalent to selecting a verification strategy near to the right of the plot in Figure 8

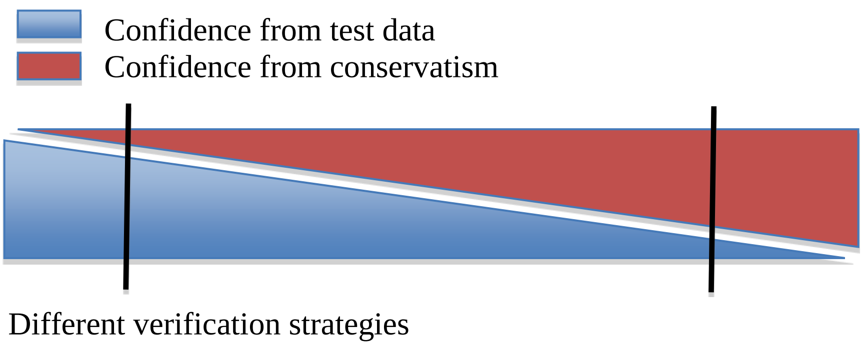


Figure 8 Interplay of conservatism and test data in verification confidence level

10.1 Selection of verification method

The selection of the verification method is at the discretion of the manufacturer. There are many factors that can affect the decision:

- Scale of production. For high volume products, it may prove more profitable to use a verification method that tests many specimens and hence has a very low degree of conservatism. This will mean that the grade limits can be set as low as possible. For lower volume products, a high frequency of testing cannot be commercially justified and a verification that uses a higher degree of conservatism may be appropriate.
- Availability of test facilities. Strategies that rely on testing require test facilities. Where these are not available, verification methods that rely only on conservatism must be selected. Under these circumstances, the commercial implications of continually producing to a conservative standard should be weighed up against the capital outlay required for in-mill test facilities.
- Flexibility. Within some of the verification methods there are choices to be made about sample rates and sample sizes. These give further flexibility to manufacturers in positioning their method with respect to testing effort or to conservatism.
- 3rd party audit requirements. In some cases, the third party audit may have additional requirements for verification of properties that may limit the choices available.
- Consequences of non-compliance. For some products, common applications of the product may mean that there is a high consequence of non-compliance and for these product, the manufacturer may feel more comfortable with a higher involvement of testing.

Often decisions about verification method are made before qualification of the grading method. The indicator properties must be selected during the Phase I analysis. However, it is possible to change the List B indicator property at any time as indicated in Section 10.1.3.

10.1.1 Flexibility of verification method

Often manufacturers of structural timber products have a range of products, each of which may require verification. Because of different scales of production of the different products, it may be appropriate to use different verification methods for different products. This is quite permissible, however, each different verification method requires its own check of verification method as discussed in Section 11.

For example, in a softwood production facility, there may be a consistent high volume stream of MGP10 produced, a lower but significant stream of MGP12 produced and rarely, some small volumes of MGP15 will be produced. For this process, it may be appropriate to use Appendix A batch verification for MGP10 and MGP12 with different sample sizes for each, and to use Appendix A continuous monitoring for MPG15. In some cases, Appendix C verification may be selected for very low volume products.

The verification methods in AS/NZS 4490 were derived using normally accepted statistical principles where possible. They have all been checked using Monte Carlo simulations to ensure that the level of confidence in compliance is compatible.

Where sampling and testing are required, random sampling and random position testing are specified so that the basis for the statistics is the same as that used in establishing the characteristic values for design. However, it is possible to develop other verification methods or strategies. (A note under AS/NZS 4490 Clause 6.2.1 covers this possibility.) Where alternative methods are developed:

- An analysis method statistically compatible with all of the sampling and testing assumptions needs to be developed.
- The whole verification process should be calibrated against other verification methods either by simulation or by experiment, to demonstrate that it achieves at least the same level of confidence that the characteristic values for design have been achieved.
- The modified verification method must be subjected to the check of verification method detailed in AS/NZS 4490 Clause 6.3 and pass the requirements discussed in Section 11 of this document. The development of the alternative verification method should include some guidance on changing parameters if the check on verification does not demonstrate that the verification method has been working satisfactorily.

10.1.2 Potential for change of verification method

While a decision on verification method is often made early in the qualification process, it can be changed at any time.

This means that producers that do not have initial capacity for testing large sample sizes can equip themselves to perform more tests and change the verification method to one which is appropriate for testing oriented verification.

The only complication in changing the verification method is in determining the significance of the check on verification. Where possible, the check sample should be split so that the data pertinent to the old verification method is analysed separately to the data from samples taken during the new verification method and separate conclusions should be drawn on the two verification methods.

10.1.3 Changing indicator properties

The indicator property for List A is fixed as MoE, but the producer selects the List B property from either bending strength or tension strength. Many producers favour bending strength as the bending test equipment will simultaneously give a result for MoE and bending strength.

While testing tension strength requires specialised test equipment, it has other advantages:

- Bending tests create high stresses on relatively small portions of the piece length. With random position tests, the test location is generated using random numbers and may or may not involve potential weak locations in the length. However, tension tests fully load the whole cross section throughout the test length. Hence the random position bending test has extra variability due to test location that tension tests do not.

- Failures in bending strength tests could originate in the tension edge in which case the failure is brittle, but could also originate at the compression edge in which case the failure is ductile. Shear failures may also occur in bending tests. All of these failure modes may have slightly different statistical distributions. However, tension tests have tension failure only and therefore results that require minimal interpretation.
- Tension tests will fail at the lowest strength location in the test length as the stresses are uniform through the test span. This makes their behaviour similar to that in biased position tests and gives information on the weaknesses of timber in the graded population. In contrast, bending strength results for random position testing may be considerably higher than those for biased position testing, so give little information on the weakest pieces in a sample. In verification it is often useful to focus on the lower end of the statistical distribution of strength.

The List B indicator property can be changed from bending to tension strength or from tension to bending strength. However, it has some implications for qualification. It is recommended that the following steps are undertaken prior to making the final decision on List B indicator property:

- The indicator property target value for List B has to be revaluated as indicated in Section 5.4. This will not require any further testing, but will involve a re-analysis of the existing Phase I test data.
- The sampling, testing and analysis for Phase II has to be repeated to give data for the new indicator property.
- Once the requirements for qualification have been satisfied with the new indicator property, then the change to verification testing can be made.

11. Checking and maintaining the verification method

The verification of timber by using one of the methods indicated in the Appendices of AS/NZS 4490 will draw conclusions on the properties of the timber products manufactured.

Another series of tests assesses the performance of the verification process itself. This is the check of verification method detailed in AS/NZS 4490 Clause 6.3. This check is the same regardless of the verification method selected for the day-to-day manufacturing operation.

11.1 Strategy of check

The check on the verification method uses a sample of verified timber drawn over a long period of time to check that the properties of the verified timber are as marked. If the verification method is functioning effectively, this will not be a problem, as there is a reasonable level of confidence that each batch has complied. Some batches may have met the minimum acceptance requirement and have the minimum level of confidence, but over a year, many of them will have exceeded the acceptance requirement by a significant margin and well exceeded the required level of confidence.

Where the verification method has been operating well, there should be no problems at all with the check. However, if the results of the check indicate that there is a problem with the annual sample, then the verification system must be tightened. Each of the methods presented in AS/NZS 4490 have some parameters that can be adjusted to either tighten or relax the verification system.

The objectives of this testing are to check the *verification*, not the timber, of any given batch. As a result, the sample must be drawn throughout the period between checks. AS/NZS 4490 requires that the check be performed at least once per year and it is expected that most producers will conduct an annual check.

As the check is focusing on the verification system, only one product is selected for the check. However, some producers may wish to perform the check on more than one product to ensure that verification is working across the range of products.

11.2 Sampling for check

A single product should be selected for the check on verification. The single product will be a single size and a single grade (e.g. 90 x 35 MGP10). If the product selected is a high volume product then it will be produced in a number of batches throughout the year and the sample will be drawn from many production runs. The sample should have the following characteristics:

- The completed sample size should be around 100 pieces.
- It should be drawn at a reasonably constant rate throughout the year so that it is truly representative of the product. Thus if there are 70 production runs expected for the selected product during the year, the sample should be drawn at a rate of 2 pieces per production run.
- The sample must be drawn in a way that is completely free of bias. This can best be achieved if the random process is programmed into a computer. There

can be many ways of accidentally introducing bias into this process and these are investigated after this list.

- The sample must be representative. The fact that the sample is drawn over a complete year of production will mean that it represents any variations in quality associated with times of the year. If a number of different species are included in the product throughout the year, then this should also be represented in the random sample. Even so, it wise to check that the mixture of variants (such as species, sawing patterns) is roughly representative of the product over the year.

Bias in sampling can be introduced by operators who can bias the sample either way. It is best not to involve an operator at all in making the choice. (For example, if a computer controlling a paint spray jet marks the sample, it has made the selection, even if an operator removes the timber from the production line).

However, care is needed that normal run practices do not influence the material that is sampled as illustrated in the following examples:

- Where the computer selects the 100th piece in the selected grade each production run, this will always be near the start of the batch. If the first rack of timber in the run is always wood cut away from the core, then the sample will be biased towards wood cut away from the core, and wood cut from the core may not be represented at all in the sample. This method of sampling will only be representative if the racks are pulled up completely at random.
- Where the computer selects the 1000th piece in the selected grade each production run, this will always be near the start of the batch. If the normal processes in a run are to process the longer lengths first and then the shorter lengths, then the sample will be biased towards wood taken from longer lengths, and wood cut from shorter lengths (e.g. top logs) may not be represented at all in the sample. If there is any pattern at all in the production process, it is better for the sample piece to be drawn at a random position in the run (e.g. next piece from the selected grade after random number (0 to 1) times the expected total number of pieces in the run).
- Where the sample is identified before the docking saw, the sample can only contain pieces where the full length is the appropriate grade. In this way some of the production (pieces recovered to the grade by docking a lower grade piece) can never be sampled. Here the sample does not represent all of the variants of the production. A better option is to draw the sample at random at the grade marker so that docked pieces can also be included in the sample.

Because the sample must be stored for a long period of time, it is important that the storage conditions do not compromise the value of the check. AS/NZS 4490 requires that the sample be stored in such a way that it still satisfies the requirements of the product standard at the completion of the storage. This has the following practical implications:

- The timber must remain at a moisture content appropriate to its description. In general, this will mean that it has to be stored under cover. In some very humid production environments this may mean that seasoned products may have to be stored in conditioned chambers.
- The timber must remain secure so that it is not inadvertently returned to production. This may require storage in a separate area away from part packs

from the end of production runs, or even separate to normal verification test samples.

- The sample should be stored in such a way that timber remains straight. (In some cases, when the timber has twisted, it returns lower than normal MoE results.)
- Where possible, the timber should be neatly stacked in the order in which it is sampled. This will facilitate the sorting of the timber into two testing groups for the next stage.

All of the timber in the check sample needs to have come from production runs in which the timber has been deemed to be verified. This includes any timber that has received:

- Verified status
- Conditionally Verified status, but the conditions to allow the timber to be deemed to be verified have been satisfied and the production has been released to the market as verified timber.

Any production runs that have been withheld from the market as Not Verified should have no specimens included in the annual check sample. Any timber that was sampled during these runs must be physically removed from the check sample and re-processed along with the rest of the rejected production.

11.3 Testing for check

The testing of the check sample is undertaken in two stages. This is to minimise the cost of the check testing where the result is a clear pass. The objective is to test 50 pieces of the sample first, analyse it, and if a pass is indicated then no further work needs to be done and the remainder of the sample can be returned to production.

11.3.1 Obtaining the first stage specimens

In the first stage of testing, 50 pieces must be randomly separated from the accumulated sample. Again, it is important that there be no bias introduced to this sort. A bias can be accidentally introduced by taking only the most recent pieces, or by using a person to select pieces from the packs of stored material.

A first step is to determine the fraction of the sampled material that is required. For example, where 140 pieces have been collected, then the 50 pieces required represent 50/140 or 36% of the collected sample. Some suggestions for selection of 50 pieces at random are as follows:

- Where the timber has been stacked neatly in time order, sample the required number of pieces in a hit and miss fashion from the packs. (For example, if 36% of the sample is required, this will require taking every third piece. This will give 46 pieces out of 140 and the additional four pieces can be taken one from the top row of the pack, one from a third the way down, then two thirds and finally the bottom row.)
- Where the timber has been stacked in an unknown order, it is best to take just one side of the stack. (For example, if 36% of the sample is required and there are 10 pieces per row in 14 rows, then the first 4 pieces in every row would be

taken. This would leave a stack with 6 pieces per row remaining, and would give a test sample of 56 pieces.

11.3.2 First stage testing

The 50 pieces, taken as representative of the year's production in the selected product are subjected to random position testing for MoE and either bending strength or tension strength. The tests are random position tests to AS/NZS 4063.1 so that the results can be directly compared with the characteristic values for design.

There is no requirement in AS/NZS 4490 for this testing to be independently performed. This is because it is Standards Policy not to assign responsibilities to tasks. However, it makes good sense to have the check testing performed in a different laboratory and on different equipment to the normal day-to-day verification testing. This makes the check a truly independent check that will also detect problems if the verification test equipment is not accurate. At the very least, these tests should be independently supervised.

In some cases, manufacturers may select tension strength for the following reasons:

- They already have a substantial data set of bending strength values for the runs that the check samples represent. Testing a different property gives some extra information to help them understand the properties of the product better.
- The tension strength information can be related to the bending strength information that they already have on the same population to confirm the relationship between bending strength and tension strength and hence provide some feedback on the List B indicator property target value.
- Independent test laboratories may have tension test equipment which will give some information that may not be obtained from in-house testing. The test results therefore have a double benefit.

In some cases, manufacturers may select bending strength for the following reasons:

- If the same property is used for the verification and for the check of the verification, then there is no difficulty in interpreting the result. However, where the check is conducted on a different property, the relationship between the two properties may affect the interpretation of the results. Thus it is simpler to use the same property.
- Bending has long been regarded as the prime strength property and reflects the fact that many applications for scantling timber are bending applications. The industry has a good understanding of compliance with bending strength.

The 50 pieces are tested as for the characteristic value and information presented in Section 5.2 applies.

11.3.3 Second stage testing

Where the results of the first stage analysis (See Section 11.4.1) are a pass, then the second stage testing is not required at all.

Where the results of the first stage analysis are a fail, then the second stage testing is required. In this case, at least 50 specimens from remainder are required. There are two options here:

- Take all of the remaining specimens. This increases the reliability of the data on which the conclusions are drawn. If there were a few problem pieces in the first stage of testing, it gives a greater chance of diluting their effect and better representing the production for the year. However, this option increases the cost of testing.
- Remove only 50 specimens from the remaining sample using techniques similar to those used to select the fist stage testing specimens. This option minimises the testing cost.

11.4 Analysis for check

In this case, the evaluation of properties is simply the evaluation of the sample. The check simply answers the question "does this parcel of timber which is taken to represent the whole year's production comply with its stated properties?". No attempt is made to predict the properties of the population.

An analysis is performed after the first stage testing. Providing the result of the first stage analysis is a pass, no second stage testing and analysis is required. Where the result of the first stage analysis is a fail, a second stage testing and analysis is required.

11.4.1 Analysis of MoE

The MoE of the sample is calculated as the arithmetic average of the MoE data from all of the tests on the sample. As the characteristic value is not found, there is no need to use the sampling error or the Coefficient of Variation (V) of this data.

However, the Coefficient of Variation of the data is of value in comparing with values assumed or obtained from regular verification. V is found by dividing the standard deviation of the MoE data by the average of the MoE data.

The value of V for graded product should not vary too much from year to year if the grading system and verification is operating successfully. Where the verification method uses an assumed value of V, the assumed value can be updated to incorporate the new data:

- The new value of V can be used if the previously assumed value did not have data to support it.
- Where previous estimates of V are available, all of the previous data can be combined with the new data to estimate a value of V, or the previous values of V and the new value can be averaged, if it is not possible to access the previous raw data.

Where the value of V varies from previously calculated values by more than 5% total (e.g. from 15% to 20.5%), then the character of the graded product has changed significantly and there is cause to revise the verification method even if the results are a pass.

11.4.2 Analysis of strength

The 5%ile of the strength data is found from the data directly. The method used can be:

- Method 1 from AS/NZS 4063.2 (the 5%ile of a log-normal fit through the data) or,
- Method 3 from AS/NZS 4063.2 (the 5%ile of the ranked data)

The other two methods presented in AS/NZS 4063.2 are not appropriate for this evaluation. However, it is only the 5%ile that is required not the characteristic value.

As with the MoE data, there is value in determining the Coefficient of Variation (V) of the strength data and comparing it with previous values assumed or obtained from regular verification. V is found by dividing the standard deviation of the strength data by the average of the strength data.

Again, previously used or assumed values can be updated using the techniques outlined in Section 11.4.1.

11.4.3 Second stage analysis

Where a second series of tests is required, the second stage analysis is the same as the first stage analysis. The only difference is that the data used for the second stage analysis is the total data from the annual check. This is all the data from both first and second stage testing for the year.

The higher quantity of test data gives a more reliable representation of the product over the year than the data from just one test series on its own.

11.5 Results of check

11.5.1 Check of verification pass

In order to obtain a pass in the check of verification:

- The average MoE from the analysis of the check data testing is greater than the design value for MoE of the product; AND
- The 5%ile strength from the analysis of the check data is greater than the corresponding design value for the product.

Where both of these are higher than the required values, it is demonstrated that the verification method has been working satisfactorily.

11.5.2 Check of verification fail

If either of the conditions for a pass (See Section 11.5.1) is not satisfied, then the result of the check on verification method is a fail. The annual sample of verified timber has not demonstrated the characteristics compatible with the grade claimed.

This has demonstrated that the verification has not been working satisfactorily. Note that it does not necessarily mean that the timber that has been produced has a problem, just that the verification method needs some tuning. In most cases, the production that is verified exceeds the requirements by more than the margin by

which the verification method needs to be adjusted. In the other cases, the confidence level attained in verified timber means that the timber produced as verified timber throughout the year will still be fit-for-purpose.

11.6 Maintenance of Verification method in response to check

Where the result returned by the annual check on verification is a fail, the verification method must be adjusted in response to the test result.

All of the verification methods (Appendices A, B, C, D and E of AS/NZS 4490) have parameters that can be adjusted to tighten the verification method. These options are presented in Sections 12 to 16 of this document.

11.6.1 Tightening verification requirements

Where a fail has been recorded in the check on verification, there is no option but to tighten the verification requirements.

The size of the correction can be guided by the size of the discrepancy between the relevant check data and the design property of the product.

Once the requirements have been tightened, a producer may want to resample and repeat the check over a shorter time period. Even so, it is suggested that the retest sample should be collected over at least two months to obtain material produced over a number of production runs.

Where an alternative verification method has been developed and is in use, the development should include some guidance on the parameters in the method that should be tightened in response to a fail result in the check of verification.

11.6.2 Relaxing verification requirements

Just as it is possible to tighten verification requirements where the verification method has been too generous, it is possible to relax it where it has been found to be too constrictive. However, this process must be approached cautiously.

A number of factors may cause a situation in which the results of the check on verification are significantly greater than the design values:

- Stiffness-limited products often have very high strength data while the MoE data is only comfortably above the design value. There is no relaxation necessary in these circumstances.
- Strength-limited products often have very high MoE data while the strength data is only comfortably above the design value. There is no relaxation necessary in these circumstances.
- Where most production settings have been very high, the product for these runs should have satisfied the verification requirements by a very generous margin. The high check results simply reflect the high production settings.
- Where the verification method uses a high level of conservatism as its verification strategy, then again, the check data should be returning high results. In this case, the conservatism addresses the need for there to be a generous margin to cover normal variations in properties from batch-to-batch.

Verification requirements should only be relaxed where:

- Both MoE and strength values from the check test data are significantly higher than the design values; AND
- The discrepancy between test data and design value is also reflected in the verification data in all production runs throughout the sample period; AND
- The discrepancy between the test data and the design value exceeds the conservatism built into the verification method.

These points are addressed with information tailored to each specific verification method in the following Sections of this report. However, where a different verification method has been developed, the development must include some guidance on the conditions that must be satisfied before the verification parameters can be relaxed.

12. Verification Method A

12.1 General

Verification Method A (AS/NZS 4490 Appendix A) is suitable for use in mills in which a program of regular sampling and testing of product is part of quality control processes. It involves random sampling out of the product for which verification is needed. Where batch monitoring is used, the status applies to all of the material in the batch that is represented by the sample. For continuous monitoring, it is normal to apply the status to the current batch.

Before undertaking verification, producers must make decisions regarding:

- definition of batch size;
- selection of sample size; and
- conditions to be satisfied by "conditionally verified" product.

Verification Method A can be used for batch monitoring or for continuous monitoring.

12.1.1 Batch monitoring

Batch monitoring collects and tests specimens throughout a production batch and, when the testing of the sample is completed, the analysis is performed and a decision about the batch is made.

AS/NZS 4490 does not fix a sample size for this method of verification. Rather, the test data must exceed a Test Comparison Value (TCV) which is a function of the sample size. Larger sample sizes have lower TCVs and as a result can use lower production settings. However, where a smaller sample size is selected, the TCV is higher and as a result higher production settings must be used to comfortably achieve a Verified status. The sample rate is calculated based on the anticipated number of pieces per grade in the batch and the selected sample size.

Thus, while the sample size is variable, there are some commercial incentives for selecting larger sample sizes for verification of high volume products.

Batch monitoring has the following advantages:

- Each decision is made based only on test data from material produced in the current batch. It cannot be affected by problems in past production periods.
- The verification is quite flexible in that the sample size and hence the sample rate can be varied to suit the requirements of each product.

However, it has the following disadvantages:

- For products with small production batches, either a very high sampling rate must be set to get sufficient specimens, or a small sample size is accepted and as a result the production settings need to be high.
- Where production batches are finished early for any reason, a small sample size may result, and as a consequence the Test Comparison Value will be set high and there is a strong possibility that the batch may fail.

12.1.2 Continuous monitoring

Continuous monitoring collects and tests specimens at a pre-determined rate. The data from each specimen is added to a rolling data set, and the rolling data set is analysed after each test. A decision is made on the production after each specimen's result becomes available.

This analysis uses the same analytical techniques as the batch monitoring, but the sampling strategy is quite different and has a number of controls that keep the continuous monitoring regime responsive to changes in timber properties in spite of the fact that it uses data collected over a number of different batches.

Continuous monitoring has the following advantages:

- It does not require an estimate of the batch size to fix sampling rates, so can be used in operations in which the size of a production run is not well known in advance.
- It is well suited for very small production runs, where sampling rates for batch monitoring would be prohibitive.

However, it has the following disadvantages:

- Because it works with a rolling data set, once a piece with very low properties is included in the data set, the results may be significantly affected by that piece while it remains in the rolling data set.
- There is some attenuation of data (particularly MoE) so the response of the continuous monitoring result to a step change at the beginning of a run may take some time to trigger a response.

The sampling strategy for continuous monitoring is more restricted to minimise the effects of these disadvantages. This is detailed in Section 12.2.2.

12.2 Sampling

12.2.1 Sampling for batch monitoring

For batch verification, the sampling rate is dependent upon the size of the batch being verified and the number of specimens required.

Sampling rate = n / time for batch (in pieces per hour)

If the batch is defined as one production run, then the sampling rate to obtain a given number of specimens would need to be more frequent than if the same number of specimens are required from a batch defined as a month's worth of production.

The number of specimens in the sample will be determined by:

- The level of confidence in the test result required by the producer and the method of analysis used to estimate the property. Some producers may want greater confidence for selected products.
- How much higher than the indicator property target value the producer is willing to set the Test Comparison Value for a verified product.
  - For example, for a given indicator property target value, the Test Comparison value for a sample of 10 specimens is higher than that for

20 specimens. Therefore, if a small sample size is used, grading parameters will generally need to be increased to ensure that the production meets the required properties.

The selection of sample size is one of the most difficult decisions a producer has to make in batch monitoring. Some guidance is presented below, but ultimately the selection is made as a compromise between the number of tests that can reasonably be conducted during the batch and the number that will result in the best recovery.

Equation 11 can be used to select a suitable sample size to deliver a selected margin between the Test Comparison Value and the indicator property target value. This margin contributes to setting the grade limits, so a higher TCV will mean higher grade limits are required.

$$n \geq \left(\frac{k_s V}{\left(\frac{IPT}{\Delta + IPT} \right) - 1} \right)^2 \qquad \textit{equation 11}$$

with n = number of specimens in sample
k_s = statistical parameter in from AS/NZS 4490 Table A1 to Table A3
V = coefficient of variation of the population
IPT = indicator property target value
Δ = margin between IPT and TCV (MPa)

If Δ is around 10% of the indicator property target value, it means that the grade limits have to be set around 5% higher than if the value of Δ was 5% of the indicator property target value.

The recommended minimum sample size is a function of the V for strength. Table 3 has been derived from *equation 11* and suggests appropriate minimum samples based on the V. However, it is possible to select different sample sizes and derive a benefit in Test Comparison Value if the sample size is larger.

Table 3: Suggested minimum sample sizes for batch monitoring

***V* (%)**	***n* min**
≤ 30	10
35	12
40	16
45	20
50	25

For batch testing, greater sample sizes will allow greater confidence in the results and so the more samples taken, the better.

12.2.2 Sampling for continuous monitoring

For continuous monitoring, the sample is a rolling sample, so can be collected over a number of production batches. A small rolling sample size is likely to have a majority of the timber from the current or at least a recent batch, so will better represent the

current properties of the production. A large rolling sample may take timber from a number of different batches, which means reductions in quality for short periods may not be detected at all. Very large rolling data sets "smooth" the data, and may mean that a single poor quality batch may not be detected at all, or at best, some time after the timber has left the mill. Therefore, sample sizes of no more than 30 are set. This ensures that the sample is responsive to current changes in properties.

The same formula is used to set the Test Comparison Values, so there is incentive to use as large a sample size as possible.

With batch monitoring, the sampling rate follows from the sample size selected. Large sample sizes require many samples to be collected in a batch (a high sampling rate) and give lower production settings. However, in continuous monitoring, the sampling rate is independent of the decision on sample size. In order to make the system as responsive as possible, a high sampling rate would be required, but in this case, there is no commercial incentive to choose a high sampling rate. As a result AS/NZS 4490 sets a sampling rate that gives more than 1 specimen per 1000 output pieces per grade, and this is compatible with the confidence level required for decisions on single batches.

Setting a maximum sample size for continuous monitoring and a minimum sampling rate ensures that each batch has a significant impact on the rolling data set, and returns an appropriate level of confidence in the estimate of current batch properties in most circumstances.

12.3 Testing

Testing specified in AS/NZS 4490 Appendix A is random position testing (the default testing in AS/NZS 4063.1). The analysis parameters have all been based on the statistics of random position testing that is the same basis for evaluation of characteristic value and design characteristic value. Biased position testing will give conservative results, which can still be used with this verification method.

Normally, any strength test is continued until the specimen fails. This means that any of the analysis methods for estimating 5%ile strength in AS/NZS 4063.2 can be used if their requirements are satisfied. However, where the tests are truncated at a proof load, then only Method 3 in AS/NZS 4063.2 can be used to estimate the 5%ile. This will require the use of higher values of k_s as given in AS/NZS 4490 Table A2 which leads to slightly higher values of TCV.

“Proof load” in this context refers to loads applied at a single randomly selected position on the piece. The loads are increased slowly and the test terminated when the proof load is reached. If failure occurs before that time, the actual load at failure is recorded. This is different to the reference to “proof load” in Appendix B of AS/NZS 4490, where the loads on the machine are set at the proof load and the entire length passes through the machine; if the piece fails, it is simply recorded as a failure at or below that proof load.

The proof load for these Method A tests has not been defined, rather the manufacturer should set it to give failures in around 10% of pieces. This gives a bit of a margin for

estimating the 5%ile value. (If fewer than 5% of pieces fail, it is not possible to estimate the 5%ile at all.) Previous experience will give a guide as to the load to establish that failure rate.

As a starting point, the proof load level can be set at a value of around 1.1 times the Test Comparison Value. That way, if the 5%ile strength is less than the TCV, it can be evaluated by interpolation using the non-parametric method (Method 2 of AS/NZS 4063.2). If however, fewer than 5% of pieces were broken, then it is not possible to evaluate the 5%ile, but it must necessarily be greater than the proof load level set or 1.1 times the TCV; hence it is verified.

12.4 Evaluation

The test data needs to be analysed to return a single value that can be compared with the TCV calculated for the claimed stress grade. Different methods are used for the MoE results and the strength test results.

12.4.1 Evaluation of MoE from test data

For Modulus of Elasticity, both the arithmetic average of the test values and the 5%ile of the test values are used to estimate the MoE of production in accordance with AS/NZS 4063.2.

- In AS/NZS 4063 the characteristic value of MoE is drawn from both average MoE for the population of graded timber and its 5%ile. The lower of the average and the 5%ile divided by 0.7 is used in both AS/NZS 4063.2 and this document. The analysis used for MoE is compatible with the method of deriving the characteristic value of MoE.
- The 5%ile should be estimated using a log-normal fit to the test data as indicated in AS/NZS 4063.2.
- For this comparison, the characteristic MoE is not determined.

12.4.2 Evaluation of 5%ile strength from test data

For strength testing, the 5%ile of the test data is used to compare with the TCV.

- Because verification requires the 5%ile value and not the characteristic value, Method 4 in AS/NZS 4063.2 is not appropriate.
- Likewise, Method 2 requires more than 100 test items and that will generally not be the case for verification testing.
- As a result, the 5%ile must be estimated using the 5%ile of the log-normal fit through the data or using the non-parametric method (Method 3 in AS/NZS 4063.2

These two values are taken to represent the test data and are compared with the TCV in the next step.

12.5 Verification

Two Test Comparison Values (TCVs) are calculated for each series of tests – TCV for Verified status and the TCV for Not Verified status. The TCVs are a function of the confidence of estimation of sampling error which is varied by the factor k_s.

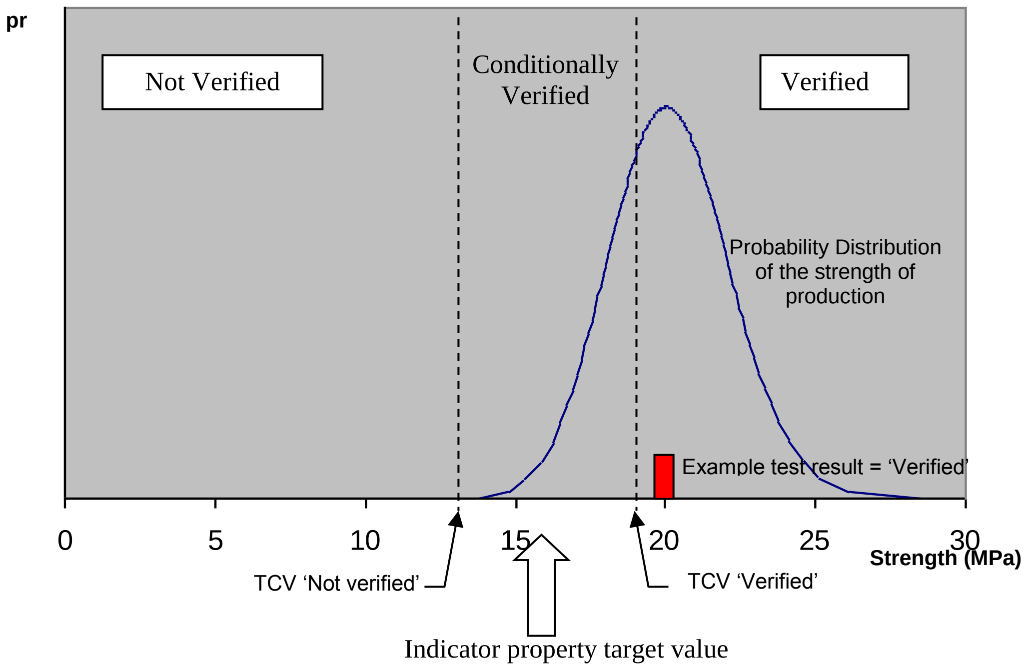


Figure 9 Statistical distribution of test data on complying material

The diagram above illustrates the three regions; "Verified", "Not Verified" and "Conditionally Verified".

- The "Not Verified" TCV separates the "Conditionally Verified" region from the "Not Verified" region, and the "Verified" TCV separates the "Conditionally Verified" region from the "Verified" region.
- The example test result falls within the "Verified" region, so it is verified.
- The test result is found from the test specimens and the property of the production they represented is likely to be close to the test result. The blue line represents the distribution of the likely property of the production.
- The plot shows there is approximately 80% chance that the production property will be greater than the indicator property target value.
- The confidence level of the verification of this test result is 80% (i.e. greater than the 75% required.)

The calculation of TCV is based on the establishment of a property using a given level of confidence. Because k_s is a function of the property estimated, different values are used for MoE, which is based on an average, and strength, which is based on a 5%ile. Also, AS/NZS 4490 Appendix A uses different levels of confidence for MoE and for strength. The levels were chosen with industry consensus in line with European and ISO standards for characteristic values and verification of timber properties. These are the minimum acceptable levels of confidence, but individual manufacturers may opt to select higher levels of confidence for their analyses. However, to claim compliance, all that is needed is the standard confidence. The values for Verified TCV associated with higher confidence are given in Table 4.

Table 4 k_s Values – Verified TCVs for different CLs

	Value of k_s		
CL	**Non-parametric mean MoE**	**Non-parametric 5%ile Strength**	**Log-normal 5%ile Strength**
95%	-1.65	-3.29	-2.66
90%	-1.29	-2.74	-2.10
85%	-1.04	-2.36	-1.73
80%	-0.854	-2.06	-1.43
75%	-0.686	-1.80	-1.17
Standard	**0.00**	**-1.80**	**-1.17**

The sampling factor k_s has a similar role to that of k_s in AS/NZS 4063.2, however the values for this constant for 5%ile strength are slightly higher for verification compared with AS/NZS 4063.2. This is because the true k_s value increases slightly as sample size decreases and sampling for characteristic values typically uses more than 50 specimens, while for verification sample sizes are typically less than 30.

12.5.1 Verified

If the test value is greater than or equal to the Verified TCV, the product will be Verified and compliance with AS/NZS 4490 can be claimed. This basically means that if the test results gave values that were right on the Verified TCV value, then there is the prescribed level of confidence that the required properties have been achieved by the whole of the grouping of product represented by the sample analysis.

12.5.2 Not Verified

If the test value is less than the Not Verified TCV, then this is indicating that there is confidence that the production does *not* exceed the indicator property target value. Not verified timber cannot be stamped as verified and released for sale. Any timber classed as not verified must be reprocessed if it claims compliance with AS/NZS 1748. Where this standard has been used with other product standards e.g. AS 2858, then if previously marked as Verified, all pieces in the affected batch must have the "Verified" mark obliterated before it can be released for sale.

12.5.3 Conditionally Verified

This status simply indicates that the material is at the grading borderline and there is not sufficient confidence to either verify it or not verify it. A decision must be made using other information. Typically, this information will be the results of previous production runs for the current material and prior experience with the production of this product.

A Conditionally Verified result is possible if the product is generally above the indicator property target value but sampling errors have forced a low test outcome.

In general, where the material is normally Verified, but there are one or two excursions into the Conditionally Verified status, then there may not be a problem in the quality of production. However, where the verification status is Conditionally Verified for a number of consecutive production runs of the same product, then this

may indicate a reduction in properties that may lead to problems in achieving the indicator property target values.

There are some conditions that must be met by Conditionally Verified product, but there is also some flexibility:

- Regardless of manufacturer conditions, there cannot be three consecutive Conditionally Verified status results. Hence the third consecutive Conditionally Verified result must be treated as Not Verified. (See 12.5.2 for the implications of this result. It may not be released marked as complying with AS/NZS 1748.
- Within the restrictions of the requirement above, manufacturers may set their own conditions for Conditionally Verified timber to be released as Verified. These may include:
  - Product which is Conditionally Verified for one property may only be deemed to be Verified if the other property is Verified.
  - Product which is Conditionally Verified may only be deemed to be Verified if 3 of the previous 5 results were Verified.
  - Product which is Conditionally Verified may only be deemed to be Verified if it is a particular type of resource or species.

12.6 Check of the verification method

There is a requirement in AS/NZS 4490 Clause 6.3 that the verification method be checked at least once a year. The results of this testing reflect the quality of the product that has been verified during the year, and so report on the effectiveness of the verification method.

Where specimen testing is truncated at a proof load as part of the Appendix A verification, the V used in setting the TCV must be estimated as it is not available from the test data. The V from the results of the most recent check of verification testing should be used. In this way, even if the result of the check of verification is a pass, the data are used to update the Verification Method.

Where Appendix A verification is undertaken and the annual check produces a fail result, this shows that the verification method needs modification. There are two reasons for the low result – mistakes due to calibration of test equipment or sampling; and a need to tighten the verification requirements. The following options are suggested for this verification method:

- Ensure that specimens taken during non-verified production are removed from the annual check on verification sample.
- Check calibration of testing equipment and the accuracy of the data transfer to the analysis.
- Increase the size of the sample taken (batch monitoring only).
- Increase the sampling rate (continuous monitoring only).
- Increase the level of confidence required (changing the k_s values to higher confidence values as given in Table 4 above).
- Tighten the interpretation of Conditionally Verified timber (only if there were a significant number of Conditionally Verified results in the sampling period).

- Adopt better analytical methods of estimating population parameters (This mainly applies to 5%ile strength values if Method 1 of AS/NZS 4063.1 is not used).
- If proof testing is used in verification, adopt the strategy of testing all specimens to failure. This increases the quality of data on which an analysis can be performed and allows more analysis options.

13. Verification Method B

13.1 General

Method B is able to verify bending strength, but not other properties, for which Verification Method A, C, D or E should be used.

Verification Method B (AS/NZS 4490 Appendix B) uses a proof grading technique for verification of a product. The method of proof grading specified in AS 3519 is used, with some variations for use as a verification, rather than grading, method. Because the verification method must be independent of the original grading method, this method of verification cannot be used for timber that has originally been graded to AS 3519.

The proof grading standard AS 3519 requires pre-sorting (usually based on visual grading criteria) and then the final grading being performed by a proof loading machine. This process aims to remove the weakest material so that the 5%ile strength of the remainder is greater than the indicator property target bending strength.
Its use as a verification method is very similar, but there are some minor differences when it is used to confirm the properties of a grade awarded by another process.

The level of confidence in the results of verification in which all timber is proof loaded follows from the probabilities of occurrence of the proof loads used in AS 3519. The setting of proof loads in the verification by proof loading only a sample has been related to its level of confidence by simulations. Monte Carlo simulations were used to demonstrate that the level of confidence in the results of the proof grading verification methods is same as that for verification using the other methods.

13.2 Verification – all timber proof loaded

This Verification Method only applies where *all* timber is passed through a proof grading machine for its verification. The machine and the process must comply with AS 3519 with a few relatively minor exceptions:

- Because AS 3519 is a grading standard, it requires that there be an initial evaluation of properties (as for machine stress grading). In this context it is used as a grade confirmation process. If required, an initial evaluation will have been called up in the grading standard, so there is no need to comply with Clause 2.2 of AS 3519:2005.
- Again, in its normal context as a grading standard, AS 3519 is a standard that must define the finished product. This is not required in the verification context, as it is already covered in the grading standard used in producing the timber. Hence AS 3519:2005 Clause 2.7.2 does not apply.
- The grading standard will have the marking requirements, and after verification, the marking requirements of Clause 2.8 in AS 3519:2005 do not apply.

This verification method entails selecting a proof loading regime, calculating a proof stress that targets less than 5% breakage, applying that stress to all of the timber to be verified, discarding the broken pieces and awarding a verification status on the results of the proof loading.

The maximum 5% damage level is selected as the 1% level is too far below the indicator property target value to give a level of reliability consistent with all of the other methods.

13.2.1 Verification criteria

Any material that has been damaged or has excessive deflection within the definition of AS 3519 is Not Verified. It may not be docked and sold as Verified timber. The whole piece has failed the verification criteria.

Any material that has passed through the proof grader without damage or excessive deflection is classed as either Verified or Conditionally Verified.

- Where less than 5% of the material was rejected (often it is considerably less), then the distribution has the right form to have confidence in the 5%ile of the remaining material. It is Verified.
- Where more than 5% of the material was rejected, then the actual distribution of the material strength is unconservative and there is doubt about the reliability of the 5%ile of the remaining product. Its status is Conditionally Verified.

The deflection limit on the machine is designed to catch pieces that have been cracked but not broken by the proof grading machine. They will have a high deflection but may not necessarily break. The deflection limit on the proof grader is not used to measure the MoE of the piece

13.3 Verification – sample proof loaded

This Verification Method is used where only a sample is proof loaded, and calls for a sample of timber to be drawn from production and be passed through a proof grading machine for its verification. The machine and the process must comply with AS 3519 with a few relatively minor exceptions:

- Because AS 3519 is a grading standard, it requires that there be an initial evaluation of properties (as for machine stress grading). In this context it is used as a grade confirmation process. If required, an initial evaluation will have been called up in the grading standard, so there is no need to comply with Clause 2.2 of AS 3519:2005.
- Again, in its normal context as a grading standard, AS 3519 is a standard that must define the finished product. This is not required in the verification context, as it is already covered in the grading standard used in producing the timber. Hence AS 3519:2005 Clause 2.7.2 does not apply.
- The grading standard will have the marking requirements, and after verification, the marking requirements of Clause 2.8 in AS 3519:2005 do not apply.

The verification method entails calculating a proof stress that allows for sampling and targets less than 10% breakage, applying that stress to all of the timber to be verified, discarding the broken pieces and awarding a verification status on the number of pieces that fail during the proof loading.

The proof load used is a function of the *V* of the strength of the material, and this should be based on the full range of strengths in the grade. It should not be based on the tail alone. This data is only available after testing all of the timber to destruction in the annual check of verification. The proof load is not affected by the number of specimens in the sample.

Where very small samples (10 or 20 pieces) are tested, then 10% of the tests may be one or two pieces. 15% would be 1.5 pieces for a sample of 10 or 2 for a sample of 20. As counts of failures are integers, the absolute minimum sample size is 20. Even this size makes the verified status particularly dependent on the actual pieces taken in the sample. As a result, the minimum sample size has been set at 40, which means 4 failures or fewer will give “Verified” status and more then 6 failures are required to give “Not-Verified” status. 5 or 6 failures will give “Conditionally Verified”.

Again, rejection of a piece could be by failure of the timber or excessive deflection. The deflection limit does not constitute a test on MoE of each piece. It is a check on cracking of specimens.

13.3.2 Verification criteria

Any material that has been damaged or has excessive deflection within the definition of AS 3519 is Not-Verified. It may not be docked and sold as verified timber. The whole piece has failed the verification criteria.

Any material that has passed through the proof grader without damage or excessive deflection may be returned to the rest of the production and is classed as either Verified, Not Verified or Conditionally Verified along with the rest of the material in the run.

- Where less than 10% of the sample was broken (often it is considerably less) then the distribution has the right form to have confidence in the 5%ile of the remaining material. It is Verified.
- Where more than 10% of the sample was broken, but less than 15%, then there is not enough confidence in the verification to classify it as either Verified or Not-Verified. Its status is Conditionally Verified.
- Where more than 15% of the material was broken, then the actual distribution of the material strength is unconservative and there is doubt about the reliability of the 5%ile of the remaining product. Its status is Not Verified.

13.4 Annual check of the verification method

Verification should be checked annually. The results of this testing reflect the quality of the product that has been verified during the year. Hence the results are a report on the effectiveness of the verification method.

As a *V* is required for evaluation of proof loads used in this Verification Method, the strength of each specimen determined as part of the annual check can be used to estimate the *V* of the strength data for use in calculating the proof loads in subsequent years.

Where the tests show that the method needs modification, then the following options for Appendix B verification are available:

- Check calibration of proof loading equipment and the accuracy of reject material counters.
- Tighten the interpretation of Conditionally Verified (appropriate where a significant number of Conditionally Verified status results occurred during the period covered by the sampling for check).
- Ensure that specimens taken during Not Verified production are removed from the annual check on verification sample.
- Adopt slightly higher proof stresses.
    - For the all timber proof loaded method in AS/NZS 4490 Clause B2, the ψ_k factors in AS 3519:2005 are good starting points, but may need adjustment if the results are not being achieved.
    - For the sample proof loaded method in AS/NZS 4490 Clause B3, the proof stress indicated in equation B1 can be increased by a factor.
- Use a more rigorous proof testing regime e.g. two pass.
- Change the acceptance criteria. (e.g. for the sample proof loaded method in AS/NZS 4490 Clause B3, less than 8% breakage may be required for a tightened Verified timber acceptance criterion.)

14. Verification Method C

14.1 General

Verification Method C (AS/NZS 4490 Appendix C) uses conservative production parameters to give adequate confidence that the design properties are achieved. Assurance that production properties can be achieved is possible with minimal or no testing provided there is a suitable level of conservatism in the production that can cope with the expected variations in properties between batches.

Verification Method C is used where the scale of production makes regular testing of a sample unviable.

This verification option sets a level of conservatism that can be applied by producers using grade settings that are higher than the nominal settings for a product. The level of conservatism is set using statistical estimates of variation of product on a batch-by-batch basis. For verification by this method, no batch testing is performed at all. The conservatism is higher than that used with some batch testing in accordance with Verification Method A, but it correlates well with the extrapolation of the AS/NZS 4490 Appendix A data to zero daily tests. Monte Carlo simulations have demonstrated that the level of confidence in the results of this verification method is the same as that for verification using the other methods.

Verification implies a level of certainty and this can only be achieved if the level of conservatism chosen is checked annually. This is achieved by the annual check on the verification method.

14.2 Conservatism in production parameters

In order to evaluate the target Production Values for strength and MoE, an estimate needs to be made of the *V* between batches. This is the likely variation in strength or MoE of production when graded using uniform methods over a long period in which variations in the input resource can be expected. It is unlikely that producers who opt for this method of verification will know this *V*. Some suggested starting points for the *V* between batches (not the *V* of the product) are as follows:

- Visually stress graded hardwoods 0.04 to 0.08
- Machine stress graded softwoods 0.08
- Visually stress graded softwoods 0.12

Where test results are available over a long period of time, analysis of variance (Anova) can be used to estimate the variation between batches. Otherwise if a little test data is available, the *V* between batches can be found by treating the average of each batch as a data in a distribution, and finding the average and standard deviation of that distribution. This is used to establish the *V* between batches. Studies have shown that the *V* between batches is similar for both MoE and strength. The above recommendations for different grading methods were made on the basis of very limited data and may vary from product to product and mill to mill. Feedback from results of the annual check on verification can be used to refine these values.

The Production Value must always be higher than the indicator property target value that is associated with the stress grade marked on the product.

Producers may demonstrate achievement of Production Values by reference to previous test data or by aiming to produce stress grades that are linked to the Production Values:

- Where test data is available and shows that a particular product graded using a specific documented method meets the Production Values for strength and MoE, then if the same specific documented grading method is used to produce the product, verification in accordance with Method C may be claimed.
    - For example, if test data in a regional study has shown that visually-graded F5 timber using specific grading rules gives properties that exceed Production Values for this type of verification, then a mill using the same grading rules can expect the same properties and claim verification.
- If test data is not available, then a producer may claim verification if the grading targets a product that satisfies the production requirements for Production Values.
    - For example, a producer has found Production Values required for an F5 visually-graded product are marginally less than F7 properties. The producer can claim a verified F5 product by visually grading to the F7 rules.

Table 5 presents factors that require sufficient conservatism (without daily testing) to give the producer the same level of confidence in verification had they been complying with the testing regime detailed in AS/NZS 4490 Appendix A.

Table 5 Values of R_g and E_g for setting conservative production parameters

V between batches	0.04	0.06	0.08	0.12	0.16
R_g	1.16	1.20	1.24	1.33	1.45
E_g	1.07	1.11	1.15	1.25	1.36

For example, if a producer is targeting F7 properties from a machine stress-grading softwood production, then the *V* between batches is likely to be around 0.08.

- The production target bending strength must be the indicator property target value (18 MPa) times 1.24 = 22.3 MPa. This is a little higher than the design characteristic strength of F8.
- Checking the MoE target properties, the IPT is 7,900 MPa, and the production target is 1.15 times 7,900 = 9,085 MPa, just less than the F8 design characteristic value for MoE.

So the production must target producing an F8 product to claim that the F7 is verified by Method C.

14.3 Application of Production Values

A suitable method of applying the conservatism will vary with the grading method used:

- For any production method, the Production Values for strength and MoE can be used to select a stress grade that will exceed the target values, and the grade limits associated with that stress grade should be used as the basis of the production grading. If the Production Values are midway between stress-grade properties it may be possible to interpolate limits between the relevant structural grades.
- For some grading methods, the multiplier can be applied directly to grade limits and thresholds.

14.4 Annual check of the verification method

Verification must be checked annually. This is especially important for Verification Method C, as no regular batch testing is performed. The results of this testing reflect the quality of the product that has been verified during the year. Hence the results are reporting on the effectiveness of the verification method.

Where some products in the product mix are verified by Appendix C and others are verified by a different verification method, different annual checks are required for the two different verification methods.

Where the check on verification tests show that the method needs modification, then the following options are available.

- Increase the level of conservatism used. This can be achieved by assuming a higher *V* between batches or by using R_g and E_g factors in excess of those given in Table 5**.**
- Changing the verification method to use a testing-based verification method.

15. Verification Method D

15.1 General

Verification Method D (AS/NZS 4490 Appendix D) is suitable for use in mills in which a program of regular sampling and testing of product is part of quality control processes. The option involves random sampling out of the product for which verification is needed. Verification Method D uses a cumulative sum (CUSUM) method for verifying the mean MoE of graded timber.

This method may be used to verify MoE only, and an alternative method must be used to verify strength.

Timber must not be released marked as “Verified” until the material is confirmed as verified. Where batch monitoring is used, the status applies to all of the material in the batch that is represented by the sample. For continuous monitoring, it is normal to apply the status to the current batch.

There are two main variations in CUSUM techniques and CUSUM in this context is a sequential analysis technique typically used for monitoring change in a quantifiable property over time. As its name implies, CUSUM involves the calculation of a **cu**mulative **sum.** It is applied widely as a quality control analysis tool in many industries. CUSUM has been applied to monitor structural timber quality since the 1980s and is used in machine stress grading operations throughout North America and Europe. A number of grading agencies and machine manufacturers also recommend CUSUM methods.

This simplified CUSUM method has been calibrated against the method in AS/NZS 4490 Appendix A to ensure that the verification criteria provide similar levels of statistical confidence. This method is based on sequential analysis of sets of 5 MoE test results. More sophisticated CUSUM methods are required to reliably monitor 5% strength values and were not considered appropriate in this document.

15.2 Sampling

Minimum sampling rates are provided, being the greater of 2 specimens per hour or 1 piece per 2000 pieces manufactured. However, the higher the sampling rate, the better the information that can be obtained about the MoE. Higher sampling rates should be considered where analysis indicates that MoE may be drifting unacceptably and/or where the MoE is found to be repeatedly conditionally verified.

15.3 Testing

Testing must be carried out in accordance with the standard test configurations in AS/NZS 4063.1.

15.4 Evaluation

15.4.1 Number of results used for analysis

Standards for CUSUM require 5 specimen tests for each analysis. Each analysis can only apply to material sampled in the same production run.

15.4.2 Estimation of E_{mean}

Arithmetic average should be used to calculate mean estimates as it is the simplest for *n*=5, however other methods with equivalent integrity are also acceptable.

15.4.3 CUSUM parameters

The CUSUM control constants, k, y, and z used to determine the CUSUM parameters have been developed to provide equivalence to Verification Method A. The coefficient of variation (*V*) of the MoE may be established from initial MoE qualification testing/analysis and can be used to determine the k, y and z values from Table 6. Accumulation of test results will enable *V* to be revised.

Table 6 CUSUM Constants

V	CUSUM Constants for *n*=5		
	k	*y*	*z*
0.10	0.9721	0.071	0.174
0.15	0.9721	0.149	0.272
0.20	0.9721	0.251	0.385
0.25	0.9721	0.356	0.504
0.30	0.9721	0.483	0.649

15.4.4 CUSUM Calculations

Charting and/or tabulation of the results of individual verification events may be used to help interpret trends in the structural properties and assist in determining improved estimates of *V*.

A table showing CUSUM results may be constructed as follows:

	Grade			**Size**				**K**	**Y**	**Z**	
	E_{design}						**E_{mean}**				
	Sample No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Date										
	Shift										
	QC Officer										
E_{mean}	**E1**										
	E2										
	E3										
	E4										
	E5										
	Mean E										
	Last CUSUM + K										
	SUM										
	CUSUM										
	Verification Result										

Figure 10 CUSUM table

15.5 Verification criteria

A chart that plots the CUSUM value against each successive sample can be used to monitor changes in structural properties over time. In such a chart "Not Verified" is a zone between horizontal lines at Y and Z. An example of a CUSUM chart is shown below.

In the zone between 0 and Y, if the CUSUM value is increasing, then the result is "Conditionally verified".

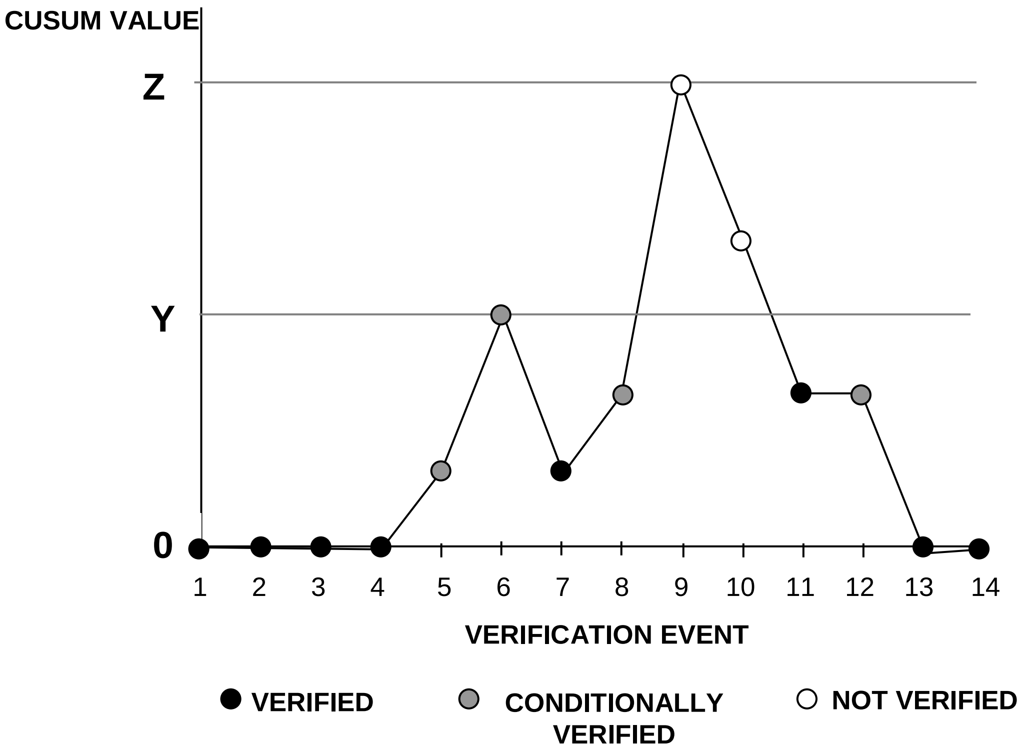


Figure 11 CUSUM chart

15.6 Annual check of the verification method

Verification should be checked annually. The results of this testing reflect the quality of the product that has been verified during the year. Hence the results are a reporting on the effectiveness of the verification method. Where the tests show that the method needs modification, then the following options are available.

- Check calibration of testing equipment and the accuracy of the data transfer to the analysis.
- Remove non-verified material from sale and at the same time, ensure that specimens taken during non-verified production are also removed from the Annual check on verification sample.
- Increase the sampling rate.
- Tighten the interpretation of Conditionally Verified.
- Adopt better methods of estimating population parameters (*V*).
- Tighten CUSUM parameters (increasing value of *k* and decreasing values of *y* and *z*).

16. Verification Method E

16.1 General

Verification Method E (AS/NZS 4490 Appendix E) uses the verification requirements of NZS 3622 to verify structural properties. The verification provisions in NZS 3622 achieve similar levels of confidence in the properties of the production to those demonstrated in the other verification methods.

16.2 Verification

Clause 9 in NZS 3622 is the only section that pertains to verification of structural products. This section refers to target values for specific grades and these must be based on indicator property target values.

- Where the product has been produced using AS/NZS 1748:2011, then the indicator property target values are found in qualification of the grading method.
- For products that meet other structural timber product standards, the qualification has not been performed and the appropriate characteristic values for design must be used.

In some cases, the qualification may have been performed with calculations based on the NZ stress-grade properties, but some product is required to meet the Australian market and will have an Australian stress-grade or vice-versa. In these cases, the indicator property target values must be calculated for the grade that will be marked on the product. This requires a little extra analysis the first time it is done, but no extra testing. For these cases:

- The indicator property target values for the new grades are found by repeating the analysis in AS/NZS 1748.2 Clause 6.3.6.2.
- The characteristic values from testing in the original qualification can be used to derive the ratios, but this time with the design characteristic values for the new stress-grades.
- The indicator property target values follow from the calculations shown in AS/NZS 1748.2 Table 6.3.2. Guidance is given in Section 5.4 of this document.

The method of NZS 3622 does not have a Conditionally Verified status. The result of verification testing is either Verified if it meets the requirements of NZS 3622 Clause 9 or Not Verified if it does not meet the requirements.

16.3 Annual check of the verification method

All verification methods in this document must include an annual check using a separate sample collected for use in this check only. While such a check is not required in NZS 3622, in order to comply with AS/NZS 4490, it is necessary to perform these tests.

The results of this testing reflect the quality of the product that has been verified during the year. Hence the results are a reporting on the effectiveness of the verification method. Where the tests show that the method needs modification, then the following options are available.

- Check calibration of testing equipment and the accuracy of the data transfer to the analysis.
- Ensure that specimens taken during non-verified production are removed from the annual check on verification sample.
- Increase the size of the sample taken for regular verification.
- Tighten acceptance criteria used in verification. The criteria in NZS 3622 are minimum requirements, and more rigorous criteria are not at odds with the standard.

17. References

17.1 Australian Standards

AS 1720.1:2010 Timber structures – Part 1: Design methods

AS 2082:2007 Timber – Hardwood – Visually stress-graded for structural purposes

AS 2858:2008 Timber – Softwood – Visually stress-graded for structural purposes

AS 3519:2005 Timber – Machine proof grading

17.2 Australian / New Zealand Standards

AS/NZS 1748:2011 Timber – Solid – Stress-graded for structural purposes

AS/NZS 1748.1:2011 Timber – Solid – Stress-graded for structural purposes Part 1: General requirements

AS/NZS 1748.2:2011 Timber – Solid – Stress-graded for structural purposes Part 2: Qualification of grading method

AS/NZS 4063.1:2010 Characterization of structural timber – Part 1: Test methods

AS/NZS 4063.2:2010 Characterization of structural timber – Part 2: Determination of characteristic values

AS/NZS 4490:2011 Timber – Solid – Stress-graded for structural purposes – Verification of properties

17.3 New Zealand Standards

NZS 3603:1993 Timber Structures Standard

NZS 3622:2004 Verification of timber properties

Appendix A Relationships between reliability of product and R^2

(Background only)

A1. Background

Capacity factors given in AS 1720.1 safeguard the reliability of timber structures. They have been calibrated on the basis of the following assumptions:

- The reliability of the product is affected by its *V*.
- MGP10 and MGP12 have assumed *V* for strength in the reference *V* range 0.35 to 0.45. MGP15 is assumed to have *V* for strength in the reference *V* range 0.2 to 0.3.

If the actual *V* of the product is higher than the reference value, then the structural reliability of the product may be compromised.

In determining compliance of a timber product, it is normally understood that the characteristic values must meet the design characteristic values. However, for a graded product to be compatible with the underlying reliability assumptions made in the design standard:

- its characteristic values must meet the design characteristic value; and
- the *V* of the product be within the bounds of the reference *V* range used in the derivation of the capacity factors.

The grading method has the potential to be used as a control for both of these:

- Separation into groups with appropriate properties is made on the basis of a grading parameter and a sorting criterion. The higher the correlation between grading parameter and properties, the better is the safeguard over the characteristic value of the graded product for varying input material.
- Coefficient of determination (R^2) between grading parameter and strength is inversely proportional to the *V* of the graded products. Hence the *V* is directly controlled by a higher coefficient of determination.

Verification testing is used as a means of checking whether or not the properties of the timber that have just been produced are able to match the design characteristic values for the product. Reliance on it alone has some limitations on the protection of reliability:

- It is reactive. It gives feedback to the grading system that a change may have occurred. This inevitably leads to a lag between detection of a change and the measures taken to address the change.
- It has a confidence level attached – for strength properties, 75% and for MoE (which also safeguards compression strength and shear strength), 50%. Thus the chance that an incorrect conclusion will be drawn about a result near the border line of acceptance with the Test Comparison Value (TCV) is 25% for bending strength and 50% for MoE. Of course, the probabilities are much lower where there is a significant margin of the result to the TCV.
- *V* from tests on small sample numbers is not a good indication of the *V* of the population, so the verification cannot be used as a direct control over *V* of the product and hence structural reliability.

The philosophy of the new standard AS/NZS 1748 is built around the following principles:

Part 1 is to be as general as possible and only focus on the requirements for the product. The fitness for purpose of the product is safeguarded by utility requirements and assurances on structural properties. The assurances on properties are delivered by the combination of, first, the qualification of the grading method so that it has demonstrated success in sorting structural timber and responding to feedback from verification, and secondly, the regular verification of the product.

Part 2 gives a qualification process that demonstrates that the grading method is able to deliver products with a full suite of complying properties at the start of the grading operation, and has sufficient control to adapt to changes over time as production continues.

The acceptability of the product at the start is found by comparing the characteristic values from test with the design characteristic values for all products, and by checking that the coefficient of determination between the grading parameter and the properties is sufficient to ensure that the expected V is within the bounds assumed for reliability of the product.

Part 3 gives the requirements for the verification process that delivers 75% confidence in bending or tension strength properties and 50% confidence in MoE.

Timber complying with the Standard will be produced in accordance with Part 1. This will be reflected in the grade stamp. Part 2 will only be used once at the commissioning of the grading operation and thereafter whenever there are significant changes to the grade parameters collected or the way they are combined. Part 3 will be used on a regular basis to check that the claims made about the timber can be justified.

A2. Acceptable R^2 to deliver appropriate V.

This part relies on some relationships derived from a number of different structural grading systems used in predicting properties of three groups of Australian plantation-grown softwood structural timber from a significant research project into grading methods in 2009:

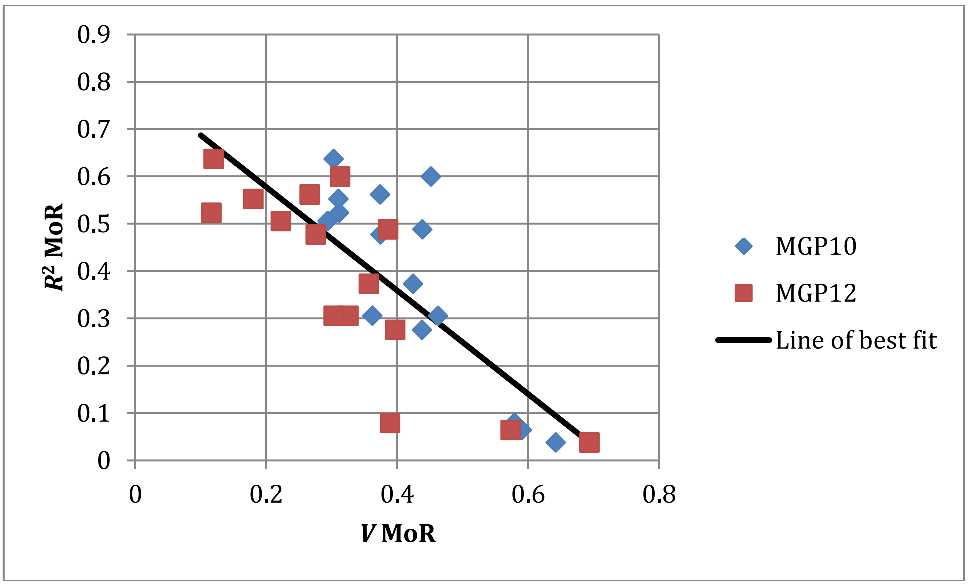
- Radiata pine (primarily stiffness limited resource),
- Radiata pine (primarily strength limited resource),
- Caribbean pine

Each resource was subjected to a number of different non-destructive evaluation methods during production, and then tested to failure in bending at the completion of the study. A number of different combinations of grading sensors could be used to allocate the timber to stress grades, and the properties of each stress grade determined from random position tests on the grade.

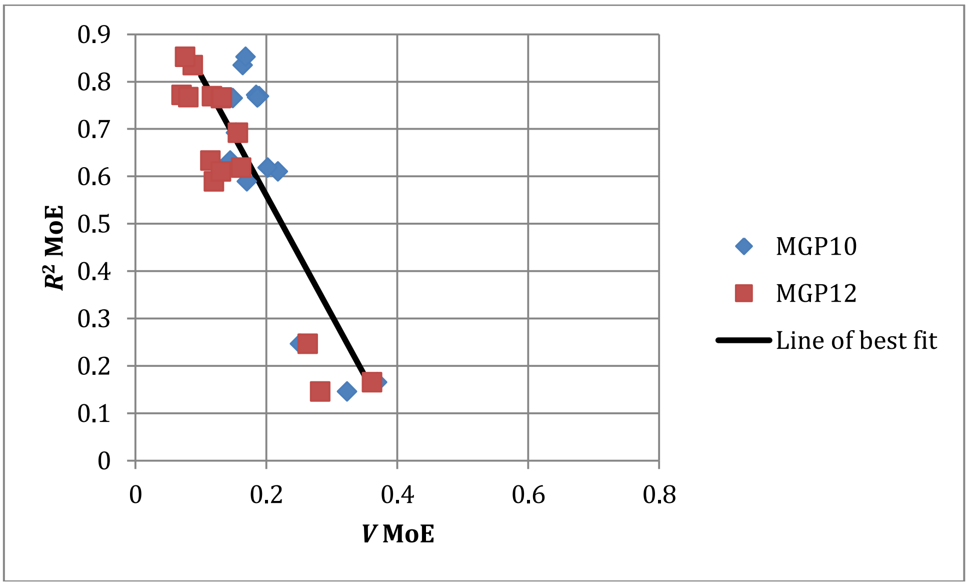
The plots show the V of two different grades (MGP10 and MGP12) from random position testing of pieces allocated to the grade using appropriate grading limits. The

*V*s are presented separately for MoE (stiffness) and MoR (bending strength) and are plotted against coefficients of determination (R^2). In this case, the coefficient of determination is the coefficient of determination for each grade over a run-of-mill sample tested in biased position bending against the grading parameter or combination of parameters for each grading method.

These plots show R^2 as measured in the draft of AS/NZS 1748 Part 2, plotted against the *V* that relates to the assumptions of reliability used in the capacity factors allocated by AS 1720.1 and obtained by testing to AS/NZS 4063.



(a) Correlations with bending strength



(b) Correlations with MoE

Figure A1 relationships between Coefficient of Determination (R^2) and *V*

For each grading method, the three batches of timber were sorted into both MGP10 and MGP12 grades. For these two grades, the capacity factor for bending strength in

AS 1720.1 is based on a *V* in bending of between 35% to 45%. Thus 40% (half of the calibration range) will be taken as the reference point. There was a significant overlap between the data from the two grades as shown in Figure A1(a).

Figure A1 shows a clear inverse relationship between R^2 and the *V* for graded products. For both MoE and bending strength, the *V* was marginally higher for the MGP10 compared with the MGP12, but both grades showed a negative slope. For the bending strength the slope was around -1, (or for each 0.1 increase in *V*, there was a reduction of around 0.1 in R^2).

For the MoE, the slope was over twice that value, approximately 2.5. The compression strength and shear strength of products are aligned with the MoE data, so even though the MoE itself does not pose a risk to safety, the properties that are inferred from it may. MoE will therefore be treated to the same kind of analysis, with a reference point of 20% *V*.

A3. Offset required for variations in *V*

In considering reliability of structures, AS 1720.1 incorporates a capacity factor that has been calibrated to ensure that all products have consistent levels of reliability in design.

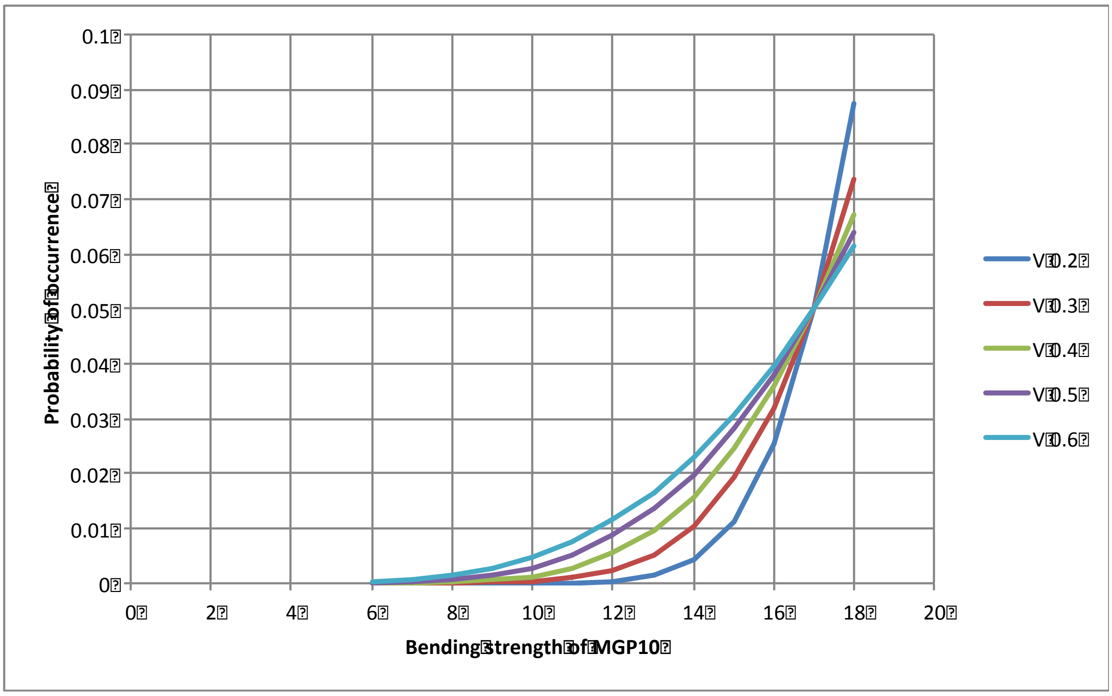
The background to this is as follows:

- Design characteristic values for strength are based on an estimate of the 5%ile strength of the population of graded products.
- The capacity factor is different for different types of structural products, and ensures that the load factors when used with materials that have varying statistical distributions of strength give a consistently low probability of failure.
- For MGP10, MGP12 and F-grades up to F17, the capacity factor in the revised version of AS 1720.1 is 0.9. This factor has been derived from an assumed *V* of strength properties that ranges from 0.35 to 0.45.

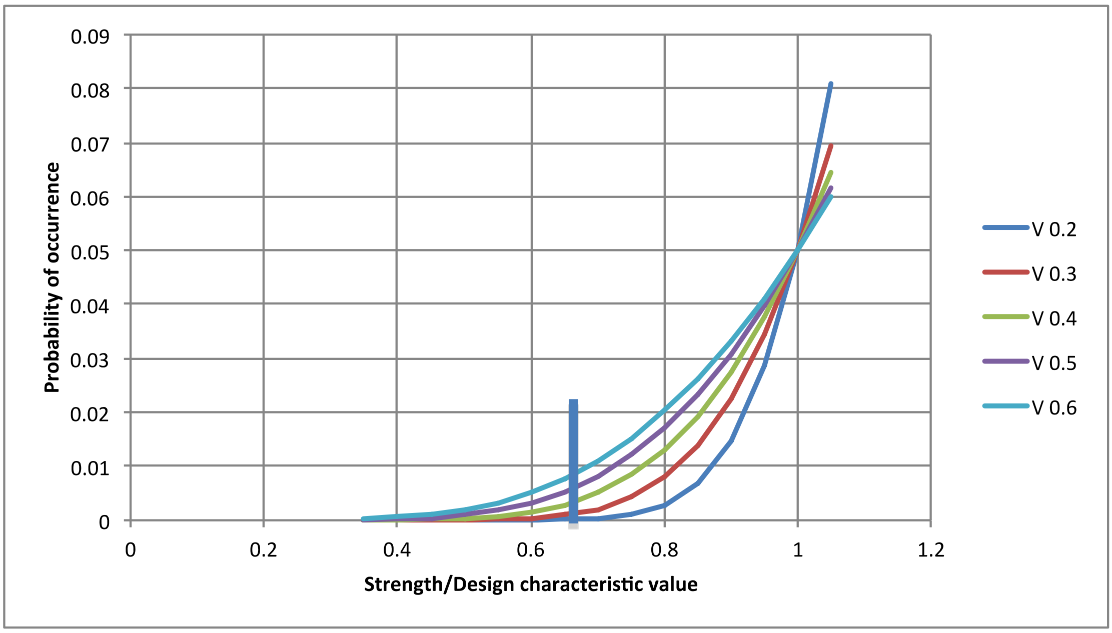
Figure A2(a) shows that assumed log-normal distributions of MGP10 bending strength with the design characteristic value at a probability of 5%, but with different coefficients of variation, have differences in the lower tail of the distribution.

Figure A2(b) non-dimensionalises the strength by dividing by the design characteristic value. This means that the same curves can apply to any structural grade, and it can be seen that the probability of occurrence at 0.9 times the design strength varies considerably with the *V* of the distribution.

The calibration of the capacity factors gave consistent levels of safety using an average load factor of 1.35, and produced a capacity factor of 0.9 for products with *V* between 0.35 and 0.45, characterised by a *V* of 0.4.



(a) log-normal properties of MGP10 lower tail for different *V*s



(b) log-normal properties of normalized strength lower tail for different *V*s

Figure A2 characteristics of lower tail strength distributions

The load factor and capacity factor combination gave a strength factor of $\frac{0.9}{1.35} = 0.667$ shown by the vertical bar in Figure A2(b).

For a *V* of 0.4, this gives a probability of occurrence of 0.0035, or around 1 in 300. This level can be seen from the green line where it crosses the vertical bar in Figure A2(b). This represents a target probability of exceedance for the reliability of a timber product to be satisfied.

The plots in Figure A2(b) can all be manipulated by sliding them left or right to intersect at a strength ratio of 0.667 and a probability of 0.0035. This will give all materials the same level of reliability as the calibration, and is illustrated in Figure A3.

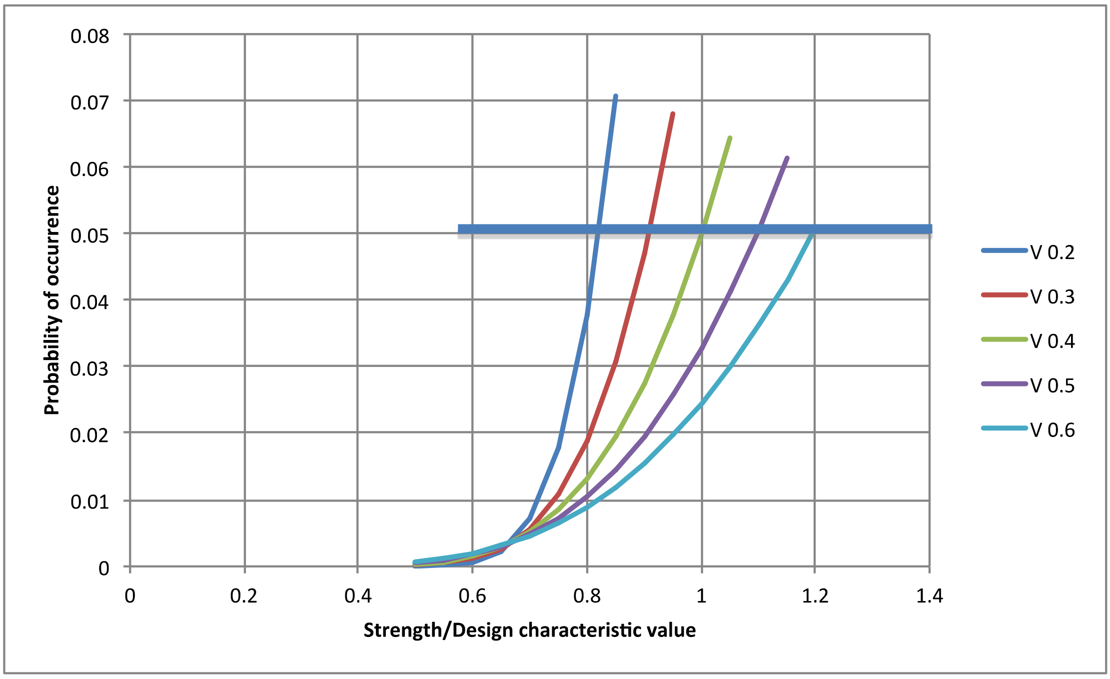


Figure A3 Distributions for different *V*s with consistent reliability at the calibration point

Figure A3 shows that for a consistent level of reliability at a strength ratio of 0.667, the 5%ile value required of each distribution is different:

- For the case of V =0.4, the strength ratio at the 5%ile level is 1.0 – this was the calibration case used for setting the capacity value.
- For *V*s less than 0.4, the strength ratio at the 5%ile level for target reliability is less than 1.0. In other words, complying material with a 5%ile strength ratio of 1.0 or better will have conservative performance as its strength ratio is greater than that required for target reliability.
- For *V*s greater than 0.4, the strength ratio at the 5%ile level for target reliability is larger than 1.0. In other words, complying material with a 5%ile strength ratio of 1.0 or a little better may have unconservative performance as its strength ratio could still be less than that required for target reliability.

The required values for the strength ratio are shown in Table A1. A linear relationship has been fitted between V and the required 5%ile strength ratio in order to satisfy target reliabilities. The relationship can be approximated by:

$$\text{Strength ratio} = 0.936\,V + 0.63 \qquad \textit{equation A1}$$

Table A1 Relationships between *V*, required strength ratio and R^2 with grading parameter

V	0.2	0.3	0.4	0.5	0.6
Strength ratio from Figure 3	0.821	0.908	1.000	1.096	1.195
Strength ratio from *equation 1*	0.817	0.910	1.004	1.098	1.191
R^2 from Figure 1	0.58	0.47	0.36	0.25	0.14

Table A1 draws information together from the material presented in Section A2 and Section A3. It enables the strength ratio required to satisfy reliability constraints to be related to the R^2 of the strength to the grading parameter relationship using V as an intermediate parameter.

- Table A1 shows that the strength ratio given in *equation A1* is a good match to the value obtained from Figure A3. It can therefore be used in predicting the relationship between V and the strength ratio for satisfying reliability constraints.

The data from Figure A1 and Table A1 show that it is possible to estimate whether or not the V will be within the appropriate band for the structural product by checking the coefficient of determination (R^2) between the grading parameter and the property.

- Table A1 and Figure A1(a) show that an R^2 in excess of 0.36 is required (suggest a limit of 0.4) between strength and grading parameter.
- Figure A1(b) and Table A2 (later in the report) show that an R^2 in excess of 0.56 (suggest a limit of 0.6) is required between MoE and grading parameter.

A4. Concession for stiffness- or strength-limited production

A4.1 Stiffness-limited production

For stiffness-limited production, the strength to stiffness ratio of the product is high. In these cases, the high strength of the product means that QC testing shows a generous margin over the design strength, and a very small margin over the design MoE. This has the following implications for these products:

- QC monitoring of MoE is much more important than QC monitoring of strength.
- Grade sorting is therefore critically dependent on sorting by MoE and much less dependent on success in sorting by strength.
- The high margin of production strength over design strength equates to a higher than 1 strength ratio. Table A1 indicates that there could be a concession in the R^2 required for strength in these cases.

Determining whether or not production is stiffness-limited can be achieved by comparing the in-grade test results for strength and stiffness with their design characteristic values. In the Qualification testing, the first series of tests performed in-grade testing for all major properties, and compared the characteristic properties evaluated from these tests with the design value by calculating the ratio r. For the indicator properties, this ratio has the subscript i.

Hence the ratio for the

- List A property (MoE) will be $r_{i,A} = \frac{E_k}{E}$ or Characteristic MoE divided by the design MoE.
- List B property (strength) will be $r_{i,B} = \frac{R_{k,b}}{f'_b}$ or Characteristic bending strength divided by the design characteristic bending strength.

Where the product is stiffness limited $r_{i,B}$ will be larger than $r_{i,A}$. The ratio of $\frac{r_{i,B}}{r_{i,A}}$ gives an indication of the degree to which the product is stiffness limited. The higher the ratio, the more stiffness limited it is. Thus the ratio $\frac{r_{i,B}}{r_{i,A}}$ gives the strength ratio referred to in Section A3 and Table A1.

The strength ratio in Table A1 is the strength required to offset an increase in *V* above the standard value used to find the capacity factor. The R^2 is the coefficient of determination between strength and grading parameter expected for the same *V*. The two can be related by *equation A2* which is found by the line of best fit through the data in the last two rows of Table A1. In this case, the strength ratio has been replaced by $\frac{r_{i,B}}{r_{i,A}}$.

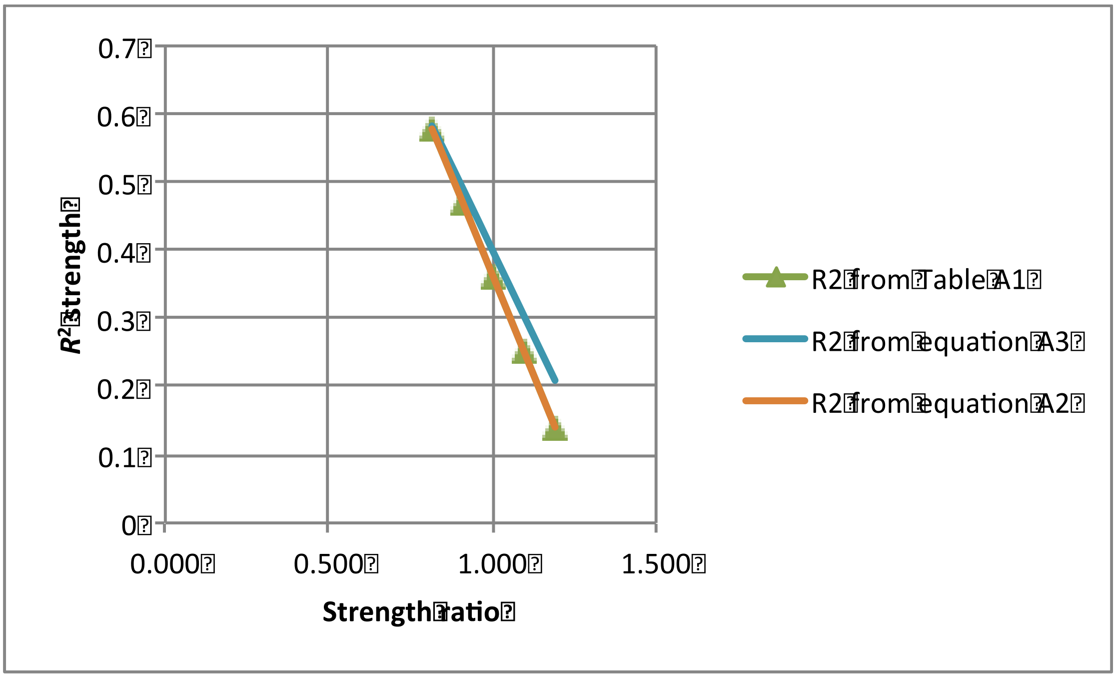


Figure A4 Strength ratio vs coefficient of determination for strength

$$R^2_{\text{lim}} = 1.53 - 1.17\,\frac{r_{i,B}}{r_{i,A}} \qquad \textit{equation A2}$$

with R^2_{lim} as the limiting coefficient of determination that gives the required reliability for a given strength ratio.

Figure A4 shows the data in Table A1 as the green points and *equation A2* as the gold line. A simplification adopted *equation A3* as the blue line. The simplification of this relationship is very close to the values taken directly from Table A1.

Equation A1 implies that $r_{i,A}$ and $r_{i,B}$ are precisely known values for all of the graded product in service. However, they have been obtained by testing samples, and have been subjected to correction for sampling error. The correction has been to lower the value of E_k and the value of $R_{k,b}$ using the sampling corrector k_s as given in AS/NZS 4063.2. In this case we need to be sure that the production is stiffness-limited in spite of any accidental bias that has been caused by sampling error or other sources of uncertainty.

The equation needs to reflect the uncertainty of the data that developed it. Figure A1 shows that the spread of data about the line of best fit was around 0.1 in a maximum R^2 of around 0.8. This indicates that only one significant figure is justified. *Equation A2* is then modified to produce *equation A3* which has the critical point of strength ratio of 1 giving R^2 =0.4:

$$R^2_{\text{lim}} = 1.4 - \frac{r_{i,B}}{r_{i,A}} \qquad \textit{equation A3}$$

This represents a concession on the correlation required for strength, and so in order to apply it to grading for a long period of time, there needs to be a high level of confidence that the production will be stiffness-limited over a long period of time, and that the data does not represent an unusual situation that existed at the time that the qualification sample was drawn. In order to achieve this level of confidence, all uncertainty must be accounted for:

- $r_{i,B}$ is found from the characteristic strength in either bending or tension (whichever property is selected as the indicator property that will be monitored in verification). It has uncertainty because while it represents a population, it was derived from a sample.
- $r_{i,A}$ is found from the characteristic property representing List A in verification. (It is likely that this will be MoE, but in any case, the V of MoE, compression strength and shear strength are quite similar.)
- There may be variations in the resource over time that have not been reflected in the samples drawn.

Sampling uncertainty only reflects the difference in properties of the sample with the population from which the sample was drawn. It still only reflects a snapshot in time, and other uncertainty must be introduced to represent variations in time.

In evaluating the uncertainty of a ratio, the uncertainty of the quotient and the divisor are added. The total uncertainty in the ratio is the sum of the uncertainties indicated as the three dot points above: $V_B + V_A + 0.08$. Here the coefficient of variation between batches is estimated at 0.08 as representative of machine graded softwood, and the top end of variability expected in machine graded hardwoods.

The 95% confidence lower limit associated with the strength ratio in *equation A3* can be taken as:

$$\frac{r_{i,B}}{r_{i,A}}\left(1 - 2.66\,\frac{(V_B + V_A + 0.08)}{\sqrt{n}}\right)$$

$$= \frac{r_{i,B}}{r_{i,A}}\left[1 - 0.38(V_B + V_A + 0.08)\right]$$

$$= \frac{r_{i,B}}{r_{i,A}}k_r$$

with $k_r = [1 - 0.38(V_B + V_A + 0.08)]$ *equation A4*

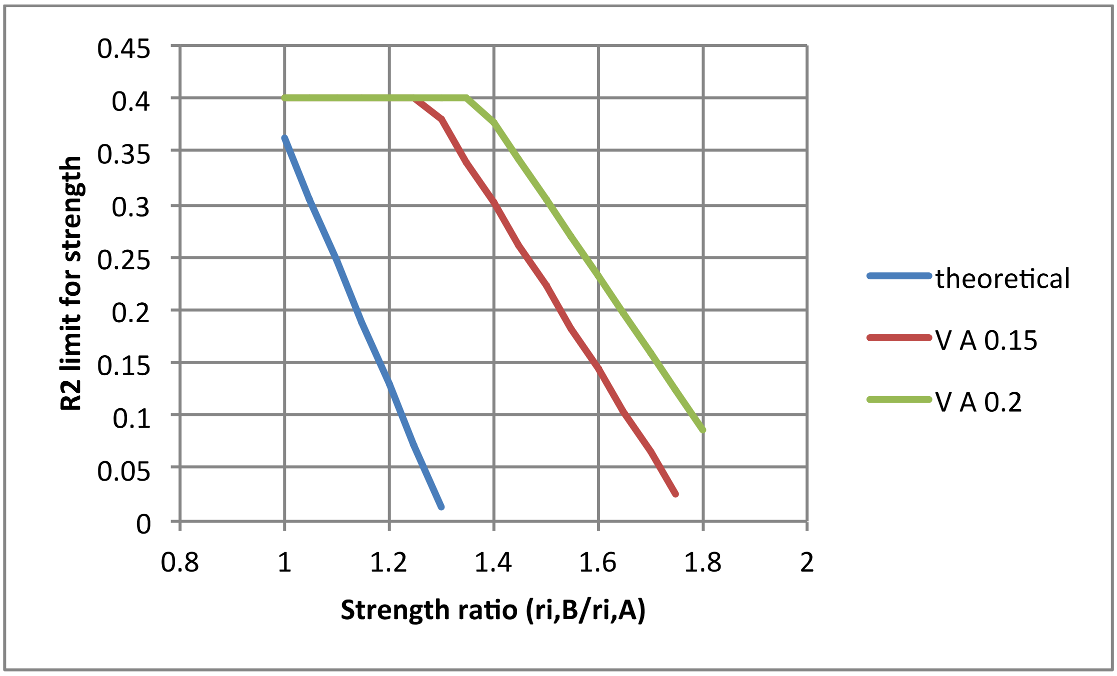
This gives a strength ratio that has a 95% confidence of being exceeded, and hence is appropriate for a reduction in correlation requirements recognizing that the product is a stiffness-limited one in the longer-term.

Hence *equation A3* can be represented by:

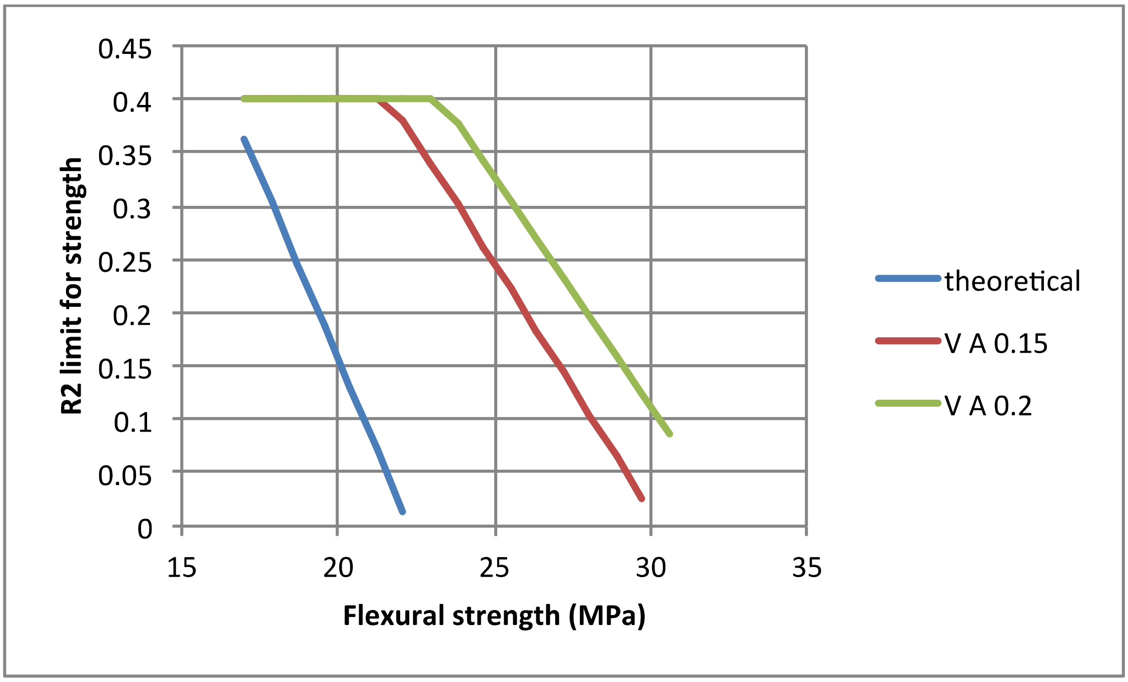
$R^2_{lim,B}$ = minimum of $(0.4,\ 1.4 - \frac{r_{i,B}}{r_{i,A}} k_r)$ *equation A5*

Figure A5(a) shows a plot of this relationship with (V_A 15% and V_B 35%) or 20% and Figure A5(b) shows how it would impact on MGP10 materials with an MoE of 10,000, but with bending strengths significantly higher than the 17 MPa new design characteristic strength.

This shows that typically for an MGP10 type product, the strength returned in the in-grade testing needs to be greater than around 23 MPa for a product with an MoE of 10,000 MPa in order to receive a concession in the required R^2 value.



(a) R^2 limit for stiffness-limited product function of strength ratio



(b) R^2 limit for stiffness-limited product function of bending strength MGP10

Figure A5 Correlation limit for stiffness-limited product

A4.2 Strength-limited production

For strength-limited production, the strength to stiffness ratio of the product is low. In these cases, the high stiffness of the product means that QC testing shows a generous margin over the design MoE, and a very small margin over the design bending or tension strength. This scenario is typical of F-graded products. It has the following implications for these products:

- QC monitoring of strength is much more important than QC monitoring of MoE.
- Grade sorting is therefore critically dependent on sorting by strength and less dependent on success in sorting by MoE.
- The high margin of production MoE over design MoE is higher than 1. The logic presented in Section A4.1 indicates that there could be a concession in the R^2 required for MoE in these cases.

Determining whether or not production is strength-limited can be achieved by comparing the in-grade test results for strength and stiffness with their design characteristic values. In the qualification testing, the first series of tests performed in-grade testing for all major properties, and compared the characteristic properties evaluated from these tests with the design value by calculating the ratio *r*. For the indicator properties, this ratio has the subscript *i*.

Hence the ratio for the

- List A property (MoE) will be $r_{i,A} = \frac{E_k}{E}$ or Characteristic MoE divided by the design MoE.
- List B property (strength) will be $r_{i,B} = \frac{R_{k,b}}{f'_b}$ or Characteristic bending strength divided by the design characteristic bending strength.

Where the product is strength limited $r_{i,A}$ will be larger than $r_{i,B}$. The ratio of $\frac{r_{i,A}}{r_{i,B}}$ gives an indication of the degree to which the product is strength-limited. The higher the ratio, the more strength-limited it is.

The logic of Section A4.1 can be repeated for strength-limited production. This relies on a log-normal distribution of stiffness and uses the same target probabilities. It is recognised that while low MoE itself will not compromise safety of a structure, because MoE is taken as an indicator of compression strength and shear strength, we are using MoE to safeguard two other properties that impact structural reliability.

The design characteristic MoE is based on the average value of the distribution, so in this case complying material has an average value that is equal to the design value. Figure A6 is the equivalent of Figure A2(b), but here all of the curves meet at a probability of occurrence of 50%.

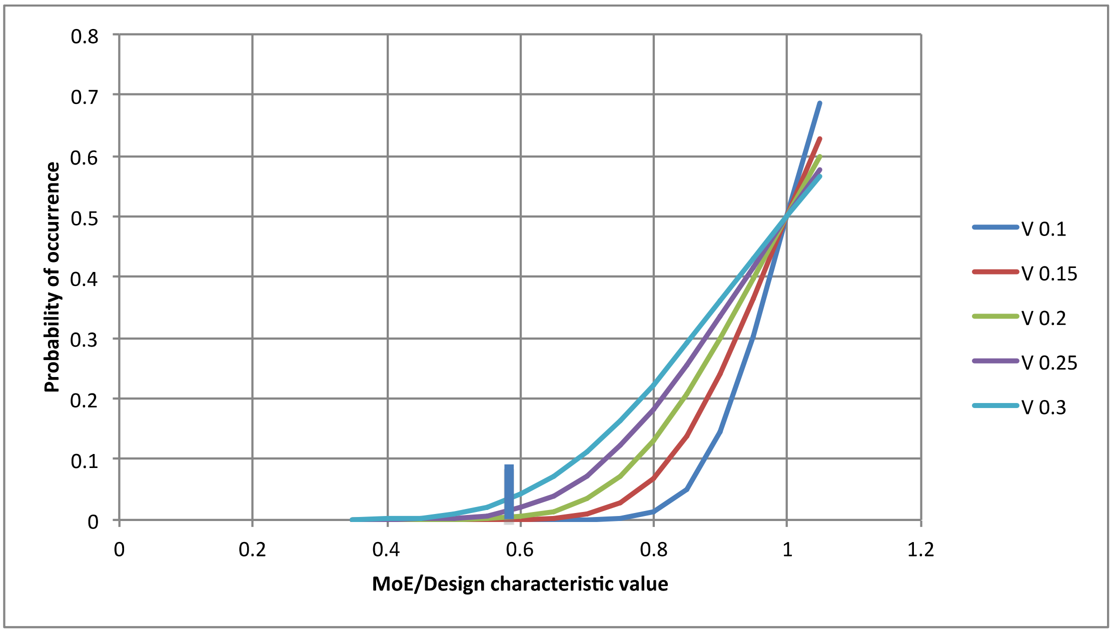


Figure A6 Normalised plot of stiffness distributions with Design MoE and different *V*s

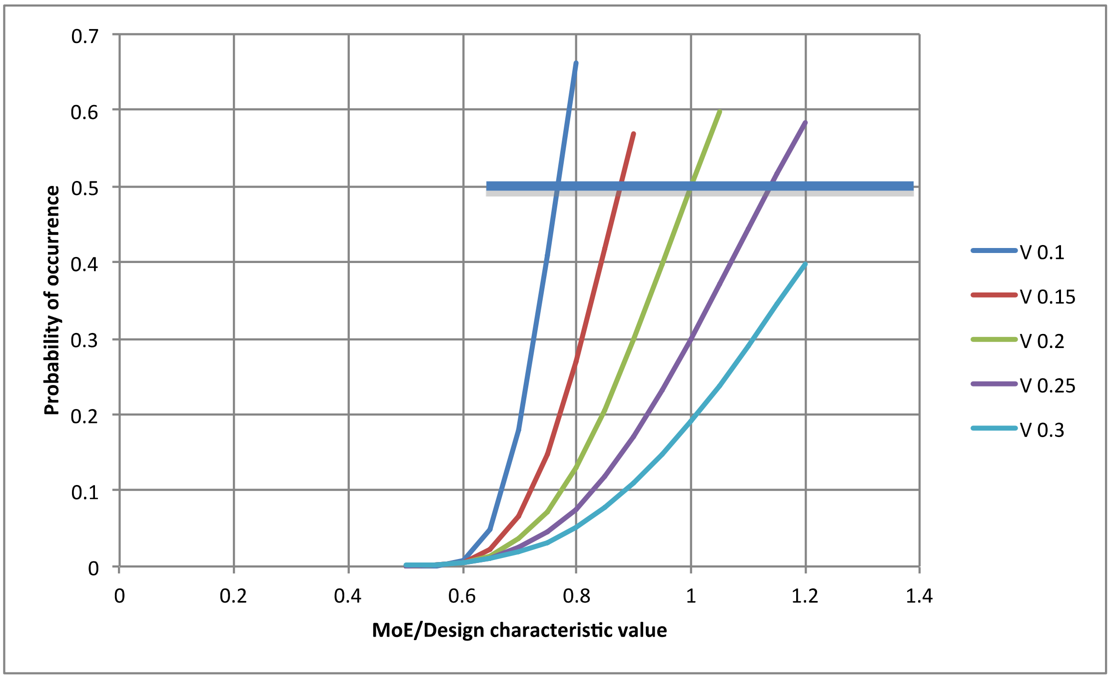


Figure A7 MoE Distributions for different *V*s with consistent reliability at the calibration point

The distributions in Figure A6 can then be shifted to match the reference curve (V = 0.2) at a probability of 0.0035 which was needed to protect the reliability of designs. In this case, the stiffness ratio at this probability was 0.586, so Figure A7 shows displacement of the curves in Figure A6 so that they all align at a stiffness ratio of 0.586 and a probability of 0.0035.

Figure A7 shows that like the strength distribution in Figure A3, the target MoE to deliver material with consistent reliability is a function of the V of the MoE. Higher

than standard *V*s require more conservative MoE to safeguard compression and shear strengths.

The required values are shown in Table A2 and this leads to a linear relationship between *V* and the required average MoE ratio in order to satisfy target reliabilities. The relationship can be approximated by:

$$\text{MoE ratio} = 2.631\,V + 0.49 \qquad \textit{equation A6}$$

Table A2 Relationships between *V*, required MoE ratio and R^2 with grading parameter

V	0.1	0.15	0.2	0.25	0.3
MoE ratio from Figure A7	0.767	0.876	1.000	1.139	1.294
MoE ratio from *equation A6*	0.752	0.884	1.015	1.147	1.278
R^2 from Figure A1(b)	0.81	0.68	0.56	0.43	0.30

Here the ratio $\frac{r_{i,A}}{r_{i,B}}$ gives the MoE ratio referred to above and in Table A2.

The MoE ratio in Table A2 is the MoE required to offset an increase in *V* above the standard value used to find the capacity factor for compression and shear strength. The R^2 is the coefficient of determination between MoE and grading parameter expected for the same *V*. The two can be related by *equation A7*. In this case, the MoE ratio has been replaced by $\frac{r_{i,A}}{r_{i,B}}$.

$$R^2_{\text{lim}} = 1.54 - 0.96\,\frac{r_{i,A}}{r_{i,B}} \qquad \textit{equation A7}$$

With R^2_{lim} as the limiting coefficient of determination that gives the required reliability.

Again, this equation implies that $r_{i,A}$ and $r_{i,B}$ are true values. However, they have been obtained by testing samples and have been subjected to correction for sampling error. The correction has been to lower the value of E_k and the value of $R_{k,b}$ using the sampling corrector k_s as given in AS/NZS 4063.2. In this case we need to be sure that the production is strength-limited in spite of any accidental bias that has been caused by sampling errors and other sources of uncertainty.

The precision of the figures in *equation A7* should be reduced to recognize the confidence in the significance of the data. Ensuring that the point $R^2 = 0.6$ at MoE ratio of 1, and rounding the constants in the equation gives *equation A8* which is the basis of the concession recommended for the standard.

$$R^2_{\text{lim}} = 1.6 - \frac{r_{i,A}}{r_{i,B}} \qquad \textit{equation A8}$$

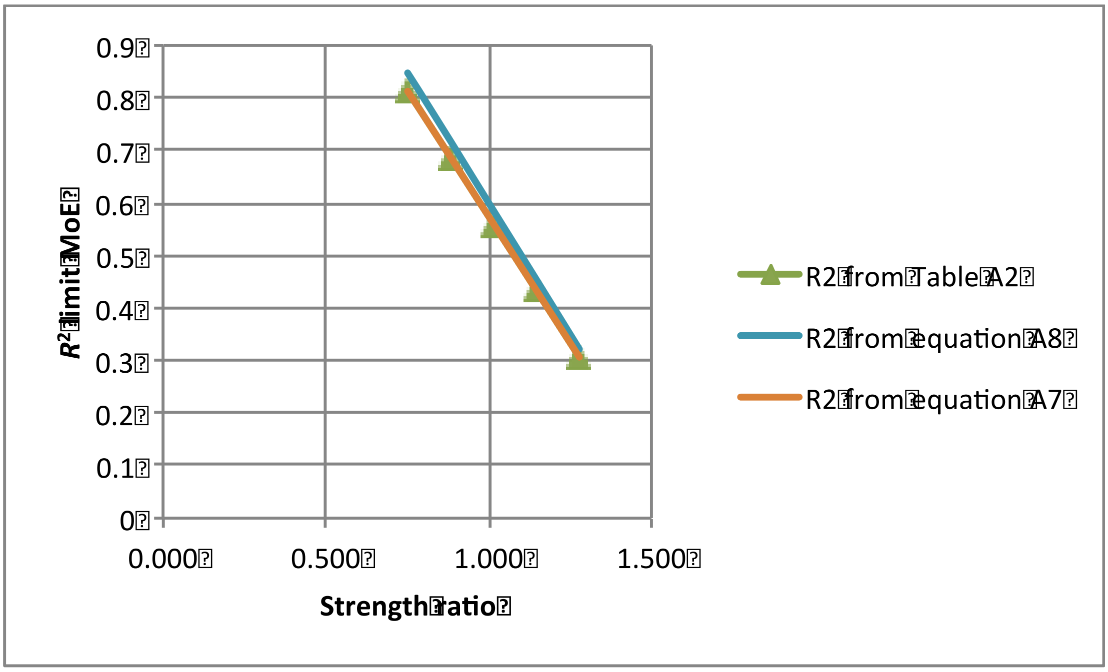


Figure A8 Approximations to R^2 for strength-limited product

Figure A8 shows that the *equation A8* approximation to the derived relationship from the data (*equation A7*) is very close. The approximation will not introduce any additional errors.

In this case, the sources of uncertainty are exactly the same as those presented in Section A4.1. Another division is performed in this ratio, and though the ratio is the inverse of that used in *equation A3*, the mathematics of allowing for the sources of error is unchanged. Therefore the statement of the limit on R^2 between MoE and the grading parameter can be represented by *equation A9*.

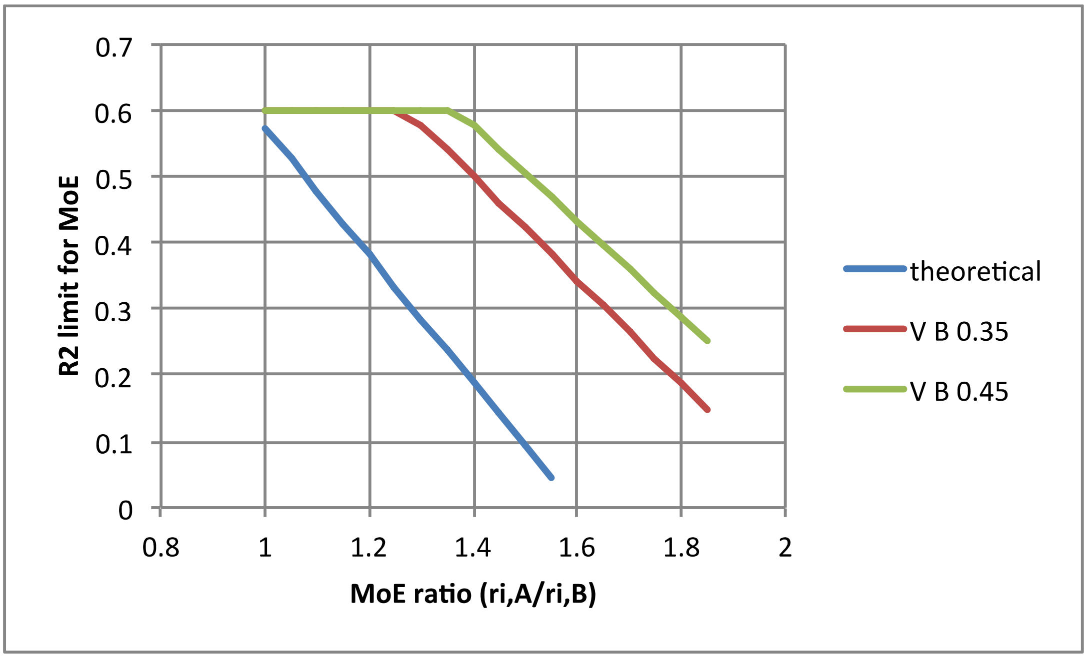
$$R^2_{\ lim,A} = \text{minimum of } (0.6,\ 1.6 - \frac{r_{i,A}}{r_{i,B}} k_r\ ) \qquad \textit{equation A9}$$

With k_r from *equation A4*.

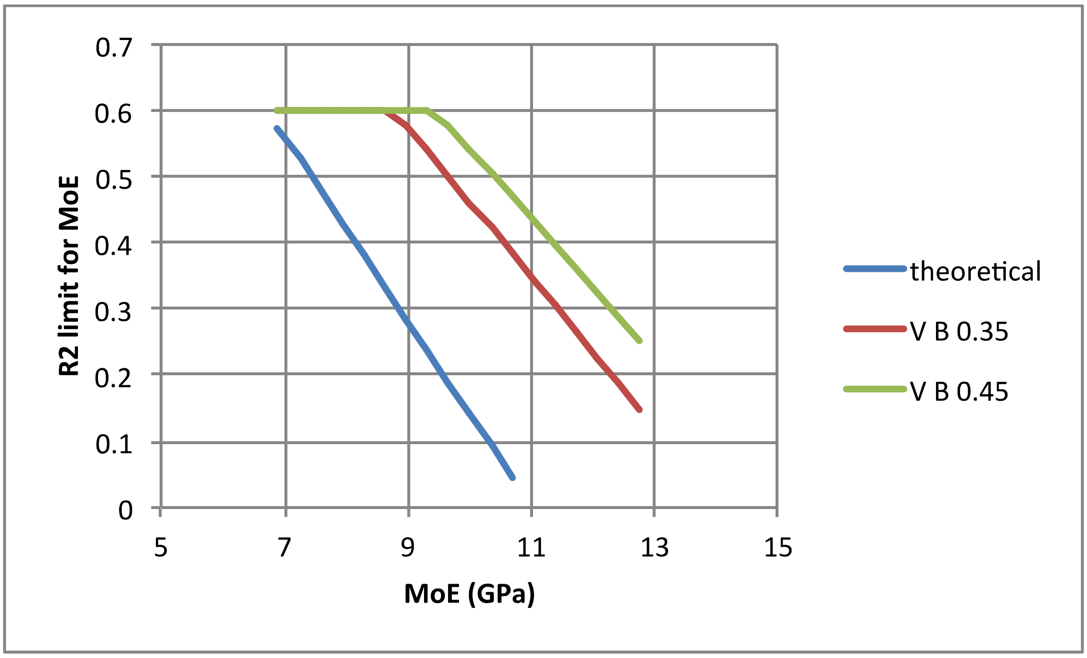
Figure A9(a) shows a plot of this relationship where V_B is typically 35% or 45% and Figure A9(b) shows how it would impact on F5 materials with a bending strength of 16 MPa, but with MoEs significantly higher than the 6.9 GPa design characteristic strength.

The curves are shown for two variations of uncertainty

- *V* of MoE 15% and *V* of strength 35%
- *V* of MoE 20% and *V* of strength 45%



(a) R^2 limit for strength-limited product function of MoE ratio



(b) R^2 limit for strength-limited product function of MoE F5

Figure A9 Correlation limit for strength-limited product

A5. Conclusions

Coefficients of determination (R^2) between indicator properties and grading parameter have demonstrated relationships with compliance with assumptions about V for reliability in limit states design.

These relationships have been used to set acceptance limits for the coefficients of determination. They are generally 0.6 for List A properties (MoE, compression strength or bending shear strength) and 0.4 for List B properties (bending strength or tension strength).

In cases, where the in-grade testing demonstrates that the product is reliably strength-limited or stiffness-limited, then concessions in these coefficients of determination are appropriate for the conservative property. This has led to the following general statements about the acceptance limits:

For List A property $R^2{}_{lim,A}$ = minimum of $\left(0.6,\ 1.6 - \frac{r_{i,A}}{r_{i,B}} k_r\right)$

For List B property $R^2{}_{lim,B}$ = minimum of $\left(0.4,\ 1.4 - \frac{r_{i,B}}{r_{i,A}} k_r\right)$

with $k_r = [1 - 0.38(V_B + V_A + 0.08)]$

These relationships are based on statistical relationships drawn from reliability studies and verification processes and have been justified by test data on bending strength and stiffness of MGP10 and MGP12 90 × 35 products. As the relationships are based on statistical processes, rather than empirically derived, they can be expected to apply to other properties and grades.

G N Boughton
TimberED Services Pty Ltd
October 2009

Appendix B Derivation of responsiveness

(Background only)

Responsiveness is the incremental increase in indicator property for a given incremental increase in grading parameter.

The derivation will be followed in detail for the responsiveness of MoE to a general Grading parameter *G*.

E.g. if the responsiveness is 0.5 then a 10% increase in the Grading parameter will produce a 5% increase in characteristic MoE.

$$\frac{\Delta E}{E} = R\,\frac{\Delta G}{G} \qquad \textit{equation B1}$$

with

ΔE	change in characteristic MoE
E	characteristic MoE
ΔG	change in average of the Grading parameter
G	average of the Grading parameter
R	Responsiveness of the MoE to mean value of *G*

In general, the characteristic value can be related to the Grading parameter using a power law as in equation B2 with A and B power law coefficients.

$$E = AG^B \qquad \textit{equation B2}$$

Rearranging *equation B1* gives

$$\frac{dE}{dG} = \frac{\Delta E}{\Delta G} = R\,\frac{E}{G} \qquad \textit{equation B3}$$

Substituting *equation B2* for *E* gives

$$\frac{dE}{dG} = R\,\frac{AG^B}{G} = RAG^{(B-1)} \qquad \textit{equation B4}$$

and differentiating *equation B2* gives

$$\frac{dE}{dG} = BAG^{(B-1)} \qquad \textit{equation B5}$$

Therefore in equating equation B4 and equation B5,

$$R = B \qquad \textit{equation B6}$$

Evaluating responsiveness of MoE then equates to evaluating the exponent in a power law fit between the Grading parameter and MoE.

By taking natural logarithms in equation B2,

$$\ln E = \ln A + B \times \ln G \qquad \textit{equation B7}$$

Equation B7 is the equation of a straight line with slope *B* and y-intercept ln *A* between ln *E* on the vertical axis and ln *G* on the horizontal axis. Thus *B* is the slope of the line of best fit through the natural logarithms of the *E* data and the natural logarithms of the *G* data.

It follows from equations B6 and B7, that the responsiveness (*R*) is the slope of the line between the ln *E* and the ln *G* data.

In this derivation, the responsiveness calculated is the responsiveness of MoE to the average value of *G* for the group. However, in practice, the average value of *G* is controlled by varying a limit on either the upper or lower end of the range of *G*. By definition of an average value, a change in ΔG of the average value of *G* must be caused by a change of 2 ΔG of either the lower or upper end of the range of *G*. So the responsiveness of *E* to a change in the grade limit of *G* will be half of the value of the responsiveness of *E* to a change in the average of *G*. This is irrespective of whether the limit is an upper limit (e.g. knot size) or a lower limit (e.g. density).

Hence the responsiveness of *E* to a change in the limit of *G* will be half of the value *R* found above. The equation for responsiveness in the standard is the expression for half the slope of the line of best fit through four points (ln G_1, ln E_1), (ln G_2, ln E_2), (ln G_3, ln E_3), (ln G_4, ln E_4).

$$\frac{4\sum(\ln G \times \ln E) - \sum \ln G \times \ln E}{2(4(\ln G)^2 - \ln G \times \ln G)} \qquad \textit{equation B8}$$

In msExcel, this value can be found by the function 0.5*SLOPE(lnGs, lnEs).
With:

lnGs the range of natural logarithms of *G* values for the four groups
lnEs the range of natural logarithms of *E* values for the four groups.

An identical derivation for responsiveness applies to the List B property.

Appendix C Excel spreadsheets

(Guidance on use of spreadsheets prepared to simplify qualification analysis)

C1. Purpose of spreadsheet

The Excel spreadsheets enable the complex analyses required for Phase I and Phase II qualification to be performed at the click of a mouse.

C2. Phase I testing spreadsheet

The Phase I testing spreadsheet performs the analyses required in Clause 6.3 of AS/NZS 1748.2:2011.

The spreadsheet is named “2101-02 Part 1 Qualification 20120109.xls”. This file must always be treated as the master copy, and any data must be entered in a renamed duplicate.

C2.1 Phase I instructions

Directions for use of the spreadsheet are located in the sheet labelled “Instructions”. The steps to be followed are:

1. Save the spreadsheet under a different name using the <File> <Save As> command.
    - Each spreadsheet may be used once only. This step is required each time the spreadsheet is used.
2. On the Summary sheet, fill in the yellow cells for each data set. Each grade for which qualification is required will need a narrow section data set. Where sizes wider than 140 mm on the wide face are produced, a wide section data set will also be required.
    - There are no spaces in the grade names (e.g. MGP10 and F8 are one word)
    - It is necessary to specify “Hwd” (hardwood) or “Swd” (softwood) to select the correct tension Design Characteristic Values.
    - The indicator strength property will normally be bending, but in some circumstances producers may select tension.

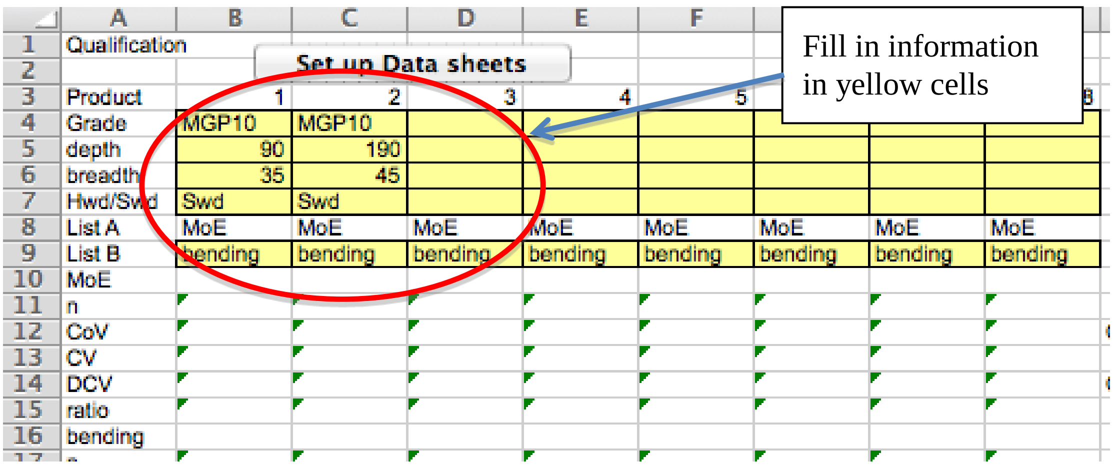


Figure C1 Screenshot of Summary sheet – enter grading information

3. Once all of the information about the test data sets has been entered into the Summary sheet, click on the button labelled "Set up data sheets".
    - This macro will set up a separate data sheet for each data set. They will be labelled "Raw data 1", "Raw data 2" etc.
    - If a debug error notification appears, this indicates that the macro is trying to create a sheet that already exists. Re-open the original file and check that the only sheets are Instructions, Summary, Output, Des Char Vals, Analysis, and Raw data. If not, delete the other sheets, and save the master copy. Then return to step 1.

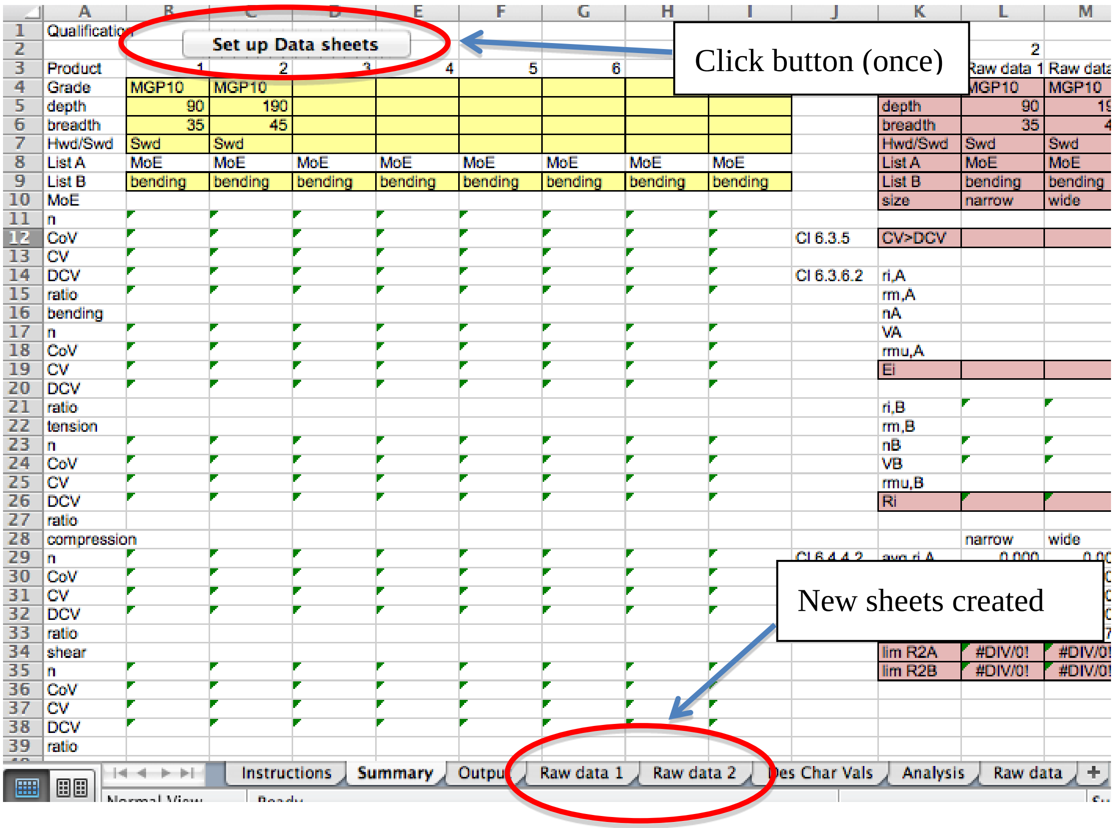
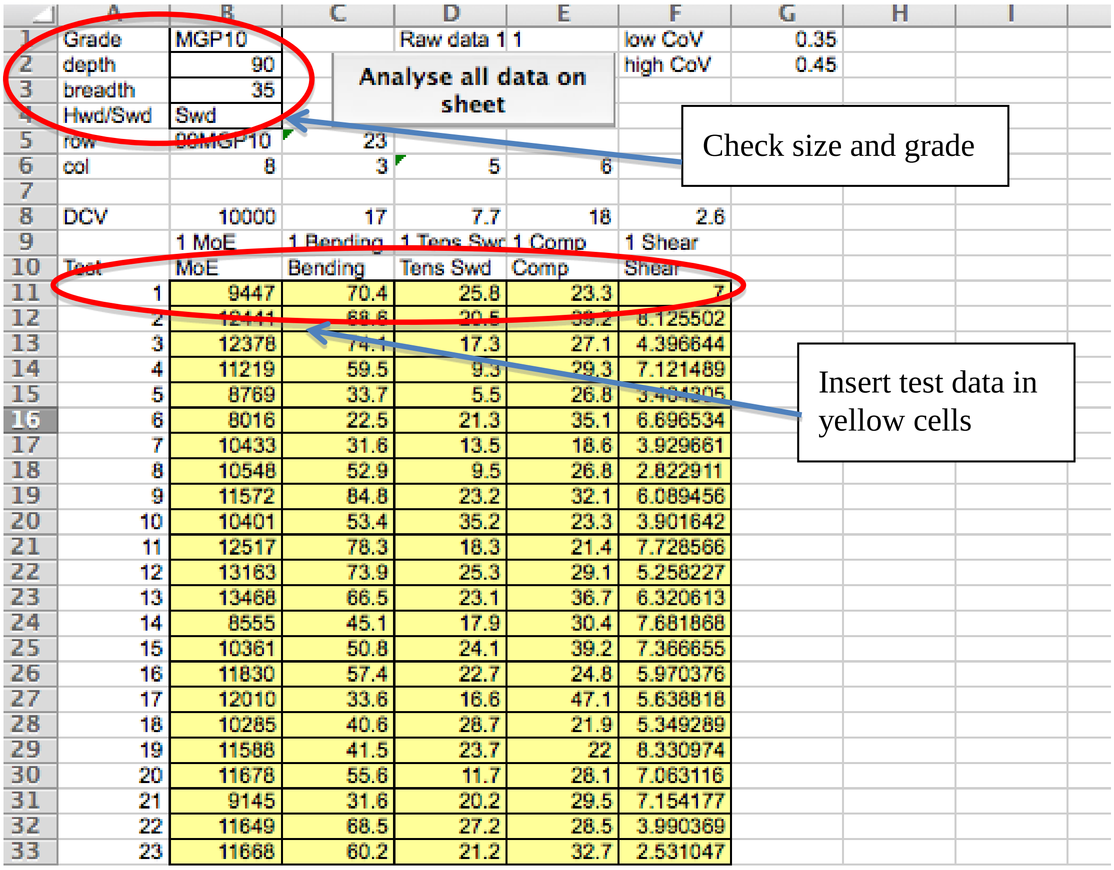


Figure C2 Screenshot of Summary sheet – run 'Set up Data sheets' macro

4. Enter all of the test data in each yellow column in the Raw data sheets.
    - The top of each sheet is already filled in, so check that the size and grade is correct.
    - Each strength and MoE should be entered in MPa.
    - The data must be entered into the correct columns, but the entries can be in any order.
    - There can be different numbers of data in each column, but there should be more than 50 data points for each property to satisfy the requirements of AS/NZS 1748.2.



	A	B	C	D	E	F	G	H	I
1	Grade	MGP10		Raw data 1	1	low CoV	0.35		
2	depth	90				high CoV	0.45		
3	breadth	35							
4	Hwd/Swd	Swd							
5	row	90MGP10	23						
6	col	8	3	5	6				
7									
8	DCV	10000	17	7.7	18	2.6			
9		1 MoE	1 Bending	1 Tens Swc	1 Comp	1 Shear			
10	Test	MoE	Bending	Tens Swd	Comp	Shear			
11	1	9447	70.4	25.8	23.3	7			
12	2	12441	68.6	20.5	39.2	8.125502			
13	3	12378	74.1	17.3	27.1	4.396644			
14	4	11219	59.5	9.3	29.3	7.121489			
15	5	8769	33.7	5.5	26.8	3.464305			
16	6	8016	22.5	21.3	35.1	6.696534			
17	7	10433	31.6	13.5	18.6	3.929661			
18	8	10548	52.9	9.5	26.8	2.822911			
19	9	11572	84.8	23.2	32.1	6.089456			
20	10	10401	53.4	35.2	23.3	3.901642			
21	11	12517	78.3	18.3	21.4	7.728566			
22	12	13163	73.9	25.3	29.1	5.258227			
23	13	13468	66.5	23.1	36.7	6.320613			
24	14	8555	45.1	17.9	30.4	7.681868			
25	15	10361	50.8	24.1	39.2	7.366655			
26	16	11830	57.4	22.7	24.8	5.970376			
27	17	12010	33.6	16.6	47.1	5.638818			
28	18	10285	40.6	28.7	21.9	5.349289			
29	19	11588	41.5	23.7	22	8.330974			
30	20	11678	55.6	11.7	28.1	7.063116			
31	21	9145	31.6	20.2	29.5	7.154177			
32	22	11649	68.5	27.2	28.5	3.990369			
33	23	11668	60.2	21.2	32.7	2.531047			

Figure C3 Screenshot of Raw data sheet – enter test data

5. Once all the data has been entered for a product, then that product can be analysed. On the Raw data sheet, click the button labelled "Analyse all data on sheet".
    - Each Raw data sheet has to be analysed separately. Check it thoroughly for errors in the data, then click the button.
    - One click will analyse each of the properties and set up 5 new sheets per data set. Do not click the button more than once.
    - The analysis sheets have plots that show the data and the lines of best fit through the data, but all of the results are summarised on the Output sheet.

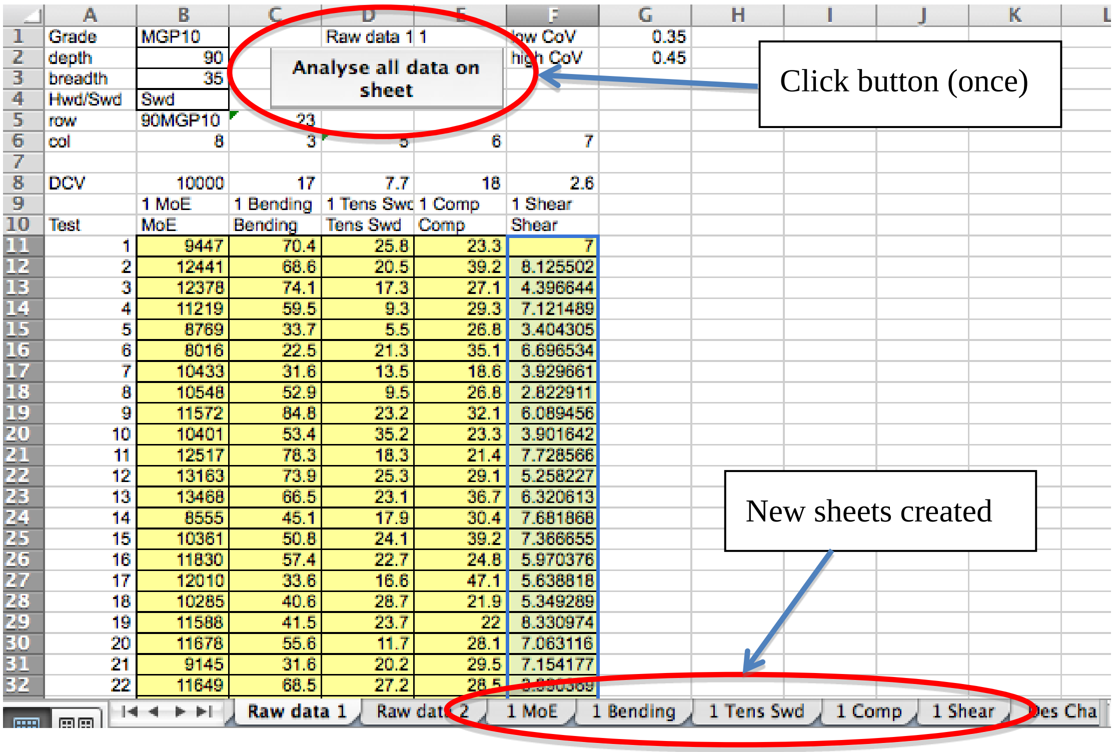


Figure C4 Screenshot of Raw data sheet – run macro

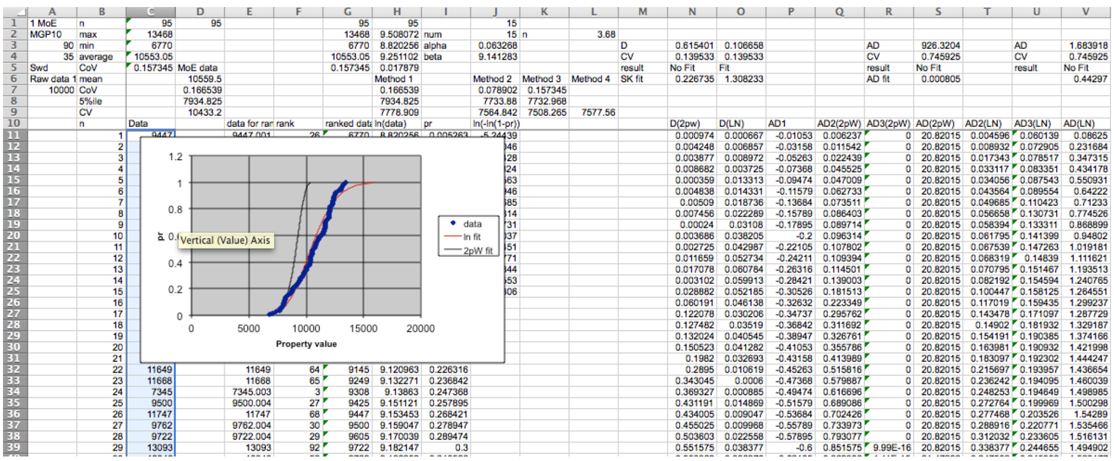


Figure C5 Screenshot of 1 MoE sheet – showing summary and plot

6. Performing the analysis puts a summary of the analysis in the Output sheet. It evaluates each property by all of the alternative methods given in AS/NZS 4063.2. At the top of the sheets is a summary of the success of each of the analysis methods for each property.
   - The 4 analysis methods for strength data (as presented in AS/NZS 4063.2) are labelled method 1 to method 4.
     - CV ratio is the ratio of the characteristic value found by the method to the design characteristic value (DCV). A higher number means Characteristic Value from test is considerably higher than the DCV.
     - %pass is the percentage of data sets that achieve the DCV. 100% is necessary and it may be that only some methods give this result.

- ○ SKFit is the Smirnov Kolmogorov goodness of fit test, a number greater than 1 indicates that fit is better than 5% significant. Only methods 1 and 2 fit a distribution to the data and use this term.
- ○ ADFit is the Anderson Darling goodness of fit test, a number greater than 1 indicates that fit is better than 5% significant. Only methods 1 and 2 fit a distribution to the data and use this term.

- Ranking combines all of the information on each method and recommends the one with the highest score.
  - ○ Colour coding is used with green highlighting a good result and red a bad one. As long as one of the goodness of fit tests has a value close to 1 or more, there is no problem.
  - ○ The yellow boxes allow you to select an analysis method for use with the rest of the program. The default value is 1.

	B	C	D	E	F	G	H	I	J	K
1										
2	Strength m	Bending	Bending	Bending	Bending	Bending	Tension	Tension	Tension	Tension
3		CV ratio	% pass	SKFit	ADFit	ranking	CV ratio	% pass	SKFit	ADFit
4	1	1.529	100.0%	1.707	0.657	2.609	1.251	100.0%	1.686	0.839
5	2	1.386	100.0%	0.840	0.121	1.163	1.035	100.0%	2.182	1.340
6	3	1.265	100.0%			1.265	1.108	100.0%		
7	4	1.275	100.0%			1.275	0.939	0.0%		
8	recommended method					1				
9	selected method					1				

	L	M	N	O	P	Q	R	S	T	U	V
2	Tension	Compressi	Compressi	Compressi	Compressi	Compressi	Shear	Shear	Shear	Shear	Shear
3	ranking	CV ratio	% pass	SKFit	ADFit	ranking	CV ratio	% pass	SKFit	ADFit	ranking
4	2.110	1.122	100.0%	3.128	2.958	3.510	1.171	100.0%	1.441	0.450	1.688
5	2.259	1.138	100.0%	0.567	0.007	0.646	1.090	100.0%	0.348	0.006	0.379
6	1.108	1.131	100.0%			1.131	1.041	100.0%			1.041
7	0.000	1.145	100.0%			1.145	1.027	100.0%			1.027
8	2					1					1
9	1					1					1

	A	B	C
10			
11		Product	1
12		Grade	MGP10
13		depth	90
14		breadth	35
15		Hwd/Swd	Swd
16		List A	MoE
17		List B	bending
18			
19		Raw Data	
20	MoE	Analysis	1 MoE
21	MoE	DCV	10000
22	MoE	Char Val	10433
23	MoE	SK fit	1.308
24	MoE	AD fit	0.443
25	MoE	check valu	1.043
26	MoE	CoV	16.7%
27	MoE	n	95

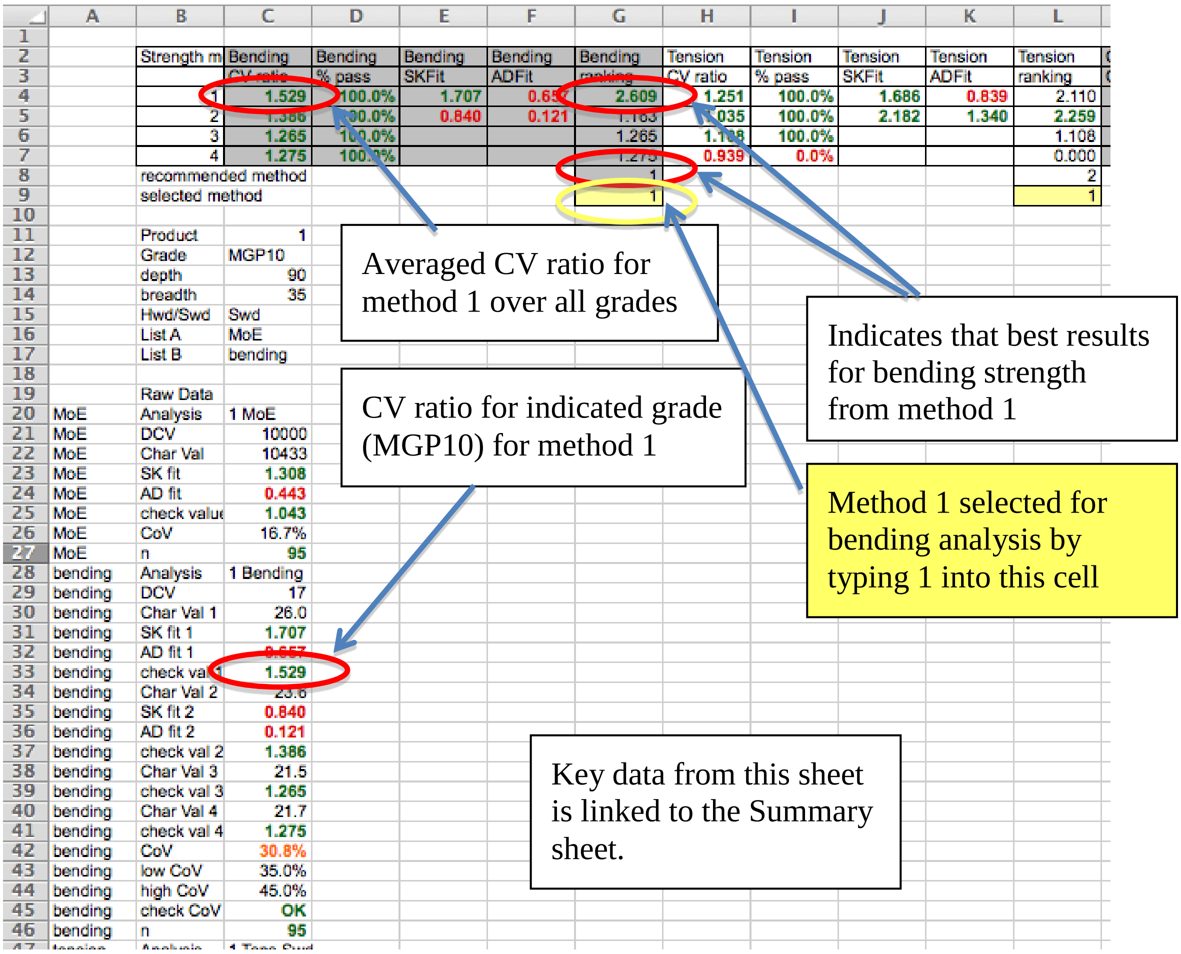
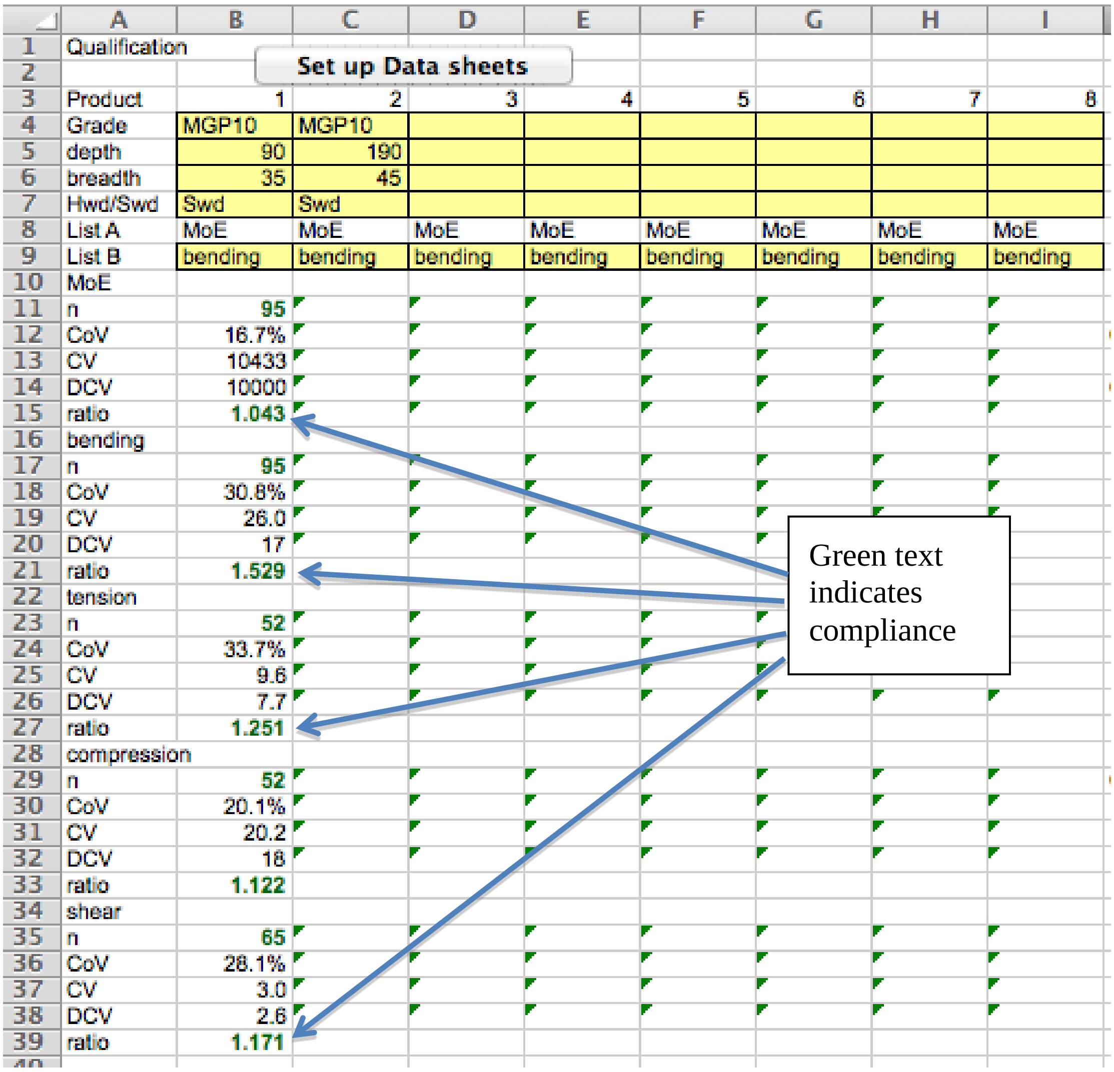


Figure C6 Screenshot of Output sheet – showing success of analysis methods

7. In the rest of the sheet, the analysis data is presented for each property and for each data set. It can be used to check for errors.
   - If the *V* is high, it will be highlighted in red. Check that the data has been entered correctly. Decimal point errors can lead to wrong data and high *V*.
   - Where fewer than 50 specimens are used, the number will be highlighted in red. The standard calls for at least 50 specimens per property.
   - Where the characteristic value is less than the Design value, the CV ratio is highlighted in red. Check the data and perhaps select a different analysis method for the property.

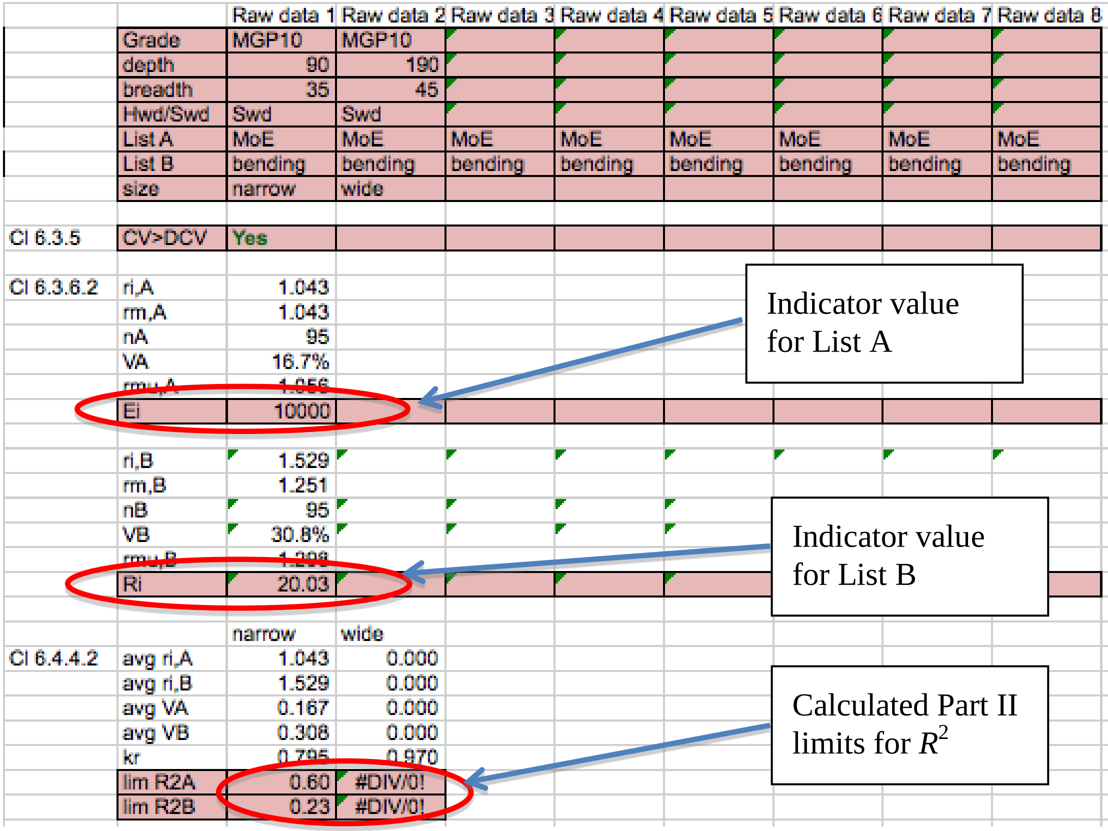
8. The final data presentation is on the Summary sheet. This has all of the information required for Testing and Analysis – Phase I as indicated in Clause 6.3 in AS/NZS 1748.2:2011.
   - The test data is summarised for each property and each data set on the left hand side of the sheet.
   - Green highlights comply with the requirements of the standard, red ones do not.



	A	B	C	D	E	F	G	H	I
1	Qualification								
2			Set up Data sheets						
3	Product	1	2	3	4	5	6	7	8
4	Grade	MGP10	MGP10						
5	depth	90	190						
6	breadth	35	45						
7	Hwd/Swd	Swd	Swd						
8	List A	MoE	MoE	MoE	MoE	MoE	MoE	MoE	MoE
9	List B	bending	bending	bending	bending	bending	bending	bending	bending
10	MoE								
11	n	95							
12	CoV	16.7%							
13	CV	10433							
14	DCV	10000							
15	ratio	1.043							
16	bending								
17	n	95							
18	CoV	30.8%							
19	CV	26.0							
20	DCV	17							
21	ratio	1.529							
22	tension								
23	n	52							
24	CoV	33.7%							
25	CV	9.6							
26	DCV	7.7							
27	ratio	1.251							
28	compression								
29	n	52							
30	CoV	20.1%							
31	CV	20.2							
32	DCV	18							
33	ratio	1.122							
34	shear								
35	n	65							
36	CoV	28.1%							
37	CV	3.0							
38	DCV	2.6							
39	ratio	1.171							

Figure C7 Screenshot of Summary sheet – showing summary test data

9. On the right hand side, the red shading indicates the key outcomes.
    - If all of the tested properties for the product were equal to or greater than the Design Characteristic Value, then there is a "Yes" in line 12. This is a requirement of qualification.
    - Each grade has indicator property target values for narrow sections and for wides. These are given for the two indicator properties.
    - In order to satisfy the requirements for the coefficient of determination (R^2) in Clause 6.4, the ratios calculated in rows 34 and 35 on this spreadsheet are used.



		Raw data 1	Raw data 2	Raw data 3	Raw data 4	Raw data 5	Raw data 6	Raw data 7	Raw data 8
	Grade	MGP10	MGP10						
	depth	90	190						
	breadth	35	45						
	Hwd/Swd	Swd	Swd						
	List A	MoE	MoE	MoE	MoE	MoE	MoE	MoE	MoE
	List B	bending	bending	bending	bending	bending	bending	bending	bending
	size	narrow	wide						
Cl 6.3.5	CV>DCV	Yes							
Cl 6.3.6.2	ri,A	1.043							
	rm,A	1.043							
	nA	95							
	VA	16.7%							
	rmu,A	1.056							
	Ei	10000							
	ri,B	1.529							
	rm,B	1.251							
	nB	95							
	VB	30.8%							
	rmu,B	1.298							
	Ri	20.03							
		narrow	wide						
Cl 6.4.4.2	avg ri,A	1.043	0.000						
	avg ri,B	1.529	0.000						
	avg VA	0.167	0.000						
	avg VB	0.308	0.000						
	kr	0.795	0.970						
	lim R2A	0.60	#DIV/0!						
	lim R2B	0.23	#DIV/0!						

Figure C8 Screenshot of Summary sheet showing key outcomes

C2.2 Phase I outcomes

The main purpose of the analysis is to obtain the indicator property target values of E_i (indicator value for list A properties) and R_i (indicator value for List B properties). These values are used in Verification.

They are found on the Summary sheet along with all values required by AS/NZS 1748.2 Table 6.3.2.

C3. Phase II testing spreadsheet

The Phase II testing spreadsheet performs the analyses required in Clause 6.3 of AS/NZS 1748.2:2011.

The spreadsheet is named “2101-02 Part 2 Qualification 20120109.xls”. This file must always be treated as the master copy, and any data must be entered in a renamed duplicate.

C3.1 Phase II instructions

Directions for use of the spreadsheet are located in the sheet labelled “Instructions”. The steps to be followed are:

1. Save the spreadsheet under a different name using the <File> <Save As> command.
    - Each spreadsheet may be used once only. This step is required each time the spreadsheet is used.

2. On the Raw Data spreadsheet, write the timber size and name of the grading system into Cells B1 and B2, and delete any data in the other yellow cells.

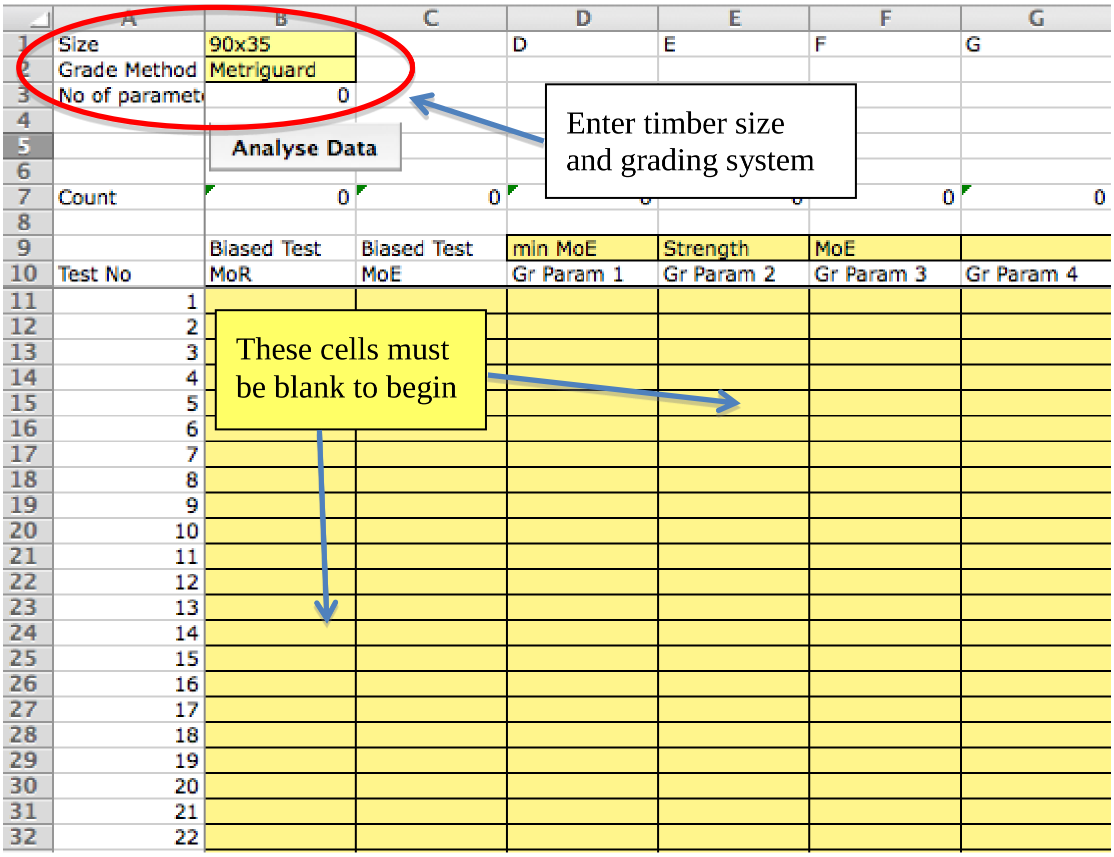


Figure C9 Screenshot of Raw Data sheet – enter size and grading system

3. Copy the test data into the yellow cells in the Raw Data spreadsheet.
    a. The columns are important. Column B must have the MoR biased test data and Column C the MoE (biased or random) test data.
    b. Write the name of the grading parameter into the yellow cells in row 9 in the Raw Data spreadsheet.
    c. A grading parameter is any measurement or calculated value used in assigning a grade to the timber (e.g. KAR, local MoE, average MoE, predicted strength, predicted MoE).
    d. Each grading parameter must be the parameter that refers to the test location on the piece. Where there is only one value per piece, that value also applies to the test location.

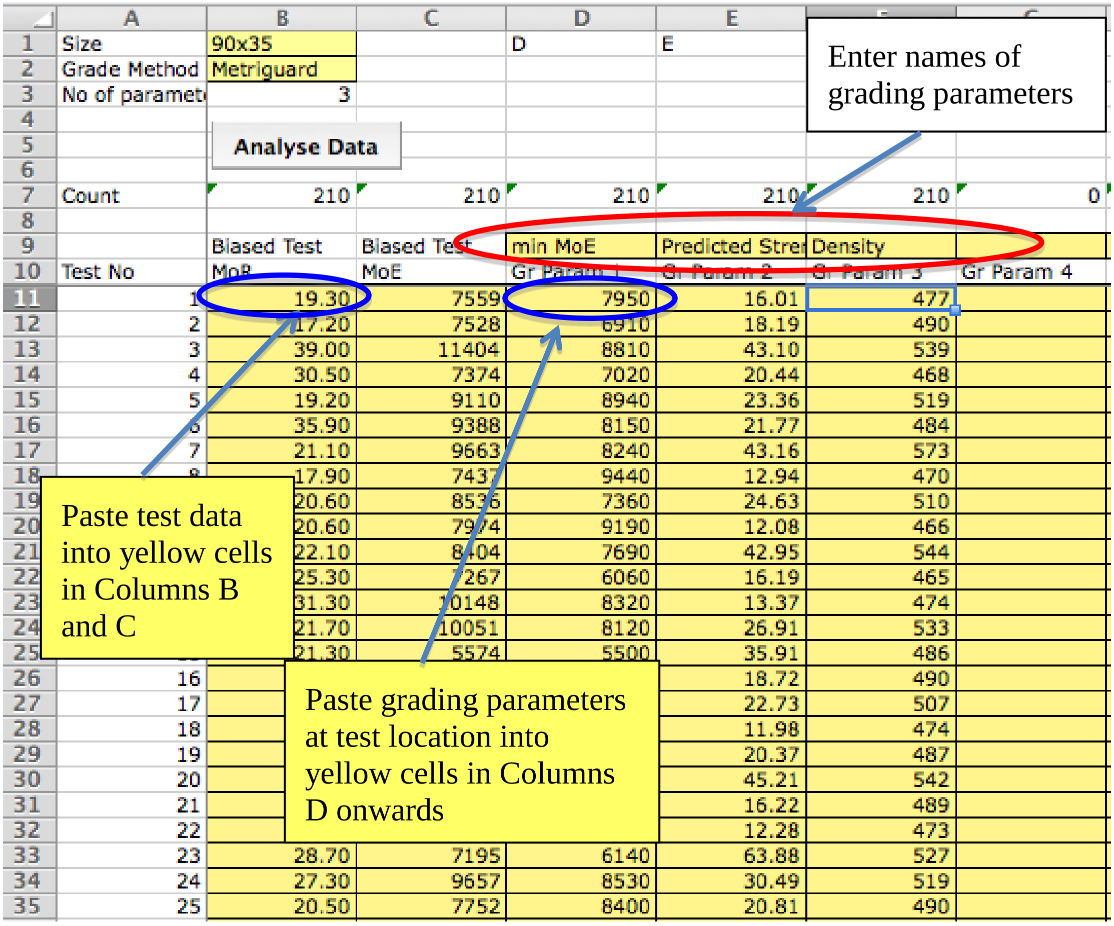


Figure C10 Screenshot of Raw Data sheet – enter test data

4. Click on the “Analyse Data” button on the Raw Data sheet. This will run a macro that will perform all of the analyses. Do not press the button more than once.
    a. The macro will create a new sheet for each grading parameter and perform the regression and responsiveness analysis on that grading parameter.
    b. Data will be transferred to the Summary sheet so that all of the results can be seen at a glance.

c. If a debug error notification appears, this indicates that the macro is trying to create a sheet that already exists. Re-open the original file and check that the only sheets are Instructions, Summary, Raw Data, Analysis, and Plots. If not, delete the other sheets, and save the master copy. Then return to step 1.

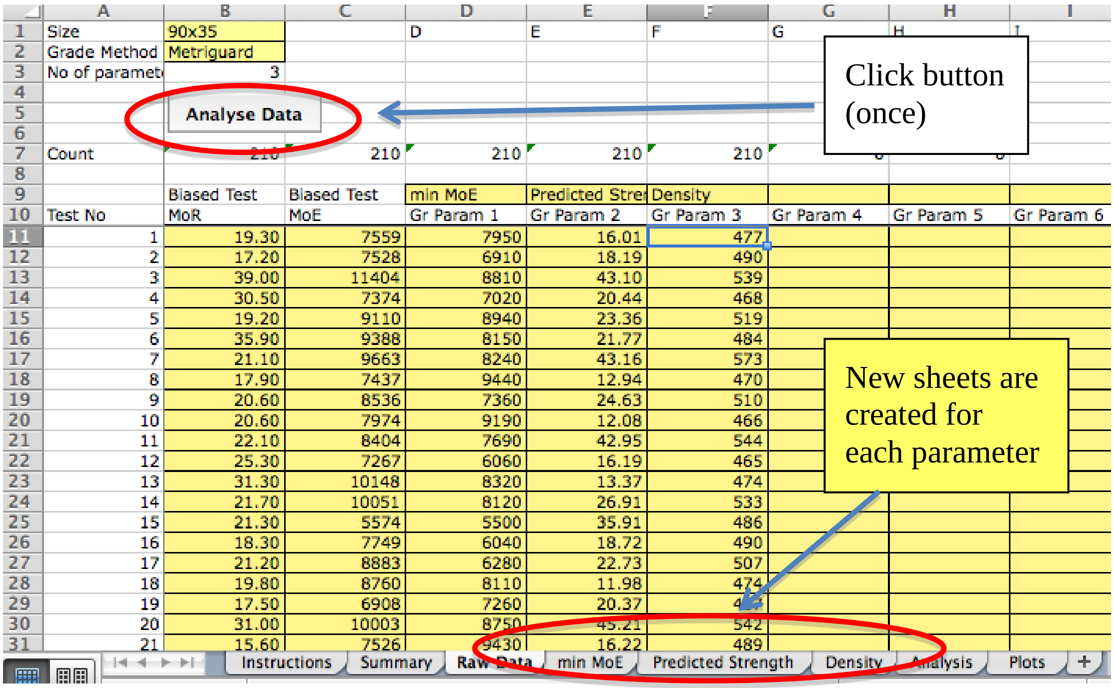
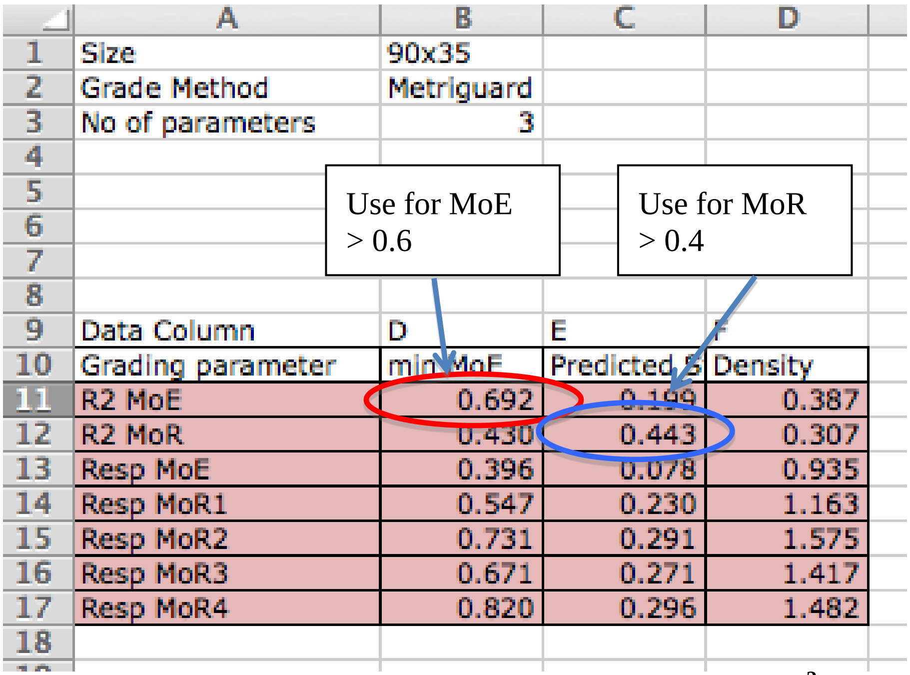


Figure C11 Screenshot of Raw Data sheet – run macro

5. On the Summary sheet, read off the results from the red shaded cells.
   a. The coefficients of determination (R^2) are presented for each grading parameter (one column per grading parameter).
   b. The sensitivity for MoE has one value as there is one method of determination of E in AS/NZS 4063.2:2010.
   c. There are 4 rows for sensitivity of MoR, one for each method of determination of characteristic value in AS/NZS 4063.2:2010.
      i. MoR1 – log-normal analysis (method 1)
      ii. MoR2 – 2 parameter Weibull tall-fit analysis (method 2)
      iii. MoR3 – non-parametric analysis (method 3)
      iv. MoR4 – ASTM D2915 non-parameteric analysis (method 4).



	A	B	C	D
1	Size	90x35		
2	Grade Method	Metriguard		
3	No of parameters	3		
4				
5				
6				
7				
8				
9	Data Column	D	E	F
10	Grading parameter	min MoE	Predicted S	Density
11	R2 MoE	0.692	0.199	0.387
12	R2 MoR	0.430	0.443	0.307
13	Resp MoE	0.396	0.078	0.935
14	Resp MoR1	0.547	0.230	1.163
15	Resp MoR2	0.731	0.291	1.575
16	Resp MoR3	0.671	0.271	1.417
17	Resp MoR4	0.820	0.296	1.482
18				

Figure C12 Screenshot of Summary sheet showing R^2 and sensitivity

C3.2 Phase II outcomes

The main purpose of the analysis is to obtain the R^2 values for MoE and MoR. They are found in the Summary sheet. The R^2 for MoE must be greater that 0.6, and the R^2 for MoR must be greater than 0.4.

The Summary sheet also indicates a sensitivity value for MoE and each method for determining MoR characteristic values. This indicates the percentage change in MoE or MoR that will result from a 1% change in the grading parameter.