Structural performance of low grade timber slabs

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ABSTRACT: Low grade timber subject to loading exhibits a poor predictability when used in structural applications. Australia produces a large amount of low grade timber yearly which is sold at a loss due to its unreliable performance characteristics. This paper investigates the structural performance of small slab units manufactured from low grade timber when used to form a floor slab. Physical testing and finite element modeling have been used to determine the limitations of low grade timber floor slabs. The experimental work revealed that the behaviour of individual low grade timber members subjected to loading are highly unpredictable due to the presence of excessive defects within the timber. It is concluded that utilizing low grade timber in small slab units in laminated form increases the reliability of the product considerably.

1 INTRODUCTION

Australia's leading plantation timber producers are continuously milling timber for use in structural applications throughout Australia. Timber produced is graded according to its mechanical and visual characteristics which dictate the applications it can be utilised in and ultimately the profit that can be made from it. Timber that is graded less than F5 cannot be used in structural applications. Therefore, it is sold at a loss. Low grade timber contains excessive defects such as knots, resin shakes and other faults resulting in unreliable behaviour of structural elements produced from this material. The timber industry in Australia is seeking to develop technologies which can better utilize low grade timber as a structural material in building applications. The study into using low grade timber floor slabs as a realistic flooring alternative in Australia has been initiated to investigate methods of making low grade timber products profitable for timber producers.

An extensive amount of research on glued laminated timber have been reported in the literature (Brandner and Schickhofer 2008, Lee and Kim 2000, Serrano et al. 2001 and Frangi et al 2004). Recently, Paevere and MacKenzie (2006) reported a comprehensive survey and review of emerging technologies and products in timber constructions field. However, there is no previous research reporting on the characteristics of the low grade timber used in a laminated slab.

The aim of this project is to investigate the structural performance of above ground low grade timber slab flooring systems with the objective of developing methods of design and construction for such systems. This will include both stress and deflection based performance studies along with slab connection methods. The proposition was to laminate individual pieces into a slab unit to achieve a degree of structural reliability and enable it to be marketed with confidence to Australian house builders. It is proposed that several slab units are connected to construct a low grade timber slab. Some testing and analysis of this technology are required to determine if it is worthwhile to pursue this idea.

2 INDIVIDUAL MEMBER TESTING

Individual low grade timber members are expected to exhibit a low level of reliability when subjected to loading, which makes them unsuitable for use in structural applications. First, we investigated the variability in characteristics of individual low grade timber members.

Individual low grade timber samples were subjected to four point bending test. The span was selected as per AS 4063 (Standards Australia, 1992) as 18xdepth of specimen. All specimens tested have a depth 90 mm. Therefore, test span L is 18 x 90 mm = 1620 mm. Load was then applied at L/ 3 centres.

Load-deflection relationship for individual member tests are shown in Figure 1. It is seen that there is a large variation in the load-deflection relationship for individual members. The results in the figure indicate that low grade pine timber when used as individual members is very unreliable. Failure was also sudden and violent, with failures happening at a point of weakness within the sample such as in a knot or resin shake. The deflection at which failure occurred varied significantly due to the various modes of failure. Samples that exhibited a low failure deflection have failed in a sudden manner through a knot or resin filled shake which extends to the edge of the timber. The samples which failed after a large deflection initiated failure at a fault which did not extend to the edge of the timber, resulting in an increase in the deflection to force the failure crack through the tensile edge of the sample. The load required to cause failure was also dependent on the type of discontinuity at which the failure was initiated.

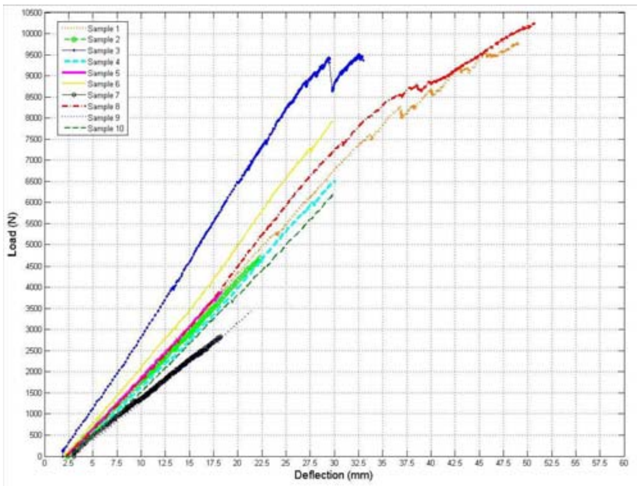

Figure 1. Load – deflection characteristics of individual low grade timber members

3 LOW GRADE SLAB UNIT TESTING

As the individual low grade timber members have shown high variability in the load-deflection behaviour, we attempted to develop a low grade timber product that has much less variability. We manufactured *slab units* consisting of twelve individual members (of 90x35 mm size) glued (or laminated) together as shown in Figure 2. The slab unit formed was 1.8 m long to allow ample span for consistency with the individual member testing and also to have room for supports during testing.

The distribution of strength grades of individual timber members within slab units tested are shown in Table 1. Note that the strength grading of individual members is done with a machine that determines the strength grade of the timber as it is passing through the mill. A member may be of a high strength rating such as MGP 15, but also contain a large stiff defect. A visual rating is undertaken to identify this defect and deems the timber to be of a low grade standard due to the issues associated with defects.

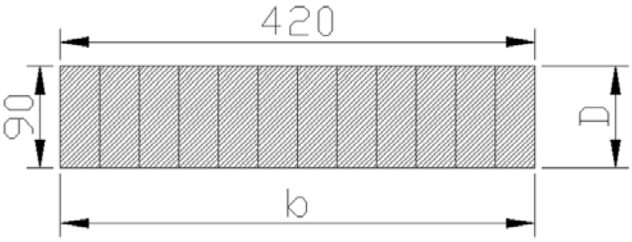

Figure 2. Low grade slab unit (Dimensions in mm)

Table 1 – Strength Grade Of Individual Members Within Slab Units Tested.

Strength grade distribution within slab units			
Individual member number	Samples 1A and 1B	Samples 2A and 2B	Samples 3A and 3B
1	F 5	F 5	F 5
2	F 5	MGP 10	F 5
3	MGP 10	MGP 10	MGP 12
4	F 5	MGP 12	MGP 12
5	F 5	MGP 10	MGP 10
6	MGP 12	F 5	MGP 12
7	F 5	MGP 10	F 5
8	MGP 10	MGP 10	MGP 10
9	F 5	MGP 15	F 5
10	F 5	MGP 12	MGP 10
11	MGP 12	F 5	MGP 10
12	F 5	F 5	F5

The slab units were tested in four point bending as in the case of individual members. The load-deflection results are shown in Figure 3. It was observed during testing that slab units showed linear elastic behaviour up to moderate loads. When load was removed slowly, the slab units returned to their original position (up to moderate loads). The slabs also gave an indication of the impending failure via creaking noises leading up to a bang which indicated one partial failure within the slab. It was noted that a defect within the timber, would fail before the laminating glue would give way.

It is seen from Figure 3 that slab units have shown consistent load-deflection behaviour despite the three variations of member strength grades and the six variations of fault distribution encountered within the test. It is also seen that, unlike in individual timber member tests, the variation in load-deflection behaviour within the six slab units is much less. From the linear portion of the load-deflection relations, we computed the modulus of elasticity for slab units. The modulus of elasticity values for six slab units fell within a very close range. In the case of individual timber tests results shown in Figure 1, the modulus of elasticity values had a wide range. The small variation in modulus of elasticity values (as indicated by the slope of load-deflections graphs) for slab units indicate that faults within twelve individual timber members have homogeneously distributed when they are laminated together.

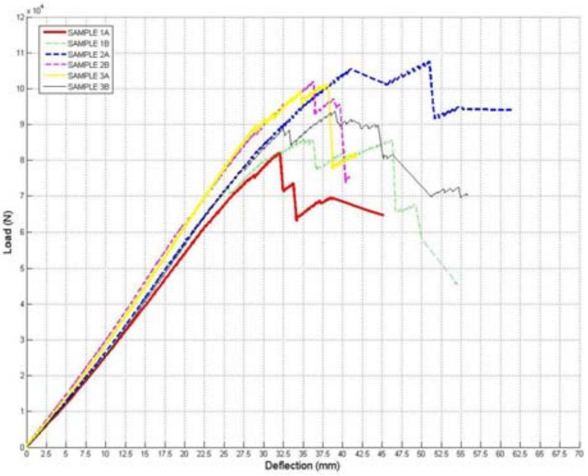

Figure 3. Load – deflection characteristics of slab units

4 FINITE ELEMENT ANALYSIS

This section will focus on the finite element analysis undertaken using Strand7 software to model the behaviour of low grade timber slab floors. From this modelling, a limiting criteria for the use of low grade timber slabs as a flooring alternative will be established. Figure 4 shows schematic diagrams of low grade floor slab and standard floor slab systems.

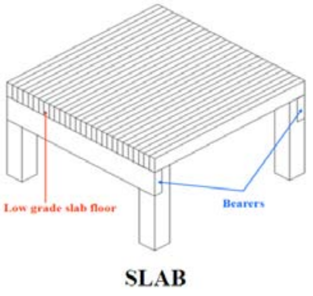

Figure 4(a)
Low grade floor slab
construction

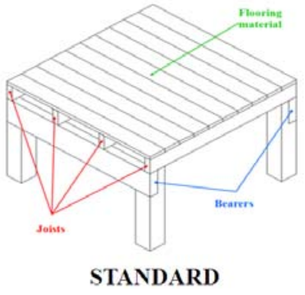

Figure 4(b)
Standard floor
construction

In order to understand the limitations of using low grade slabs as a flooring alternative, modelling was conducted to develop the deflection relationship between applied load and clear span. This information is required to develop a design chart which defines the limitations of loading based on prescribed deflection limitations.

The use of three dimensional modelling elements yields slightly different results to that of the two dimensional elements and one dimensional element models. It was found that bricks elements could be used efficiently for fast convergence in results and accuracy in stress distributions corresponding different loading patterns applied on the slab.

Figure 5 shows a comparison of finite element results for load-deflection relation with experimental results for a single slab unit (width = 420 mm, clear span = 1620 mm) simply supported over its width at both ends and loaded in four point bending. It can be seen that there are only slight differences in the modelled slab deflection and the physical test for given load values. Note that all differences in the deflection on the linear region of the graph are less than 1 mm, with the major differences between the modelled performance and the physical performance being at higher loads. This occurs where the load – deflection relationship starts becoming non-linear as can be seen around 100 kN load.

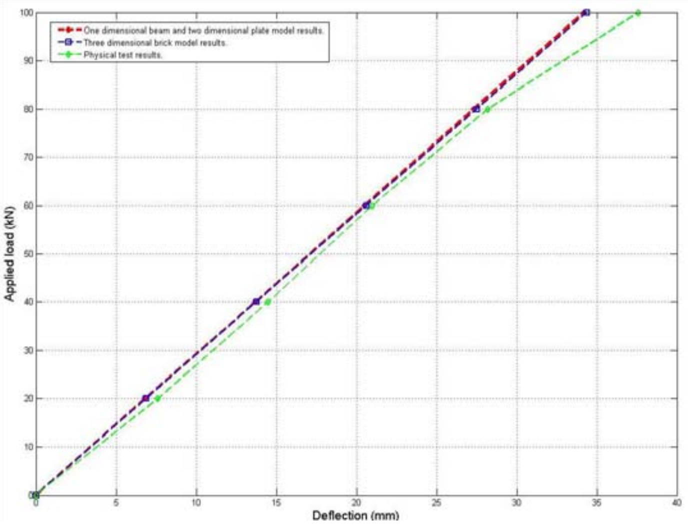

Figure 5. Comparison of Strand7 models results with experimental results for a simply supported slab unit under four point bending.

In order to demonstrate the performance of the low grade timber slabs, their structural performance was modelled with Strand7 over eight spans and six separate load cases. To ensure that the chart was representative of the slab behaviour only, the bearer was removed to eliminate the deflection it adds to the system, and the associated two way bending effects. The model was fully supported against deflection in the vertical direction (ie simply supported) in place of the bearers to ensure that only one way bending could occur within the model. Each model was made of 3.605 m wide (due to the width of the members in each slab unit being 35 mm). The design developed from finite element results is shown in Figure 6. The loads indicated on the chart are assumed to act as uniformly distributed design loads over the entire slab. Despite the design chart being generated for a 3.605 m wide slab, it is applicable for all slab widths under one way bending when subjected to a uniformly distributed load.

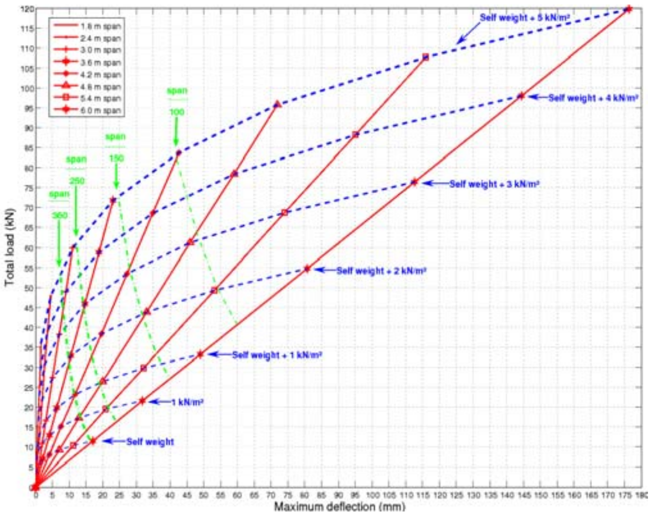

Figure 6: Deflection based low grade slab design chart.

5 SLAB UNIT CONNECTIONS

This section outlines a connections system proposed for joining slab units into a realistic size floor slab. The major force that will be present in the joint between slab units is the shear force at the joint between slab units. We aimed to have the strength of this joint exceed the strength of the glue used to laminate individual timber pieces into slab units. This presented a challenge as the strength of individual members in bending, shear and tension has been proven to be highly variable. Therefore the analysis has to be done based on the expected load range that will be applied to the slab which will not cause deflections greater than that given in the design chart in Figure 6. The chosen method of connection for this purpose is bugle head batten screws shown in Figure 7. The method of constructing the joint involved marking the centre of the second laminate in from the edge of the slab unit and drilling a countersinking hole so that the heads of the screws were just below the surface of the slab, and would penetrate to the depth shown in Figure 7.

A 4 mm pilot hole was then drilled at 30^0 to the horizontal into the slab to guide the screws in at the correct angle. The pilot hole did not extend through the edge of the slab unit. After that 125 mm long bugle head batten screws were driven into the holes and through into the adjacent slab as shown in Figure 8. Bench clamps were applied over the span of the slab to ensure that the screws pulled tight and formed a bond between the slabs equal to the screws capacity. The forces applied to the slab induce various forces within the connection as shown in Figure 8.

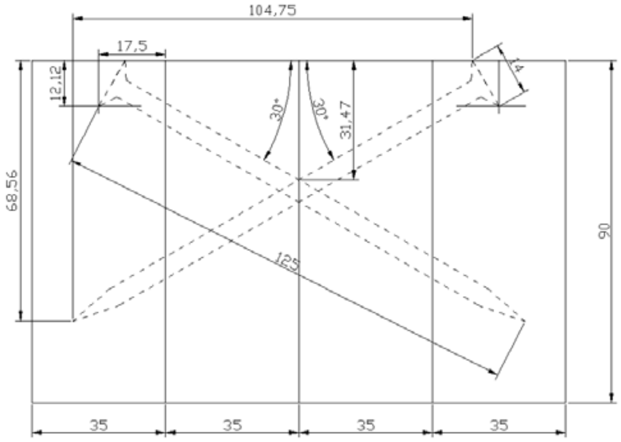

Figure 7 – Cross section of chosen connection method

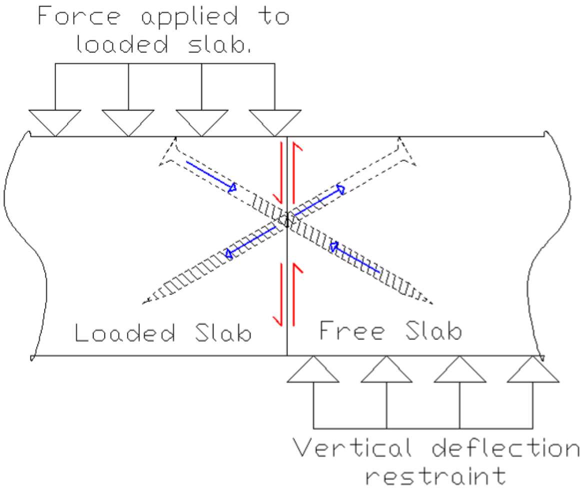

Figure 8 – Forces present within slab unit connection

5.1 *Connection testing*

Multiple methods of connection testing were undertaken to quantify the performance of the bugle head batten screws relative to the strength of the timber and glue laminations in the slab when subjected to expected force combinations. This was done by testing the connection under pure shear as shown in Figure 8, a combination of shear and bending applied to a loaded slab unit connected between two external unloaded units, as well as one loaded slab connected to one unloaded slab. From this testing it was found that the connections could be made to exceed the strength of the timber in one way bending.

Investigations were then conducted into the extents at which a single member within a slab unit could be loaded before a shear failure would occur along the glue lines. This testing revealed that the low grade timber will fail before the glue if the direction of the growth ring within the sample is not in the vertical direction. The direction of the growth rings within an individual timber specimen is dependent on the location from which it was sawn from the source log as shown in Figure 9. The shear capacity of the screws was determined to estimate the number of screws required to prevent shear failure within a connection between slab units.

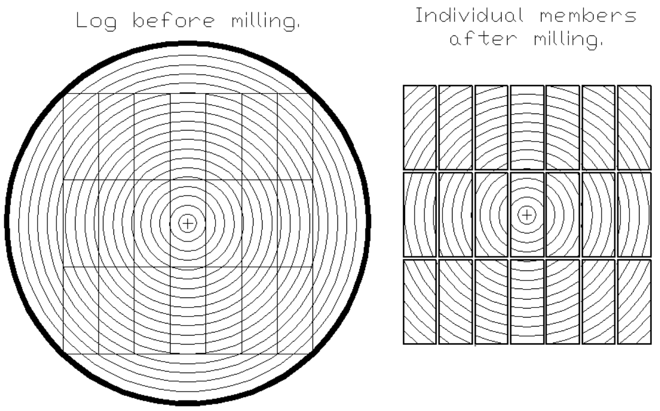

Figure 9 – Growth ring direction within individual members

The combination of results obtained from two slab (where two slab units are connected together) bending test and the three slab (where three slab units are connected together) combined shear and bending test revealed that the load deflection characteristic for the loaded slab in each experiment are nearly similar from a load of 0 kN through to 35 kN.

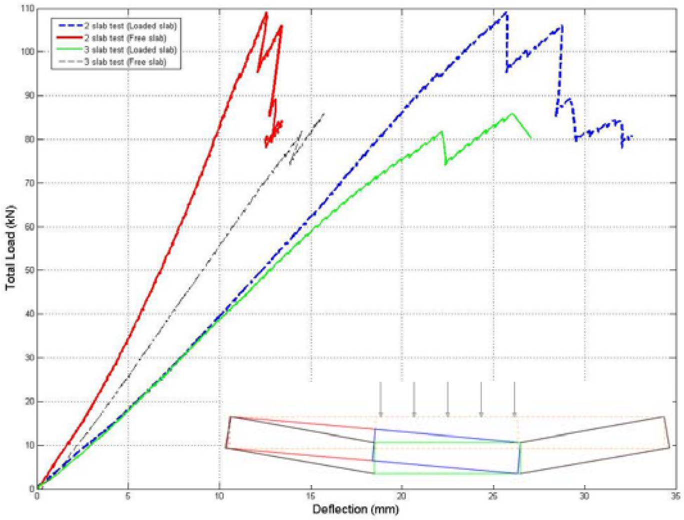

Figure 10. Comparison between two slab and three slab shear and bending test.

5.2 *Connection design chart*

The required characteristics of a connection to withstand the forces which arise between low grade slab units was determined by creating a connection in a three slab pure shear test which would fail at a low load before the low grade timber, followed by another test with a greater number of screws in the connection. This information was used to develop an a relationship between the number of screws in the joint per metre and the capacity of the joint to withstand shear per meter length of slab. These findings are summarised into the design chart shown in Figure 12.

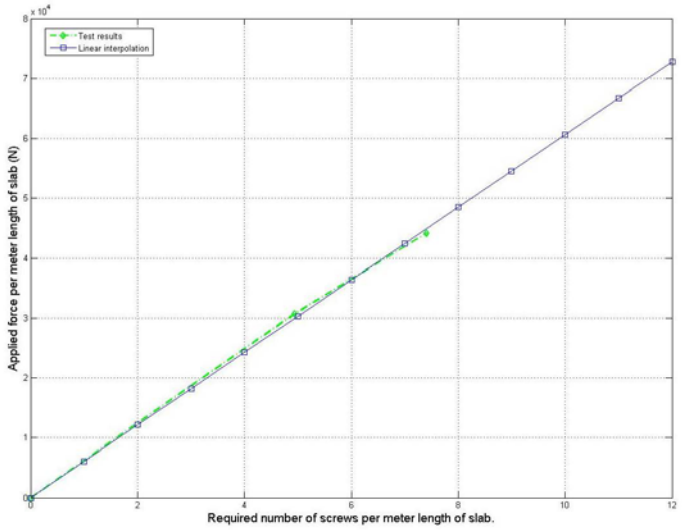

Figure 12. Bugle head batten screw requirements for a low grade slab unit connection

6 CONCLUSION

This study has investigated the structural performance of low grade timber laminated into slab units to be used as a flooring system. A detailed analysis from the behaviour of individual members and slab units through to the performance of slab units connected to form a floor slab has been investigated with the intention of determining the limitations of using low grade timber slabs in flooring applications.

Test results and modelling revealed that the critical limiting factor associated with low grade timber slabs used in a flooring application is deflection. An analysis of various loading intensities and clear floor spans has been undertaken to develop a deflection based design chart for low grade timber slabs for flooring applications.

The testing of connections between individual slab units has shown that a connection can be made to exceed the strength of the slab in any combination of forces applied. Further testing and analysis provided a simplified method for joint design based on the load applied per meter length of the slab.

7 ACKNOWLEDGEMENT

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