

# MACHINE STRESS GRADING REVISITED

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## SUMMARY

With New Zealand's adoption of the random location testing standard AS/NZS 4063:1992 and the move to shorter tree rotations and younger age at clear-felling, the effectiveness of current machine stress grading (MSG) procedures is questioned. A known and reliable relationship between strength and stiffness forms the basis of any MSG operation. This relationship has deteriorated making the prediction of strength implicit in an MSG operation often unreliable and inefficient in terms of grade recovery. Options for improving the effectiveness of MSG on young radiata pine are examined.

## INTRODUCTION

Since 1992 the basis for evaluating the in-grade strength of timber has changed with the adoption of the new joint Australian/New Zealand Standard AS/NZS 4063:1992. The important change in this standard is that timber is tested to simulate actual use. That is the test specimen is taken at random from a length of graded timber rather than being chosen so as to contain the grade-determining defect. Historically the in-grade timber test methods used in Australia and New Zealand relied on a worst defect, worst location (biased) approach. With machine graded timber, this approach was described in the New Zealand standard NZS3618:1984. This standard requires the point of low stiffness as a plank ( $MoE_{pmin}$ ) to be positioned it in the test machine such that the obvious strength reducing defect was on the tension side.

The intention of this paper is to discuss:

*Firstly* can a machine stress grader be made to work more accurately when aligned with the random location test method and what are the implications on the machine stress grader's ability to predict strength?

*Secondly* what are the other options for improving the assigned strength properties?

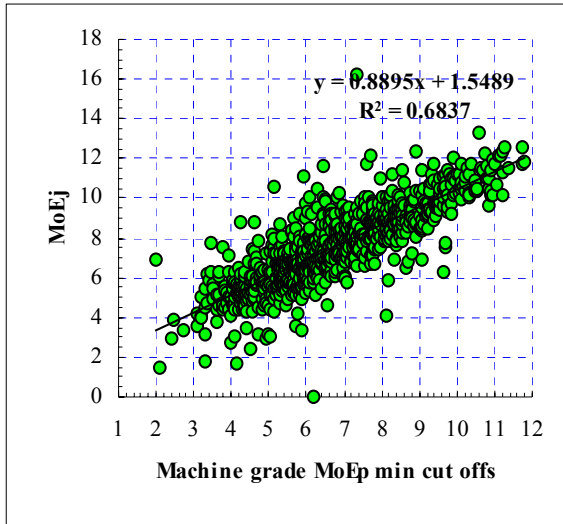
## MINIMUM MODULUS OF ELASTICITY AS A PLANK ( $MoE_{pmin}$ ) VERSUS AVERAGE MODULUS OF ELASTICITY AS A PLANK ( $MoE_{average}$ )

The change in test method away from determining grade stresses always being at the position of  $MoE_{pmin}$  (the historic biased tested approach) to a random location, raises the issue of the actual importance of this  $MoE_{pmin}$  location. Machine grading in New Zealand has, and still does, rely on the minimum  $MoE_p$  as the means for assigning a grade for the overall piece. With the  $MoE_{pmin}$  point now often being outside the test span zone, questions of its relevance in the prediction of structural properties have been raised.

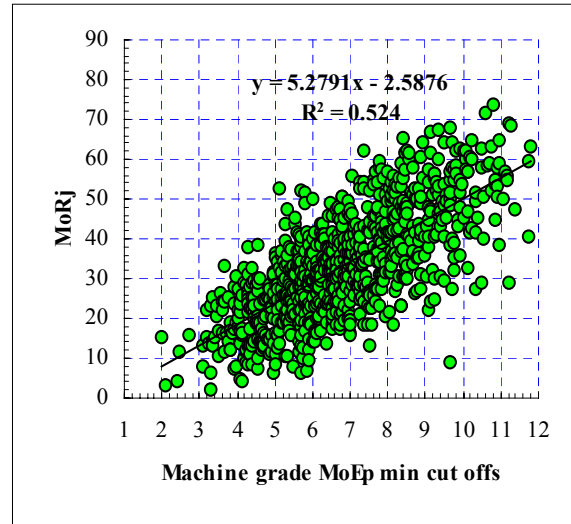
To reiterate the effect of the random test method, in reality within a six metre length of timber the  $MoE_{pmin}$  location maybe in the first 1.2m whereas the test location may well be in the last 1.8m. The net result of this separation between the  $MoE_{pmin}$  position and the test position is a deterioration in the relationship between  $MoE_{pmin}$  and the strength properties. This deterioration is readily apparent in the lower linear regression coefficients ( $r^2$ ) between  $MoE_{pmin}$  and bending stiffness ( $MoE_j$ ) and bending strength ( $MoR_j$ ). It is these regression equations that presently form the basis by which a machine grader predicts strength and stiffness from the measured  $MoE_{pmin}$ . Figures 1, 2, 3 & 4 show these differences:

- Figures 1 & 2 showing the relationships between  $MoE_{pmin}$  with  $MoE_j$  and  $MoR_j$  in old crop radiata pine when tested using the biased approach.
- Figures 3 & 4 show the relationships between  $MoE_{pmin}$  with  $MoE_j$  and  $MoR_j$  in 19 year old radiata pine when tested using the random defect location approach.

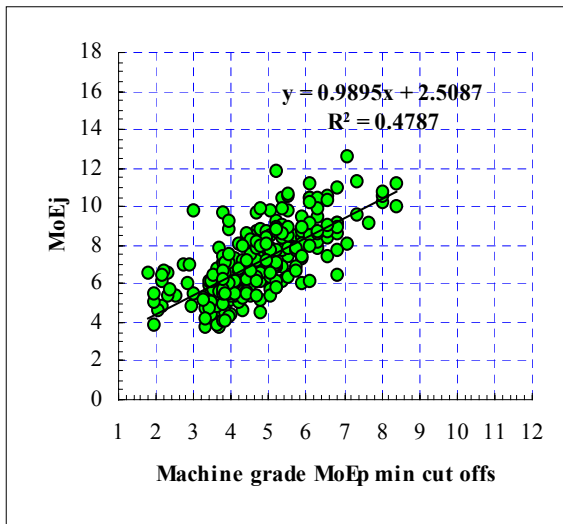
Similar relationships are found between  $MoE_{pmin}$  and the tension and compression strengths but not been included in this paper.



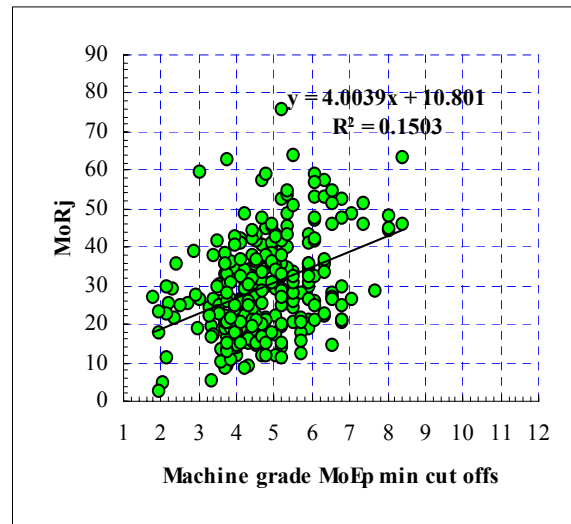
**Figure 1:** 90x45 Old crop MoE<sub>pmin</sub> vs MoE<sub>j</sub>  
Biased Testing



**Figure 2:** 90x45 Old crop MoE<sub>pmin</sub> vs MoR<sub>j</sub>  
Biased Testing



**Figure 3:** 90x45 New Crop MoE<sub>pmin</sub> vs MoE<sub>j</sub>  
Random Testing



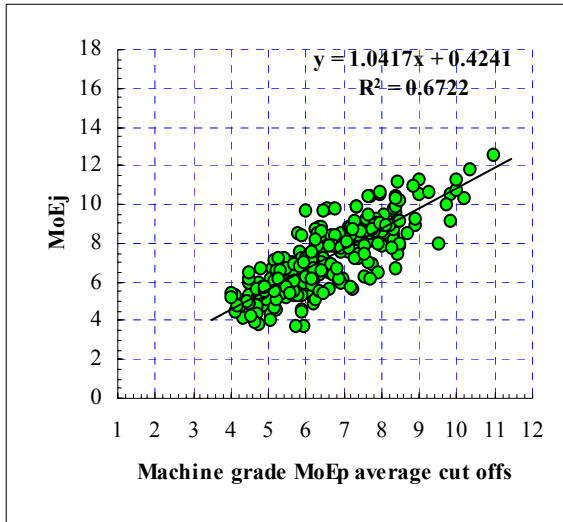
**Figure 4:** 90x45 New Crop MoE<sub>pmin</sub> vs MoR<sub>j</sub>  
Random Testing

Comparing Figures 1 & 2 with 3 & 4 shows:

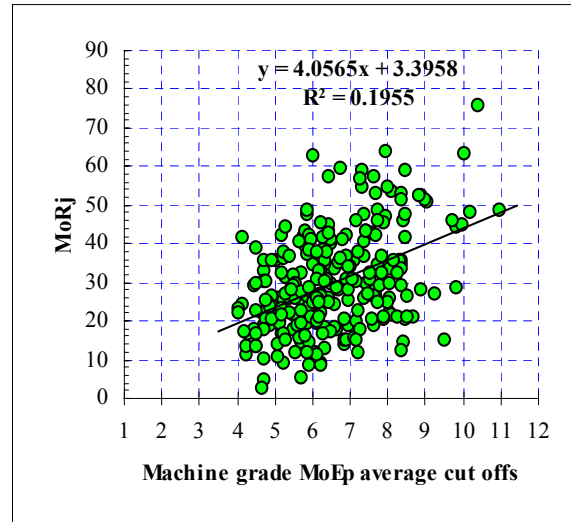
- Stronger relationships exist between MoE<sub>pmin</sub> with MoE<sub>j</sub> and MoR<sub>j</sub> in the biased test method compared to the random location test method.
- In this case for the biased test method, 68% and 52% of the variation in MoE<sub>j</sub> and MoR<sub>j</sub> respectively can be accounted for by changes in MoE<sub>pmin</sub>.
- With the random location test method, only 47% and 15% of the variation in MoE<sub>j</sub> and MoR<sub>j</sub> respectively can be accounted for by changes in MoE<sub>pmin</sub>.

Presently a machine grading operation relies on reliable relationships between MoE<sub>pmin</sub> and the other strength properties to predict the MoE<sub>j</sub> and MoR<sub>j</sub> strength properties. The type of relationships shown in Figure 4, will produce, at best, questionable predictions of the MoE<sub>j</sub> and MoR<sub>j</sub> strength properties.

It is suggested that the use MoE<sub>paverage</sub>, instead of the present MoE<sub>pmin</sub>, could be used as a means of improving the accuracy of these relationships, particularly for prediction of MoE<sub>j</sub>. Figures 5 & 6 show the same data as in Figures 3 & 4 but with MoE<sub>pmin</sub> replaced by MoE<sub>paverage</sub>. It can be noted the regression coefficient rising from 0.47 to 0.67 and 0.15 to 0.20 in the relationship with MoE<sub>j</sub> and MoR<sub>j</sub> respectively. The prediction of stiffness is improved but the prediction of strength still remains questionable. Methods to improve the prediction of strength are discussed later. Appendix A shows these relationships for both 150x50 and 250x50 sizes. Again MoE<sub>paverage</sub> is better stiffness predictor. In the 150x05 size, MoE<sub>paverage</sub> predicts strength slightly better but not so in the 250x50 size.



**Figure 5:** MoE<sub>Paverage</sub> vs MoE<sub>j</sub>  
Random Testing



**Figure 6:** MoE<sub>Paverage</sub> vs MoR<sub>j</sub>  
Random Testing

The reason proposed for the improvement in the prediction of MoE<sub>j</sub> using MoE<sub>Paverage</sub> is explained as: The random test method produces data that is considered more representative of the actual timber properties i.e. more like an average value of the actual timber properties. Thus comparing these ‘average’ test values with the average MoE<sub>P</sub> values must improve the relationship i.e. comparing like with like. Whereas MoE<sub>Pmin</sub> is a minimum value and will not relate well the average timber stiffness.

The poor relationship that exists between MoE<sub>Paverage</sub> and MoR<sub>j</sub>, which continues to seriously compromise the ability of a machine stress grade to predict strength from MoE<sub>P</sub>.

It is accepted however that with adjustments to the machine grader (MoE<sub>P</sub>) cut off settings it is still possible to sort timber into grades of timber in which all the strength properties are achieved. However this is hopelessly inefficient as raising the cut off limits using the type of regressions in Figures 4 or 5 relegates a lot of acceptable timber to the reject pile. Table 1 shows this effect on our 19 year old timber sample when sorted by MoE<sub>Pmin</sub> to align the strength properties with the requirements of the grades F4, F5 & F8.

In Table 1 the first band of data relates to a computer sort done using MoE<sub>Pmin</sub> that results in only the grade stiffness properties being achieved. Whereas the second band of data has similarly been sorted to ensure that all the strength properties are achieved. The net result of the two sorting methods is a dramatic reduction in the grade recoveries, as seen in the percentage recovery column. This is a direct result of the poor MoE<sub>Pmin</sub> to strength relationships. A machine grader can only measure stiffness as a plank and relies on robust strength relationships thus trying increase the strength properties by adjustment of the MoE<sub>P</sub> cut off limits must be hopelessly inefficient.

	MoE <sub>Pmin</sub> low cut off MPa	MoE <sub>Pmin</sub> high cut off MPa	MoE <sub>j</sub> GPa	Bending strength MPa	Comp strength MPa	Tension strength MPa	Percentage Recovery %	Number of pieces
<b>Only the ‘F’ grade stiffness requirements achieved</b>								
reject							9%	21
F4	3.0	4.0	6.2	10.5	17.0	4.5	53%	126
F5	4.0	5.7	7.7	13.8	20.7	7.7	38%	89
F8	5.7	10	9.2	18.0	18.1	9.2	15%	43
<b>All the ‘F’ grade stiffness and strength requirements achieved</b>								
reject							53%	147
F4	4.7	5.7	7.6	12.7	20.8	7.7	27%	76
F5	5.7	8.2	8.9	20.1	20.2	9.8	19%	54
F8	8.2	10					1%	2

**Table 1** Characteristic stresses

If the data presented thus far can be considered as the lower bound (but still fairly common) of New Zealand's current crop of radiata pine. Then relying on the abilities of the present stiffness only based machine stress graders to reliably predict strength has its problems. The next section of this paper explores two commonly promoted solutions.

### PROOF LOADING AS AN OPTION FOR IMPROVING STRENGTH

When assigning a strength to a sample of timber, the 5<sup>th</sup> percentile strength value is commonly used with some adjustment for sample size and variation. Thus by definition, it is the lower strength pieces that are more critical to assignment of strength to batch of timber. Thus removing the lower strength values should have a significant positive effect on the assigned strength values. Recognising this, proof loading was developed as means of culling out these few low strength pieces.

Proof loading can either be done in tension or bending, the timber is simply passed through the machine and if it strong enough it passes through unbroken, while the weaker pieces simply break and are thus culled out.

A computer based study has been done using the 19 data already presented Figures 3, 4, 5 & 6 and in Table 1. The study simulated a proof load grading operation using three different bending proof load levels namely 10, 12.5 and 15MPa. In applying these bending proof load criteria to the data we have assumed that those pieces with a tension stress equal to or less than half the bending proof stress would also be removed.

Table 2 shows the effect of proof loading on the characteristics strength and stiffness properties in four bands:

1. No bending proof loading
2. Bending to 10MPa & Tension 5MPa
3. Bending to 12.5MPa & Tension 6.25MPa
4. Bending to 15MPa & Tension 7.5MPa

In this case however we have sorted the timber using better predictor i.e.  $MoE_{paverage}$ .

	MoEp average low cut off MPa	MoEp average high cut off MPa	MoE <sub>j</sub> GPa	Bending strength MPa	Comp strength MPa	Tension strength MPa	Grade Percentage Recovery %	Number of pieces in grade	Percentage change in grade numbers
<b>All in Data (no pieces removed from sample)</b>									
Reject	0	4.4					3%	9	
Grade 1	4.4	6.6	6.2	10.3	17.1	7.3	56%	155	
Grade 2	6.6	7.6	7.7	13.8	20.5	5.7	18%	50	
Grade 3	7.6	20	9.1	16.6	17.5	8.6	23%	65	
<b>All data but with pieces with MoR<sub>j</sub>&lt;10MPa &amp; Tension strength &lt;5MPa removed</b>									
Reject	0	4.4					6%	17	
Grade 1	4.4	6.6	6.3	13.6	17.0	7.4	53%	148	-4.5%
Grade 2	6.6	7.6	7.7	13.7	20.5	6.4	18%	49	-2.0%
Grade 3	7.6	20	9.1	16.6	17.5	8.6	23%	65	0%
<b>All data but with pieces with MoR<sub>j</sub>&lt;12.5MPa &amp; Tension strength &lt;6.25MPa removed</b>									
Reject	0	4.46					9%	26	
Grade 1	4.46	5.26	6.4	15.6	16.9	7.3	51%	142	-8.4%
Grade 2	5.26	7.85	7.8	13.8	20.3	6.6	17%	47	-6.0%
Grade 3	7.85	20	9.1	16.5	17.5	9.4	23%	64	-1.6%
<b>All data but with pieces with MoR<sub>j</sub>&lt;15MPa &amp; Tension strength &lt;7.5MPa removed</b>									
Reject	0	4.46					15%	43	
Grade 1	4.46	5.26	6.4	17.2	16.8	8.3	47%	130	-9.7%
Grade 2	5.26	7.85	7.8	14.1	20.1	7.9	16%	45	-10.0%
Grade 3	7.85	20	9.1	18.4	17.2	9.8	22%	61	-6.2%

**Table 2** Characteristic stresses associated with different proof loading regimes

With reference to Table 2 the effect of the different proof loading regimes on the characteristic strength properties are:

- Generally no change in bending stiffness ( $MoE_f$ )
- A consistent improvement in the bending strengths particularly in grade 1, with smaller improvements in other higher grades.
- An improvement in tension strength for all the grades, with smaller improvements in other higher grades.
- No change in the compression strength.
- The percentage of pieces removed is generally greatest in grade 1 but there are significant numbers of pieces being removed from grade 2 with lesser numbers in grade 3.

For this sample several interesting features become apparent. Firstly proof loading removes low strength pieces in all three  $MoE_{Paverage}$  sorted grades. This reflects in the characteristic stresses. This effect means that pieces with a high  $MoE_{Paverage}$  can have low tension and bending strengths. The reverse is also true for those low  $MoE_{Paverage}$ . Figure 6 graphically shows this effect for bending strength.

For the data used in this example, increasing the levels of proof loading results in grade 2 having a lower bending and tension strengths than grade 1 but with a higher stiffness. This is a departure for the norm of higher grades having both higher stiffness and strength. Or could this imply that for this sample at least, that the two or three lower grades having the same characteristics strengths but different characteristics stiffnesses assigned to them.

Either way it would that proof loading will remove the lower strength pieces and does have a positive effect on strength. But when combined with machine stress grading cannot produce higher stiffness grades with corresponding higher strength when applied to timber with the variation shown in Figure 6.

## **USING A VISUAL OVERRIDE AS MEANS OF IMPROVING THE SELECTION FOR STRENGTH**

This option is one that combines the abilities of machine stress grading to sort for stiffness with visual grading to sort for strength. A machine grader is good at sorting for stiffness and poor at sorting for strength whereas visual is usually good at sorting for strength and poor at sorting for stiffness.

It is however important to look at the relationship between knot are ratio (KAR) and the two critical strengths ie.. bending and tension. Figures 7 and 8 graphically show these relationships. KAR being defined as the cross sectional area of the knot over the total timber cross section expressed as a percentage. Figure 9 shows the MKAR which is defined as average margin knot area ratio with the margins being the two outer quarters of the joist section. Figure 10 shows the lack of any significant relationship between KAR and  $MoE_{Paverage}$

From the these Figures we note the following:

1. There is a considerable range in strength for those pieces free of any knots.
2. There a general trend with increasing knot size leading to lower strength. However, particularly in the case of bending strength there is no significant relationship.
3. It is possible to have large knots giving reasonable strength and small knots giving low strength.
4. For virtually any given  $MoE_{Paverage}$  it is possible to have a range in KAR from 0% to 80%.

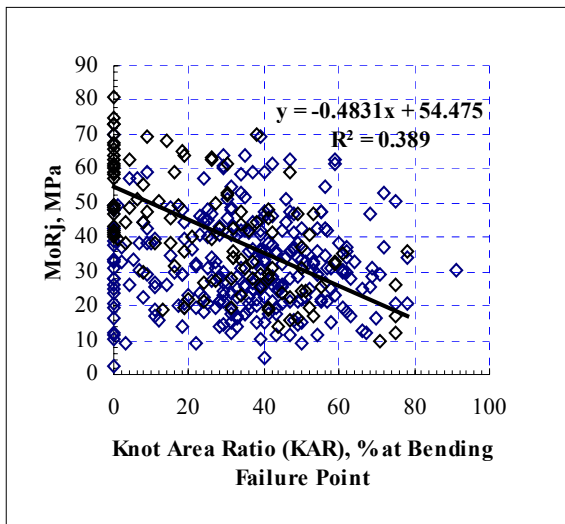


Figure 7: KAR vs Bending strength

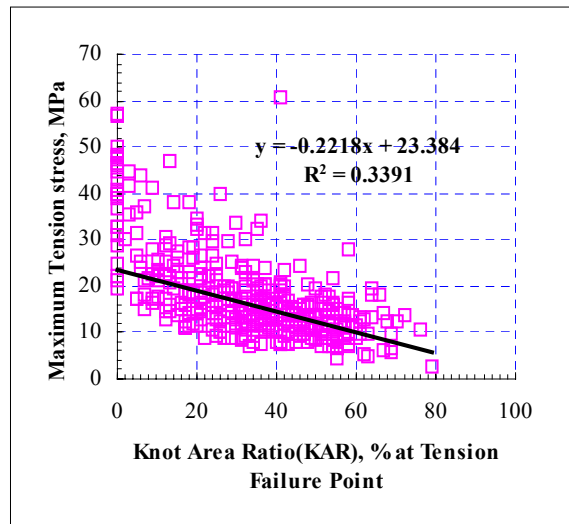


Figure 8: KAR vs Tension strength

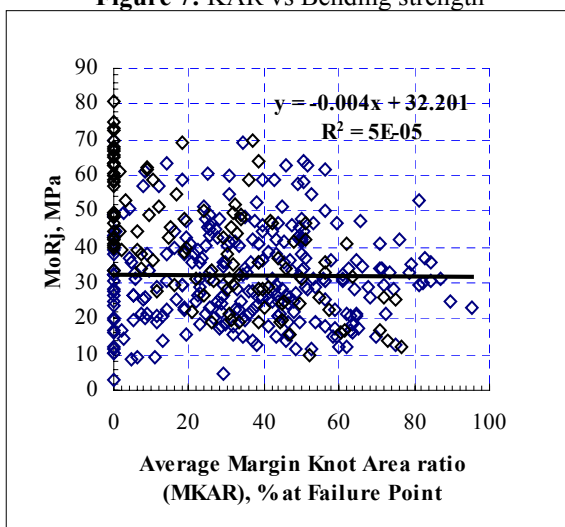


Figure 9: MKAR vs Bending strength

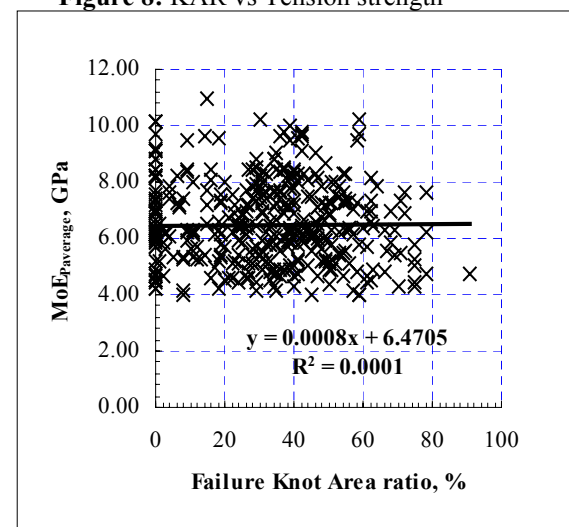


Figure 10: KAR vs MoE<sub>Paverage</sub>

In summary the data presented in Figures 7, 8, 9 & 10 indicates using KAR as an override after machine grading will be very inefficient in ensuring that the strength properties can be achieved for a particular grade.

## CONCLUSIONS

1. MoE<sub>Paverage</sub> is a better predictor of MoE<sub>j</sub> than MoE<sub>Pmin</sub>. It is recommended that MoE<sub>Paverage</sub> be used as a basis of assigning machine stress grades.
2. With the adoption of AS/NZ4063 and New Zealand's current variable resource neither MoE<sub>Pmin</sub> nor MoE<sub>Paverage</sub> predict strength with any level of confidence. As it is these relationship that a machine grader relies on, the ability of these machines to reliably predict strength must be questioned. While it is theoretically still possible to use these relationships to meet a grade strength requirement, this is at the expense of significant grade recovery reductions. Ie.. this approach relegates a lot of good timber to the reject pile.
3. Proof loading is effective at improving the assigned strength properties by removing those few strength controlling low strength pieces.
4. The positive effects of proof loading are not just reflected in the lower stiffness grades but in all stiffness grades. This effect reflects the variable nature of New Zealand's current resource. It means it is possible to have high stiffness/low strength pieces and low stiffness/high strength pieces.
5. For the sample tested, the implication is that proof testing should not only be used on the lower grades but on all grades.
6. A set of structural grades with similar strengths but different stiffnesses could be a potential solution.
7. The relationship with KAR and strength shows it is possible to have large knots giving high strength and small knots (and clear timber) giving low strength.

8. A visual override in conjunction with machine stress grading appears not to be an effective means of grading for both stiffness and strength.
9. There are other grading machines and methods that could potentially provide better sorting ie.. scanning/X-ray's and grading on edge etc, but these have not been discussed in this paper.

## REFERENCES

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APPENDIX A

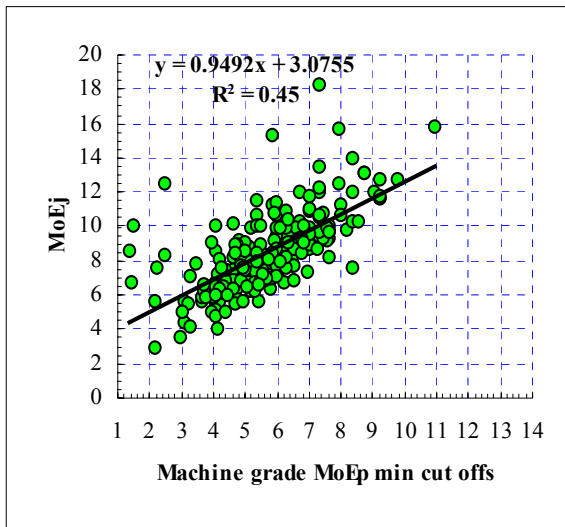


Figure A1: 150x50 MoE<sub>pmin</sub> vs MoE<sub>j</sub>  
Random Testing

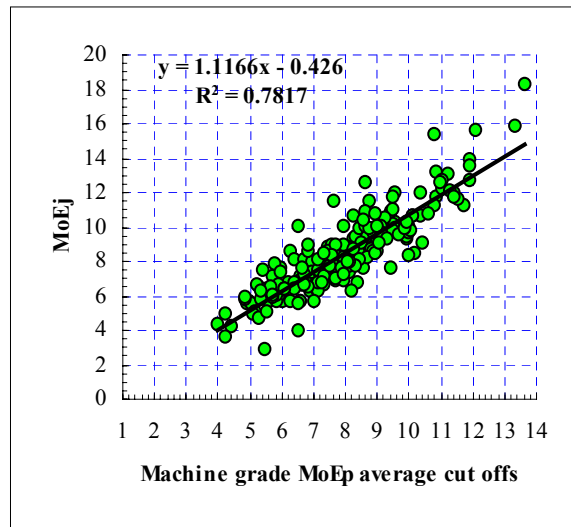


Figure A2: 150x50 MoE<sub>P average</sub> vs MoE<sub>j</sub>  
Random Testing

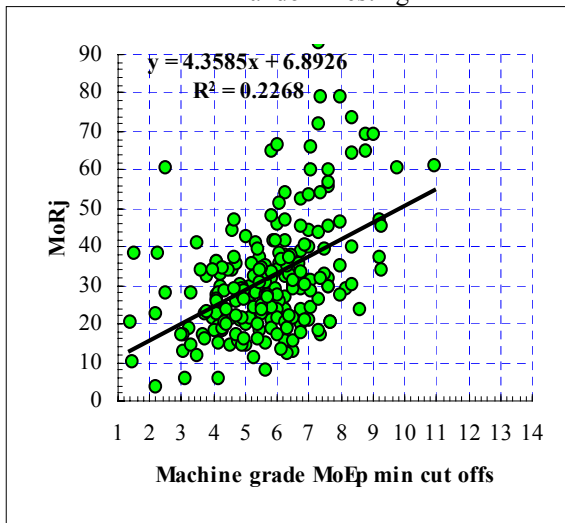


Figure A3: 150x50 MoE<sub>pmin</sub> vs MoR<sub>j</sub>  
Random Testing

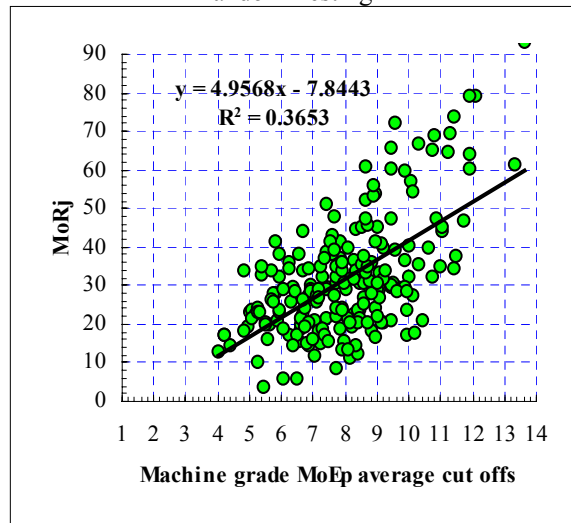


Figure A4: 150x50 MoE<sub>P average</sub> vs MoR<sub>j</sub>  
Random Testing

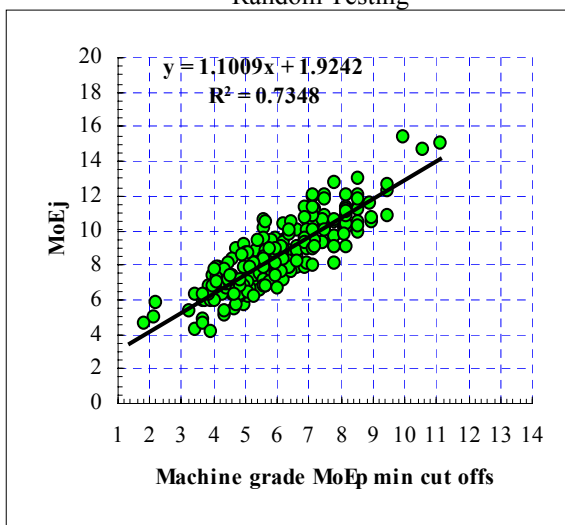


Figure A5: 250x50 MoE<sub>pmin</sub> vs MoE<sub>j</sub>  
Random Testing

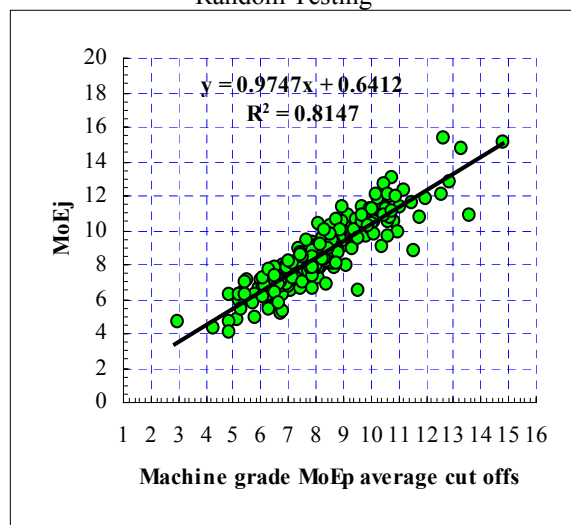
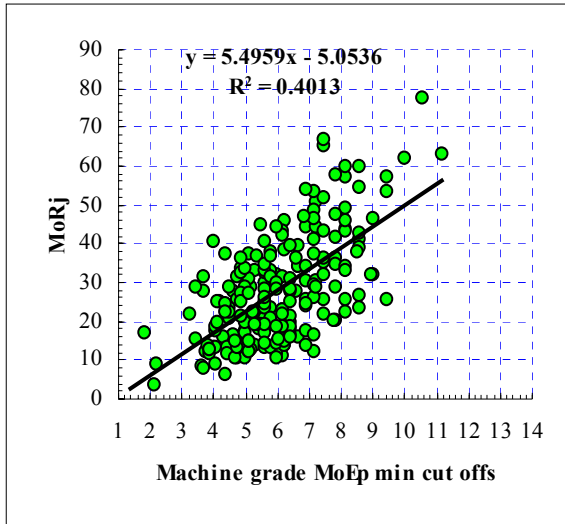
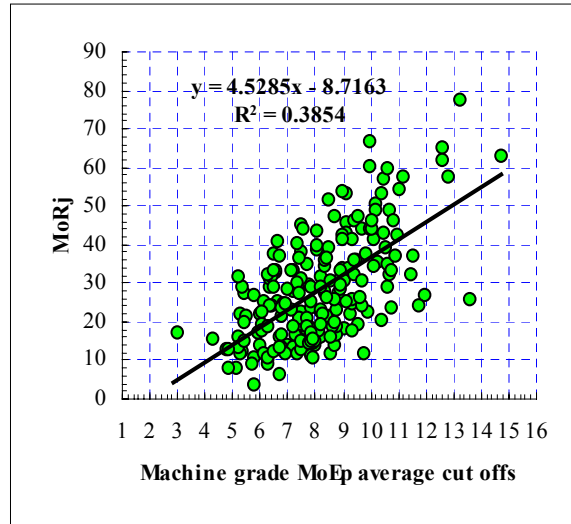


Figure A6: 250x50 MoE<sub>P average</sub> vs MoE<sub>j</sub>  
Random Testing





**Figure A7:** 250x50 MoE<sub>pmin</sub> vs MoR<sub>j</sub>  
Random Testing



**Figure A8:** 250x50 MoE<sub>paverage</sub> vs MoR<sub>j</sub>  
Random Testing