University of Southern Queensland

Faculty of Engineering and Surveying

Investigation of the Suitability of Finger Jointed Structural Timber for Use in Nail Plated Roof Trusses

A dissertation submitted by

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Abstract

The most common method of roof framing employed by Australian builders in modern construction is the use of pre-fabricated nail plated timber roof trusses. These trusses are predominantly manufactured from structural framing timber limited in length to a maximum of 6 metres. The style and size of houses increasingly preferred by Australian homeowners means that trusses are regularly required to span further than 6 metres. Truss manufacturers therefore use larger or additional nail plates to splice members during fabrication, and the assembly process becomes far more complex. Finger jointing of sawmill off-cuts and other short lengths of timber is a means of manufacturers economically producing timber in longer lengths. This dissertation investigates the suitability of using finger jointed structural timber for the fabrication of nail plated roof trusses.

Physical testing and statistical analysis has been used to compare the performance of finger jointed structural timber with standard structural framing timber normally used in truss fabrication. This study involved characterizing the mechanical properties of the timber, as well as assessing the performance of joints including mechanical fasteners. These methods, along with the static modelling of loading situations, were also used to quantify the probability of inducing failures unique to finger jointed timber, during the truss fabrication and erection process.

These investigations concluded that finger jointed timber could be produced with equivalent mechanical properties to standard framing timber. Joints manufactured from finger jointed and solid structural timber also exhibited no significant difference in performance. Furthermore, failures unique to finger jointed timber could occur during fabrication and erection, however, the probability of these, under normal use conditions, is generally quite low.

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

Date

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Anthony G Dakin

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Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.0 Outline of the study

This study into the suitability of using finger jointed structural timber for the fabrication of nail plated timber roof trusses is motivated by the ongoing investigation into methods of producing timber house frames more efficiently. The project aims to assess the performance of finger jointed timber through the fabrication and erection process, and in final use, by comparing it with the performance of standard non-finger jointed timber. The ultimate objectives of the research are to determine whether direct substitution of solid structural timber with finger jointed structural timber of the same cross section and grade is possible, and to provide information to ensure its successful implementation by the building industry.

1.1 Background

Australians enjoy the largest houses in the world (*Timber Talk*, 20 September 2011), and timber has long been the material of choice. The ever increasing desire for open-plan living means roof frames have to span further than ever. Construction history indicates that one of the most efficient means of achieving large spans is through the use of trusses. The use of trusses in residential construction was rare until the mid twentieth century, but the advent of World War II, and the population boom that followed, saw timber roof trusses adopted as a means of reducing house construction times.

This technique has continued to evolve with modern materials and fasteners, to the point that trusses are now used in the majority of houses constructed. These modern trusses are fabricated in factories and delivered to site ready for installation. The members of the truss are normally standard framing timber, connected with pressed in metal "nail plates", as shown in Figures 1.1 and 1.2. A diagram of a typical nail plated roof truss is shown in Figure 1.3.

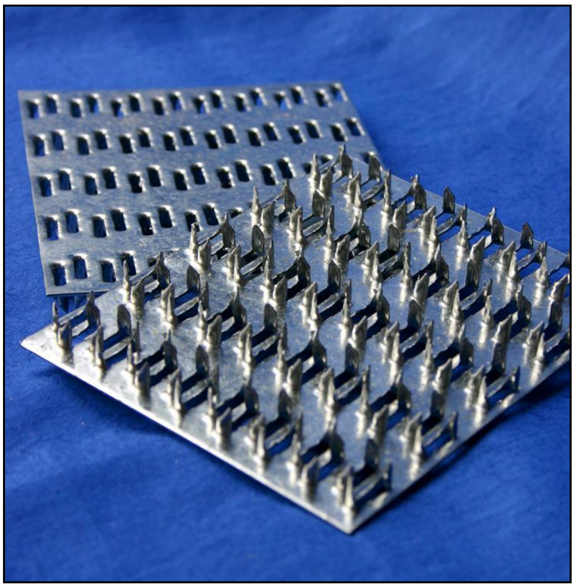


Figure 1.1 – Metal Nail Plate

Figure 1.2 – Nail Plated Truss Joint

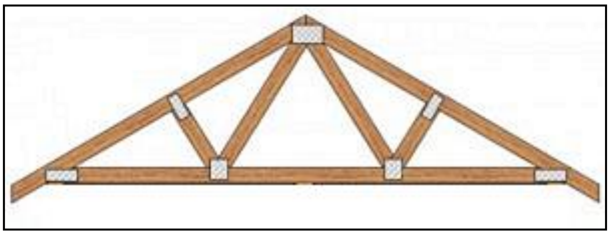


Figure 1.3 – Typical Nail Plated Roof Truss

The standard framing timber used for the members is most commonly plantation grown softwoods. Growth characteristics such as trunk taper, limit the length of rectangular framing sections that can be cut from the tree. The maximum length to which softwood framing can be produced is also constrained by the practical handling capabilities of the processing equipment. These factors result in standard softwood framing generally being available in 0.6 metre increments, with a maximum length of 6 metres.

Given that most of the trusses used in modern houses are required to span well beyond this maximum available length, end jointing of the framing timber is required to produce truss chords of adequate length. Currently this is achieved by splice jointing the timber using nail plates. Along with increasing the complexity of the truss fabrication process this also requires the use of more, or larger, nail plates per truss, resulting in decreased production efficiency and increased cost.

Although they are produced in factories, roof trusses are fabricated to the exact specifications of each individual house. Variations in roof pitch and truss span mean truss members need to be cut to the appropriate lengths for the truss being produced.

Due to the incremental nature of standard framing this results in unusable off-cuts. Multiple members are cut from individual feedstock lengths where possible. Reduced off-cut volumes, and hence greater efficiency, are achieved when longer feedstock lengths are used.

Economical methods exist for overcoming this length limitation. Glue-laminated timber beams and timber I-beams are currently produced in lengths of twelve metres and beyond using the same standard framing feedstock. The required lengths are achieved by "finger jointing" shorter lengths of timber.

Finger jointing involves machining matching profiles into the ends of lengths of timber, applying an adhesive, and pushing the profiles together until a permanent connection is formed. Examples of a finger joint profile, and finished finger joint, are shown in Figures 1.4 and 1.5, respectively.

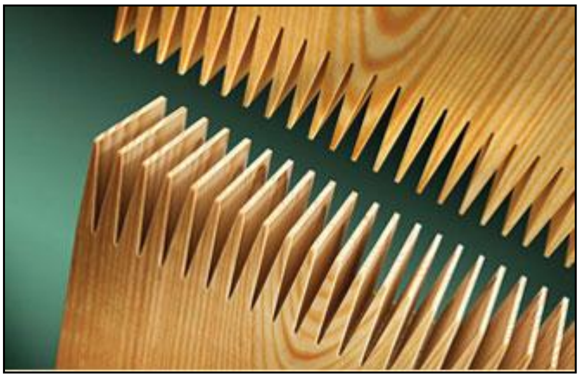


Figure 1.4 – Machined Finger Joint Profile

Figure 1.5 – Finished Finger Joint

Along with producing "over-sized" lengths from standard framing timber, finger jointing has been used to join off-cuts produced during framing production into useable lengths, improving the efficiency of sawmilling operations.

Despite successful use in both glue-laminated timber, and timber I-beams, finger jointed timber has not been used as a "stand alone" structural element in Australia, except in primarily compression applications such as wall studs. This is most likely due to an industry perception that finger jointed timber lacks tensile capacity.

Existing anecdotal evidence suggesting that finger jointed timber is already used successfully for the fabrication of roof trusses in South Africa. If this was to be implemented in Australia several benefits are foreseeable. As mentioned previously, sawmill efficiency could be improved through the jointing and use of framing off-cuts. Truss fabrication efficiency could also be improved by reducing the size and number of nail plates required, and by reducing the unusable off-cuts produced.

This project seeks to investigate the suitability of finger jointed timber for use in nail plated roof truss fabrication, allowing the aforementioned benefits to be realised.

1.2 Project Aim and Scope

The aim of this project is to determine the suitability of finger jointed timber for use in nail plated roof trusses from a fabrication, erection and in-service perspective. This will involve performance comparisons of truss components fabricated from conventional fixed length timber and from proposed continuous length finger jointed timber.

Finger jointed timber was produced as part of this trial as a means of providing material for test specimens. Manufacture was completed on commercially operated equipment using a proven timber adhesive. Whilst the manufacture techniques, including joint profile and adhesive type, are reported they do not form part of the scope of the project. The scope of the project is limited to the performance of the finished material only, from the perspectives indicated in the aim.

1.3 Project Objectives

In order to satisfactorily complete the research project, it was determined that the following aims and objectives, initially identified as a part of the Project Specification, included as Appendix A, had to be met:

1. Research the in-service performance requirements of finger jointed timber in nail plated roof trusses and associated assessment methods.

2. Research fabrication and erection techniques relating to nail plated roof trusses to determine material requirements and associated assessment methods.

3. Design and complete a testing regime to assess the mechanical properties of finger jointed timber.

4. Design and complete a testing regime to assess the structural capacity, and deformation, of typical roof truss joints containing finger jointed timber.

5. Design and complete a testing regime to replicate and assess issues related to fabrication and erection techniques.

6. Analyse and interpret the results of all testing to compare the performance of trusses fabricated from finger jointed and standard fixed length framing timber.

As an extension, and time permitting, the following further objectives were proposed:

7. Monitor the fabrication of full scale trusses from finger jointed timber and assess fabrication issues not previously identified.

8. Test full scale trusses fabricated from both finger jointed and fixed length timber to compare failure modes.

9. Fabricate trusses from finger jointed timber and place into a real structure for longer term performance monitoring.

1.4 Overview of the Dissertation

This study of the suitability of finger jointed timber for use in nail plated roof trusses involved the review of related literature, experimental testing and statistical evaluation of results. This section presents the general structure of the dissertation.

Chapter 1 is an introduction. It contains background information to provide an understanding of the motivation for this project. It also outlines the aims and objectives of the project.

Chapter 2 contains a review of existing information on both nail plated roof trusses and finger jointed timber. As little work has been completed on combining the two, the research focuses on current practices and their applicability to assessing the possibility of fabricating roof trusses from finger jointed timber.

Chapter 3 outlines the materials and processes used to manufacture the finger jointed timber assessed as part of this project.

Chapter 4 describes the testing and assessment of critical performance criteria identified in the literature review. It discusses the preparation of test specimens and the methodology involved in the experimental testing of the specimens. The chapter also includes the data analysis techniques employed and the methods used to assess the suitability of the results.

Chapter 5 presents and discusses the experimental test results, analysed and assessed using the methods described in Chapter 4.

Chapter 6 presents the conclusions that can be drawn from this research. Recommendations for further work are also provided in this chapter.

References and Appendices provide the supporting information referred to throughout the dissertation.

Chapter 2

Literature Review

2.0 Introduction

This chapter aims to present an overview of the literature to substantiate the proposed project objectives, and to identify appropriate methods of achieving these. As this project involves the combining of two established technologies most investigation was focussed on preocesses currently used for these.

This project was supported by a timber producer and a truss fabricator. Hyne and Son operate the two largest softwood sawmills in Australia. These mills predominately produce structural framing sections for the residential housing market. A large portion of the framing produced is sold to truss fabricators for the production of nail plated roof trusses. Sid's Place supplies building materials and hardware from several locations in South East Queensland. Its operations include pre-fabricated wall frame and roof truss manufacturing facilities.

As a part of initial project discussions, representatives from both Hyne and Son and Sid's Place (2011, pers. comm.) indicated that they were unaware of any previous work, with regards to the use of finger jointed timber in roof trusses, being completed in Australia. Subsequent searches validated this claim. Anecdotal evidence, provided by several timber and truss industry sources, suggested that finger jointed timber is currently being used successfully for nail plated truss fabrication in South Africa. Further searches were again unable to identify existing research related to this work.

As a result the project was guided by the advice of industry experts, predominately representing the aforementioned companies. The consensus of discussions conducted indicated that if it could be proven that finger jointed timber would perform equivalently to the fixed length framing timber currently used, there would be nothing to prevent its use in the fabrication of nail-plated roof trusses.

Based on this advice, research was conducted assuming that no special considerations would be made when fabricating roof trusses from finger jointed timber, as compared to current practices using standard framing timber.

2.1 In-Service Performance

Roof trusses are a key load-bearing component of house frames. The way in which trusses perform as a part of the overall structure was investigated. Through this investigation, the critical performance criteria were identified. Finger jointed timber will need to be assessed against these criteria.

2.1.1 Truss Action

Roof trusses are provided in a structure as a means of transferring roofing loads to the supporting walls. These loads are then transferred via the floor, be it a slab or frame, to the ground. Roofing loads typically consist of the following (Multinail, n.d.):

- Dead Loads – due to roofing materials, ceiling materials, and the self weight of the truss.

- Live Loads – due to temporary occurrences such as people or snow.
- Wind Loads – which vary depending on the buildings location.

Typically these loads are distributed loads and are applied to the truss chords. The truss chords support the load by firstly acting as beams between the panel points (Multinail, n.d.). As a result of this bending action the loads are then applied at the panel points. These loads are then supported by the truss members as axial loads. As the truss joints are assumed to be pin connections the sum of forces acting on the joint must be zero, and consequently the axial force in each member can be determined (Multinail, n.d.). Figure 2.1 describes this process graphically when loads are applied to a typical "A-Type" truss.

Consequently, the mechanical properties of the timber used as truss chords are critical to the truss's ability to carry the required loads. Multinail (n.d.) states that truss chords must be designed for strength and stiffness when subjected to axial forces, bending moment and shear, whilst truss webs are designed for axial forces. This indicates that to perform equivalently to the solid timber currently used, finger jointed timber of the same cross section must have equivalent Tension Strength, Compression Strength, Shear Strength, Bending Strength (Modulus of Rupture) and Bending Stiffness (Modulus of Elasticity).

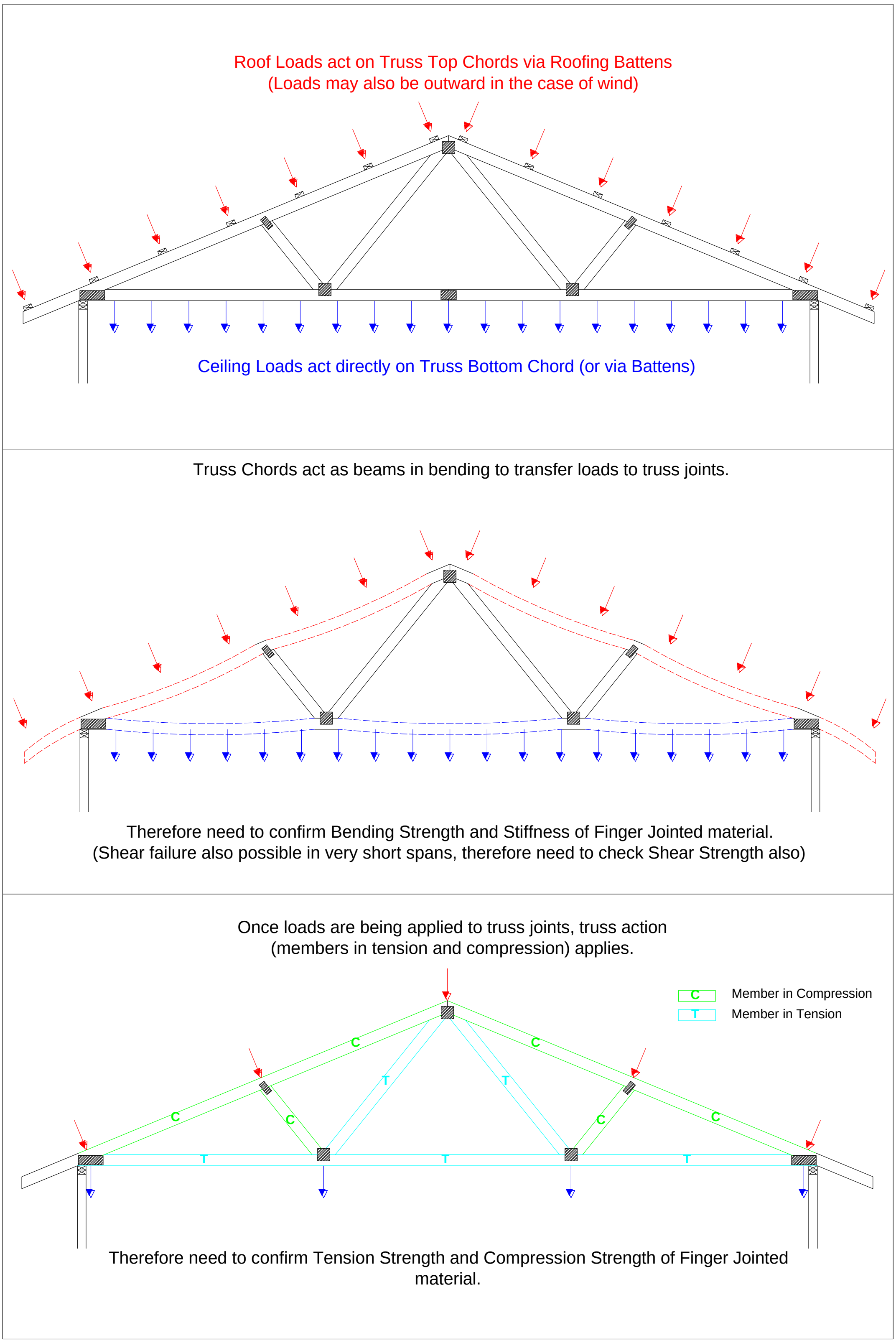


Figure 2.1 – Truss Loading Process

2.1.1.1 Details of Material in Application

Structural framing timber in Australia is produced in a range of standard cross sections and grades. The categorising of structural timber into standardised grades ensures users a consistent level of performance between framing sourced from different suppliers, and from different production runs. For structural framing to be assigned a particular grade it must possess the appropriate mechanical properties for that grade as specified in Australian Standard AS1720.1 (2010).

The softwood framing used for roof truss manufacture is most commonly MGP10, MGP12 or MGP15 grade. Table 2.1 contains data extracted from AS1720.1 (2010) Table H.3. It shows the required values of selected mechanical properties, discussed above, for timber assigned each of these grades.

Stress Grade	Section Size		Characteristic Values (MPa)				
	Depth (mm)	Breadth (mm)	Bending (f'_b)	Tension Parallel to Grain (f'_t)	Compression Parallel to Grain (f'_c)	Shear in Beams (f'_s)	Average modulus of elasticity parallel to grain (E)
MGP10	70 to 140	35 and 45	17	7.7	18	2.6	10 000
	190		16	7.1	18	2.5	
	240		15	6.6	17	2.4	
	290		14	6.1	16	2.3	
MGP12	70 to 140	35 and 45	28	12	24	3.5	12 700
	190		25	12	23	3.3	
	240		24	11	22	3.2	
	290		22	9.9	22	3.1	
MGP15	70 to 140	35 and 45	39	18	30	4.3	15 200
	190		36	17	29	4.1	
	240		33	16	28	4.0	
	290		31	14	27	3.8	

Table 2.1 – Characteristic Values for Design – MGP Stress Grades

Discussions with Hyne and Son salespeople indicated that the most common product supplied to truss fabricators is 90 x 35 mm MGP10 framing (McDonald, J 2011, pers.

comm.). This data was substantiated with Sid’s Place confirming that 90 x 35 mm MGP10 is the most commonly used feedstock for the chords of trusses they manufacture for the residential market (Blanch, S 2011, pers. comm.). It was also indicated that 70 x 35 mm is generally used for truss webs as they are subjected to less severe loading. Given that truss webs are extremely unlikely to ever exceed the 6 metre available length limit of structural softwood framing, this project is focussed on finger jointed timber replacing standard framing material in truss chords. As such, finger jointed material, 90 x 35 mm in cross section, will be compared with the mechanical properties of MGP10 timber.

2.1.1.2 Test Methods

Structural framing timber is required to have certain mechanical properties, governed by Australian Standards, to allow it to be classified as the appropriate stress grade. To confirm that it does in fact possess the required properties, representative samples of the timber must be tested. As discussed previously the assigning of standard stress grades aims to ensure uniformity between timber acquired from different sources. To further ensure this uniformity, the testing to determine the mechanical properties on which classification is made must be conducted consistently. To guarantee that this occurs, given that the testing is completed on different equipment, by different people, standardised methods have been developed.

The Australian Standard series, AS/NZS4063 (2010), provides the procedures for testing and characterising timber to the stress grades contained in AS1720.1 (2010). The necessary loading configurations, test spans, sample lengths and testing processes are specified in AS/NZS4063.1 (2010), whilst the methods required for the statistical analysis of test results are prescribed by AS/NZS4063.2 (2010).

The AS/NZS4063 (2010) series provides test and analysis methods appropriate to all mechanical properties previously identified as being critical. Specific details of all testing conducted is contained in subsequent sections of this report. The assessment of mechanical properties as a part of this project is conducted strictly in accordance with AS/NZS4063 (2010) wherever possible.

2.1.2 Truss Joints and Connections

Along with the adequacy of individual truss members, the interaction of these members with each other, and with other structural elements, is critical to the overall performance of the truss. Loads need to be transferred between truss members and this is achieved by the use of nail plates. This method of load transfer is referred to as a “truss joint” in this project. Loads also need to be transferred between trusses and other structural elements. This project refers to these interactions as “connections”.

2.1.2.1 Truss Joints

Nail plated joints occur at the intersection of truss chords and webs. They transfer loads between combinations of these members intersecting at various angles. Figure 2.2 highlights the locations at which nail plated joints occur in a typical “A-Type” truss.

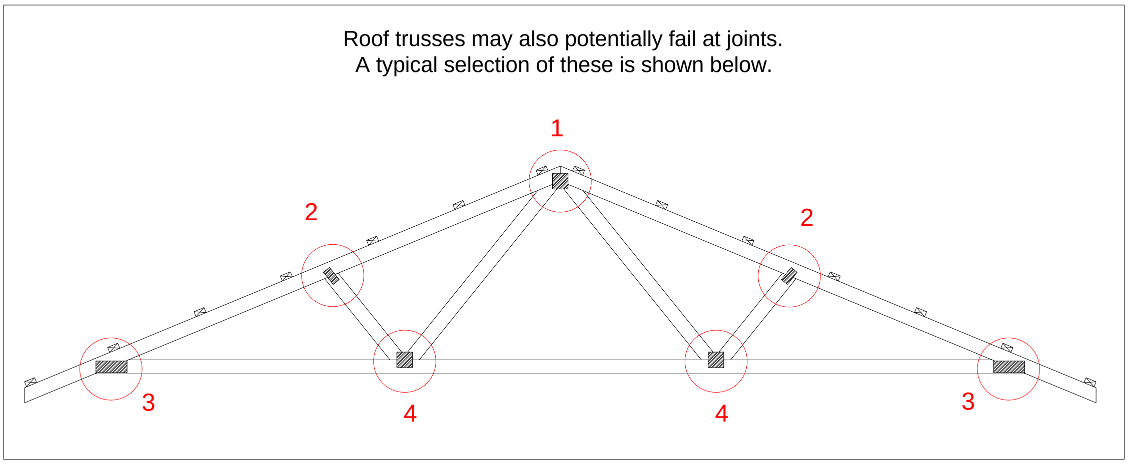


Figure 2.2 – Truss Joint Locations

Nail plates can also be used for the splice jointing of timber, as shown in Figure 2.3. Splice joints can potentially occur in trusses when the length of one or more of the chords exceeds the maximum available length of feedstock material. Discussions with Sid’s Place indicate that splice joints are made to coincide with existing chord / web joints wherever possible to avoid the need for additional nail plates (2011, pers. comm.). Figure 2.4 shows a joint of this type.

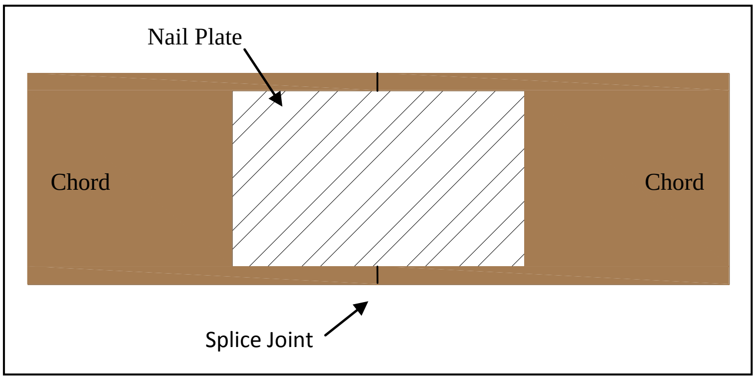


Figure 2.3 – Nail Plated Splice Joint

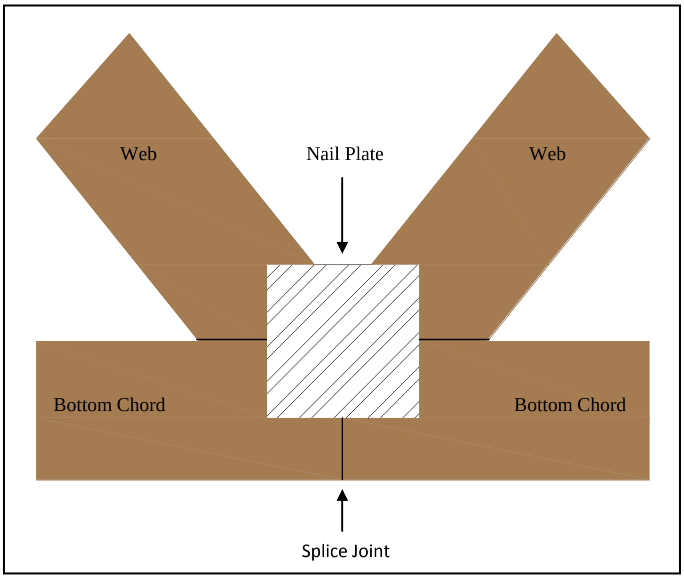


Figure 2.4 – Combined Splice and Chord / Web Joint

By not imposing restrictions on the use of finger joint timber for roof truss chords it is highly likely that a finger joint will coincide with a nail plate at some point. Closer inspection of the joint locations highlighted in Figures 2.2 and 2.3 indicates that finger joints may occur at various angles under nail plates. These angles range from finger joints in timber with its grain running approximately parallel to the major axis of the nail plate, to finger joints in timber with its grain running approximately perpendicular to the nail plate major axis, as shown in Figure 2.5.

Finger jointed timber will be considered to perform equivalently to standard framing timber if joints, using the same sized nail plates, do not suffer a reduction in load carrying capacity when a finger joint is located under the nail plates, at any of the angles shown. Further to the strength requirement, nail plated joints coinciding with finger joints should not experience a significant change in joint deformation, when compared to nail plated joints in standard framing timber.

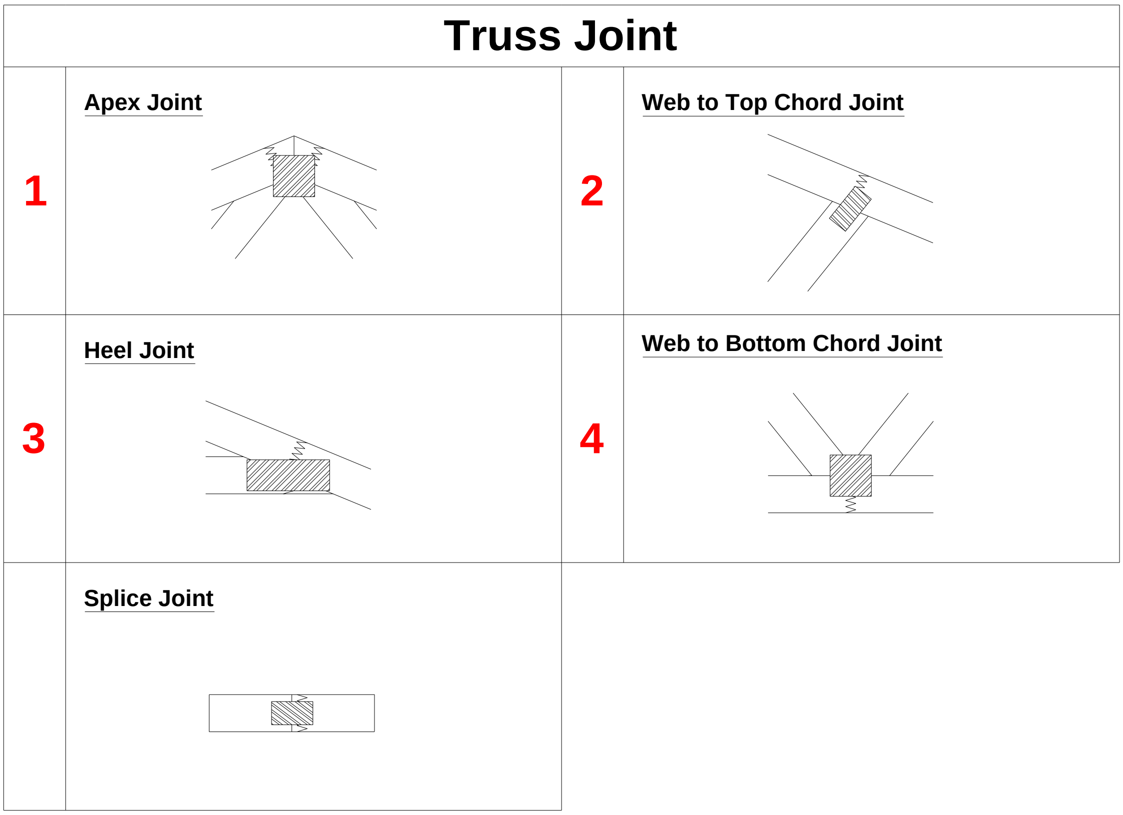


Figure 2.5 – Finger Joints Under Nail Plates

2.1.2.1.1 Details of Material in Application

A number of variables exist that are likely to have an impact on the load carrying capacity of a nail plated truss joint. These include timber size, grade and species, along with nail plate size, thickness and manufacturer. As a result, standard joint capacity values are not published for all combinations. In order to assess the effect of finger joints on joint capacity this project compares the performance of solid timber and finger jointed timber.

The previous section showed that nail plates can be orientated at various angles to the grain of the timber, and hence, to finger joints. Taking into account the variability of roof slopes and spans these angles become almost infinite in number. Australian Standard AS1649 (2001), which defines the testing of nail plated joints in timber, indicates that, as a minimum, testing must be conducted with nail plates orientated parallel, and perpendicular, to the grain of the timber. Joint capacities of intermediate angles can then be interpolated. Following discussion with Hyne and Son and Sid's Place representatives it was decided that if equivalent results for standard and finger jointed timber were obtained from testing in these two orientations, equivalent performance at all angles could be assumed (2011, pers. comm.). As such, testing in the orthogonal orientations only will be completed as a part of this project.

It can be seen from Figure 2.5 that nail plates orientated parallel to the grain of the truss chord most closely represent splice joints and truss heel joints. For trusses with 90x35 mm MGP10 chords Sid's Place would typically use 150 x 75 mm nail plates in these locations (Blanch, S 2011, pers. comm.). This plate size has been adopted for testing, with solid 90 x 35 mm MGP10 used to provide baseline results for comparison with finger jointed timber.

Similarly, Figure 2.5 shows that nail plates orientated perpendicular to the grain of the truss chord most closely represents a top chord / web joint. In this case, for a truss with 90 x 35 mm MGP10 chords, Sid's Place would typically use 100 x 40 mm nail plates (Blanch, S 2011, pers. comm.). This size has been adopted for testing. As described previously truss webs are most often 70 x 35 mm material. This size, in MGP10 grade, has been selected as the web material for testing of both finger jointed and solid truss chords. Again, solid 90 x 35 mm MGP10 chords have been used to provide baseline results for comparison with finger jointed timber.

2.1.2.1.2 Test Methods

For a truss to perform successfully adequate load transfer between members, via nail plates, is required. Nail plates are proprietary products with values of their load carrying capacity provided by the plate's manufacturer. To allow comparison of, and confidence in, nail plates sourced from different suppliers, standardised methods for assessing load carrying capacity have been developed.

Australian Standard AS1649 (2001) defines the testing of nail plates. It provides the necessary loading configurations, test spans, sample lengths, testing processes and statistical analysis methods. The assessment of nail plated joint capacities as a part of this project are conducted in accordance with AS1649 (2001) wherever possible. Specific details of the testing completed are contained in subsequent sections of this report.

2.1.2.2 Connections

Trusses need to be connected to other structural elements in order to complete the transfer of loads to the ground. This includes elements transferring loads to the truss, and elements taking loads from the truss. Loads are transferred to the truss by two major means. Firstly, via battens that are fixed directly to the chords of the truss, and secondly, via secondary trusses supported by the truss rather than by walls. Loads being transferred from the truss predominately consist of the truss being tied to the supporting wall frames to resist wind uplift loads.

Figure 2.6 shows typical locations of these connections and the orientation of the most significant loads.

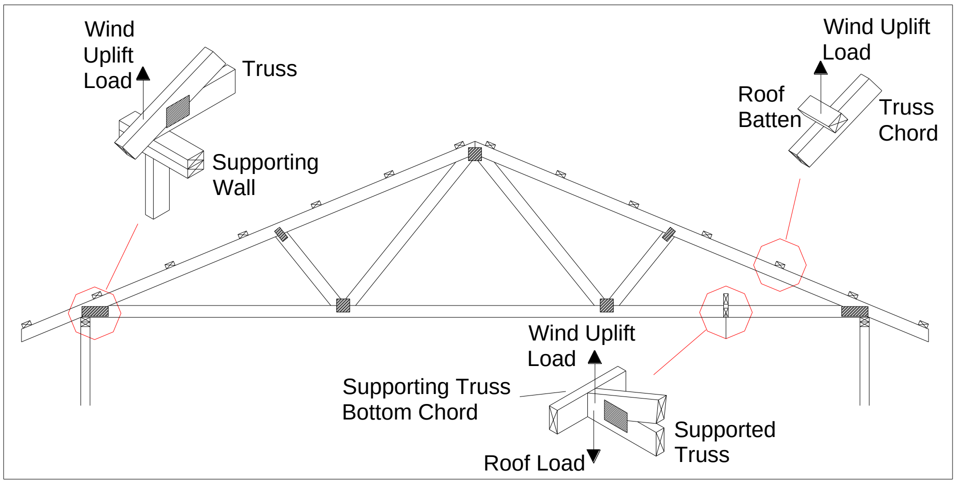


Figure 2.6 – Truss Connection Locations and Loads

As can be seen, the truss chords are intrinsically involved in all of these connections. As was indicated for nail plated truss joints, by not imposing restrictions on the use of finger jointed timber in truss chords it is inevitable that finger joints will coincide with the connections at some stage.

To perform equivalently to the solid timber currently used, connections using the same hardware in trusses fabricated from finger jointed timber must not suffer a reduction in load carrying capacity should a finger joint be located at the connection point.

2.1.2.2.1 Details of Material in Application

Australian Standard AS1684.4 (2010) provides several options for the tie down of roof battens to truss top chords. The most appropriate method is determined based upon the batten and truss material used, and the applicable loading. Discussion with Sid's Place indicates that one of the commonly used methods, for trusses with 90 x 35 mm chords, is 70 x 35 mm timber battens connected with a single Type 17 No. 14 Batten Screw, 75 mm long (2011, pers. comm.). The batten screw is required to resist axial withdrawal loads due to wind uplift. Figure 2.7 shows this connection, and indicates how a finger joint may be penetrated by the screw.

Figure 2.7 – Batten to Truss Chord Connection

This connection type has been adopted to assess the effect of finger joints on batten to truss chord connections. Solid 90 x 35 mm MGP10 chords have been selected to provide baseline results for comparison with finger jointed timber.

Australian Standard AS1684.4 (2010) also outlines the requirements for roof tie down to supporting walls in residential construction. Several manufacturers of nail plates and other timber connectors produce a range of products that meet these requirements. Sid's Place identified the use of Gang-Nail MultiGrips fixed with Mitek 30 x 2.8 mm nails as common practice for trusses with 90 x 35 mm MGP10 chords (2011, pers. comm.). Figure 2.8, taken from Mitek (2007) indicates the number of nail required, and their locations.

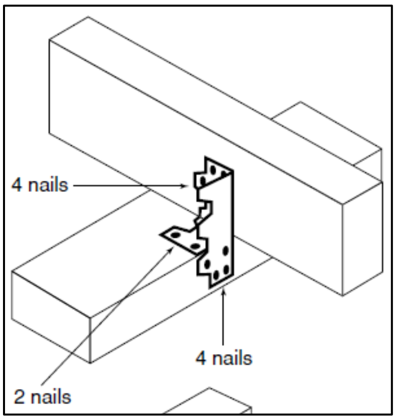


Figure 2.8 – MultiGrip Nail Requirements

It can be noted that some of the nails are required to resist axial withdrawal loads, while others are laterally loaded. Figure 2.9 indicates how a finger joint may be penetrated by nails in this connection type.

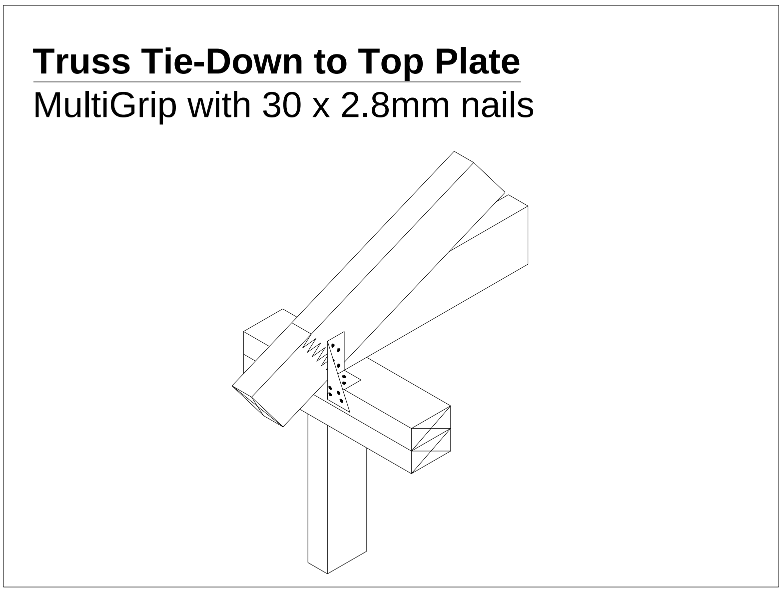


Figure 2.9 – Truss to Top Plate Connection

This connection type has been adopted to assess the effect of finger joints on truss to top plate connections. Solid 90 x 35 mm MGP10 chords have been selected to provide baseline results for comparison with finger jointed timber.

The manufacturers of nail plates and other timber connectors also produce a range of products for attaching secondary trusses to supporting trusses. These connections generally take the form of steel brackets fixed to the trusses with nails, screws or bolts. Sid's Place advised that the most common practice, currently, is the use of self tapping screws (2011, pers. comm.). Mitek (2007) indicates that the most appropriate screw, for use with trusses having 90 x 35 mm chords, is a Mitek No.14 x 30mm. Figure 2.10, shows the typical number of screws required, and how a finger joint might be penetrated by these screws.

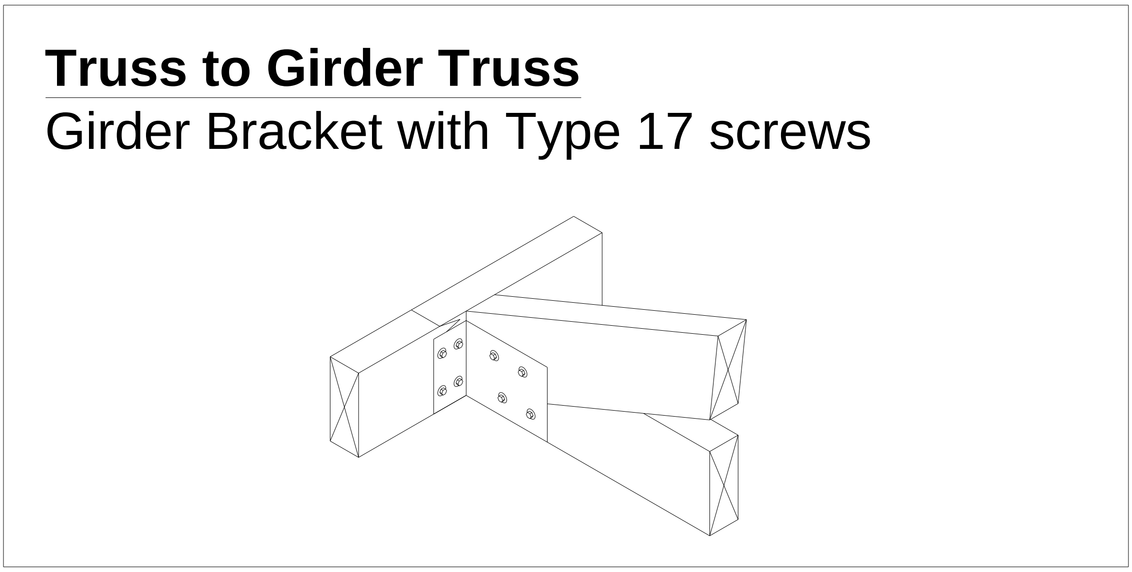


Figure 2.10 – Truss to Girder Truss Connection

It can be noted that the screws penetrating the chord of the supporting truss are subject to lateral loading. This connection type has been adopted to assess the effect of finger joints on the ability of trusses to support loads from other trusses. Solid 90 x 35 mm MGP10 chords have been selected to provide baseline results for comparison with finger jointed timber.

2.1.2.2.2 Test Methods

Australian Standard AS1649 (2001) contains methods for determining the capacity of fasteners such as nails, screws and bolts when subjected to axial or lateral loading. Although each of the connections identified includes components fitting these criteria, this project seeks to assess any effect finger joints may have on the load carrying capacity of the connection as a whole.

The general concepts of joint and connection testing described in AS1649 (2001) will form the basis of testing the identified connections, with the specific configurations altered to represent the overall connection being assessed. The statistical methods provided in AS1649 (2001) will be used to analyse the test results. Specific details of the testing completed are contained in subsequent sections of this report.

2.1.3 Fabrication Issues

The handling of long length feedstock was identified by both Hyne and Son and Sid's Place as a potential difficulty of fabricating trusses from finger jointed timber (2011, pers. comm.). Apart from the additional length, it is anticipated that finger jointed timber could be handled identically to the standard framing timber currently used. Of particular concern is the possibility of feedstock breaking at finger joints under the increased bending moments induced during handling due to the increased length of the boards.

By observing the timber manufacturing processes of Hyne and Son, and the truss fabrication processes of Sid's Place, three typical handling techniques were identified. Discussions with representatives of both parties confirmed that these techniques are common practice (2011, pers. comm.).

Firstly, levering is a technique that allows individual boards to be raised or moved by a single person. The board is held at one end and supported at a single point part way along. Downward pressure is applied at the held end raising the far end of the board allowing it to be repositioned.

Secondly, a two man lift allows individual boards to be raised, moved and relocated by hand. The board is supported at each end whilst it is lifted and repositioned.

Finally, individual boards, or packages of boards, can be moved by fork lifting. This involves supporting the boards at two locations near to their centre, with the ends unrestrained, while raising or lowering the boards. Inspection of the forklifts used at Hyne and Son operations, and discussion with the timber despatch manager, showed that the most common support spacing is 1.5m on the machines used for timber handling (Muller, R 2011, pers. comm.).

For all of these techniques bending moments are typically induced about the minor axis of the timber section. This project seeks to determine the probability of finger jointed timber failing under these techniques by modelling the stresses likely to occur and testing the capacity of the finger joints in the appropriate orientation.

2.1.3.1 Modelling of Handling Stresses

When observing these handling techniques in practice it was realised that both static and dynamic loading was being applied to the timber. Due to the modelling methods and test equipment available during the short duration of this project, only the static loads have been assessed.

It was also identified that forklifts handle timber in both individual board and package form. The strapping together of boards into packages reduces the severity of actions acting on individual boards. As a result only individual boards have been assessed when subjected to each of the handling techniques.

When considering static loads only, each of the handling techniques can be represented by a simple loading diagram. Figure 2.11 shows the loading diagram for each technique.

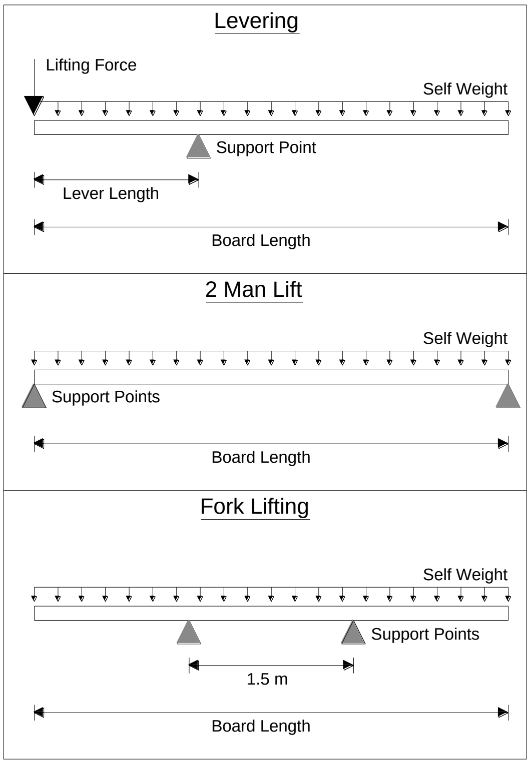


Figure 2.11 – Loading Diagrams for Handling Techniques

As can be seen, each technique is made up of one or more statically determinate loading and support configurations, such as simply supported single spans and cantilevers. American Wood Council (2007) provides bending moment diagrams, and equations, for each configuration. These can be combined to determine the overall bending stresses applied to a board when handled by each technique.

The loads applied to each board, as shown in Figure 2.11, are dependent upon the self weight of the boards. Values of self weight for typical finger jointed boards can be obtained by weighing boards after manufacture. Australian Standard AS/NZS4063 (2010) describes methods of assigning frequency distributions to data. These methods will be used to determine the probability of a board of a certain weight occurring.

2.1.3.2 Test Methods

For a board to break during handling a finger joint must occur in a board whose weight provides stresses substantial enough to exceed the joints capacity. To determine the probability of this event occurring, the capacity of typical finger joints, when loaded in the appropriate orientation, must be known.

Australian Standard AS5068 (2006) describes a method of determining the strength of finger joints in timber sections bent about the minor axis. The necessary loading configurations, test spans, sample lengths and testing processes are specified. AS5068 (2006) provides this test method for the purpose of production quality control and as a result the methods provided for analysing test results are limited. Australian Standard AS/NZS4063 (2010) describes methods of assigning frequency distributions to data, and hence, can be used to determine the probability of a finger joint with a certain capacity occurring.

For the purposes of this project the testing of finger joints in timber bent about the minor axis will be conducted in accordance with AS5068 (2006), with the results analysed in accordance with AS/NZS4063 (2010).

2.1.4 Truss Erection Issues

The possibility of truss chords failing under temporary construction loads, due to an adversely located finger joint, was suggested by representatives of Sid's Place (2011, pers. comm.). Further investigation indicated that two areas for concern existed. The first related to a truss top chord failing at a finger joint when a builder stands on the end of the truss overhang, and secondly, the bottom chord failing at a finger joint if a builder stands at the centre of bottom chord panel. The described loading locations are shown in Figure 2.12.

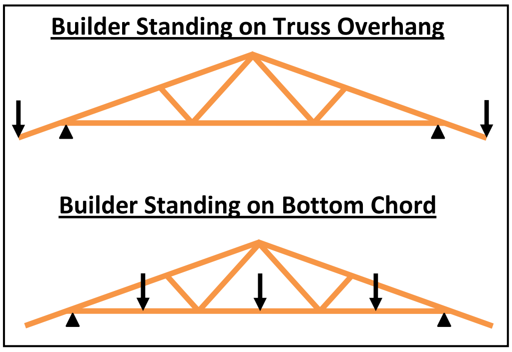


Figure 2.12 – Location of Temporary Construction Loads

This project seeks to determine the probability of truss chords failing at a finger joint when subjected to the temporary construction loads discussed. It is planned to model the stresses that are likely to occur and compare them to the capacity of finger joints loaded in the appropriate orientation.

2.1.4.1 Modelling of Temporary Construction Stresses

The building industry is male dominated. It seems fair to assume that the temporary construction loads, discussed in the previous section, will most likely be due to adult males. A study by the McLennan and Podger in 1995 found the average body weight of an Australian adult male to be 81.9 kilograms, with the standard deviation of the data being 15.02 kilograms.

Statistical methods exist, such as those described in AS/NZS 4063.2 (2010), to determine the distribution of a data set based on these parameters. These methods can be used to determine the probability of a man with a certain weight occurring.

American Wood Council (2007) provides bending moment diagrams, and equations, for statically determinate beams. By considering the top chord of a truss, when subjected to a point load at the end of the overhang, as a simply supported beam with overhang, the stresses induced in it can be determined using these.

The bottom chord of an “A-type” truss, as shown in Figure 2.12, is a three span continuous member. Multinail (n.d.) suggests that bending moments in the chord should be evaluated using Clapeyron’s Theorem of Three Moments. By application of this theorem the stresses induced by a builder standing at the centre of a bottom chord panel can be determined.

2.1.4.2 Test Methods

For a truss chord to break at a finger joint, under temporary construction loads, a finger joint must occur at an appropriate location when a builder, whose weight is great enough to provide stresses sufficient to exceed the joints capacity, stands at the critical location on the chord. To determine the probability of this event occurring, the capacity of typical finger joints, when loaded in the appropriate orientation, must be known.

Australian Standard AS5068 (2006) describes a method of determining the strength of finger joints in timber sections bent about the major axis. The necessary loading configurations, test spans, sample lengths and testing processes are specified. AS5068 (2006) provides this test method for the purpose of production quality control and as a result the methods provided for analysing test results are limited. Australian Standard AS/NZS4063 (2010) describes methods of assigning frequency distributions to data, and hence, can be used to determine the probability of a finger joint with a given capacity occurring.

For the purposes of this project the testing of finger joints in timber bent about the major axis will be conducted in accordance with AS5068 (2006), with the results analysed in accordance with AS/NZS4063 (2010).

Chapter 3

Manufacture of Finger Jointed Timber

3.0 Introduction

This project aims to determine the suitability of finger jointed timber for use in nail plated roof trusses. This suitability will be gauged by comparing its performance with the standard framing timber currently used for truss manufacture. Physical testing must be performed to assess the performance of finger jointed timber. As Hyne and Son do not currently produce structural grade finger jointed timber for sale adequate quantities were manufactured for the purposes of this project.

This chapter outlines the materials and processes used as a part of this manufacture. The selection of materials and manufacture techniques does not form part of the scope of this project. The scope of the project is limited to the performance of the finished material only.

3.1 Materials

Structural grade finger jointed timber consists of two material components, graded timber feedstock joined with structural grade adhesive. This section provides details on the type and source of each of these components.

3.1.1 Timber Feedstock

Hyne and Son's Tuan Mill processes plantation grown softwood, predominately Slash Pine (Pinus elliottii) and Caribbean Pine (Pinus caribaea). These species are not separated as a part of the normal operation of the mill. No special sorting measures were undertaken as a part of sourcing timber feedstock for this project and as such it is expected that the finished finger jointed timber consists of both species.

As a part of the literature review it was determined that 90 x 35 mm finger jointed timber would be assessed in this project, with the mechanical properties of MGP10 targeted. Ungraded off-cuts, 600 mm in length, were collected during a standard 90 x 35 mm production run at Hyne and Son's Tuan Mill. No physical assessment, mechanical or otherwise, was made of the mechanical properties of the off-cuts.

The off-cuts were visually graded to eliminate defects that fall outside Hyne and Son's proprietary limits for standard MGP10 production. This included discarding pieces containing knots with a diameter greater than 50% of the wide face dimension. Knots of any diameter were not permitted within 50 mm of the end of a block to ensure a good quality joint. Off-cuts containing wane, the rounding of section corners due to the circular nature of a tree, greater than the limits shown in Figure 3.1 were also excluded.

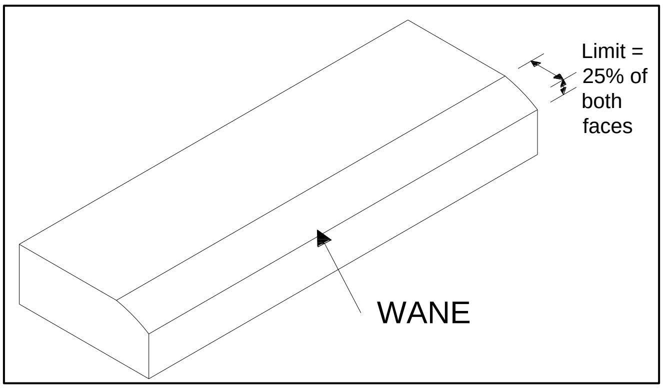


Figure 3.1 – Hyne and Son Wane Limits for MGP10

3.1.2 Adhesive

Although Hyne and Son do not currently produce structural grade finger jointed timber for sale they have done so previously. During this time a polyurethane adhesive was used successfully. Adhesives of this type have a proven record of successful performance in structural applications both in Australia and overseas, particularly in Europe.

A polyurethane adhesive, Purbond HB S109 was selected when manufacturing finger jointed timber for this project. It was applied and cured in accordance with the manufacturer's directions. More information about Purbond HB S109 can be found on the technical data sheet, included in this report as Appendix B.

3.2 Process

The general procedure for manufacturing finger jointed timber involves machining matching profiles into the ends of timber blocks, applying a suitable adhesive to the profiles, applying mechanical pressure to force the joints closed, and allowing the adhesive to cure and form a permanent bond. This process was followed when producing finger jointed timber for this project.

A finger jointer currently operates at Hyne and Son's Melawondi plant manufacturing non-structural finger jointed timber feedstock for the production of mouldings. By replacing the finger joint cutters this machine was used to produce structural grade finger jointed material for this project.

The finger jointer used as a part of the project produces vertical finger joints. Cutters were sourced to provide a joint with 15 mm long fingers, a profile used widely for structural finger joints in Europe. Figure 3.2 contains a picture of the profile used, and Figure 3.3, sourced from AS5068 (2006), provides its dimensions.

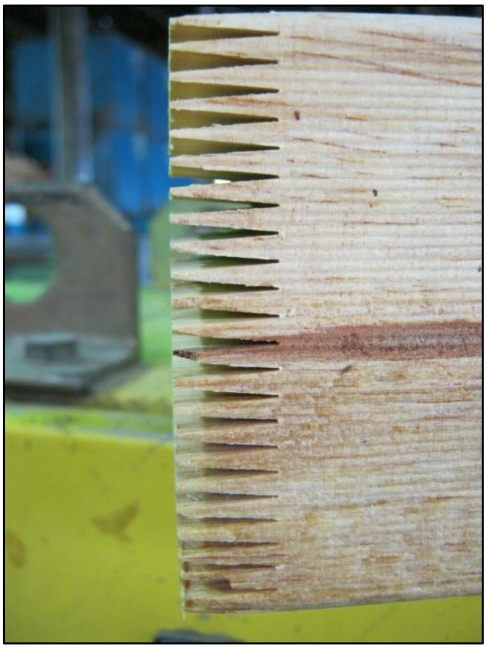


Figure 3.2 – Finger Joint Profile Used

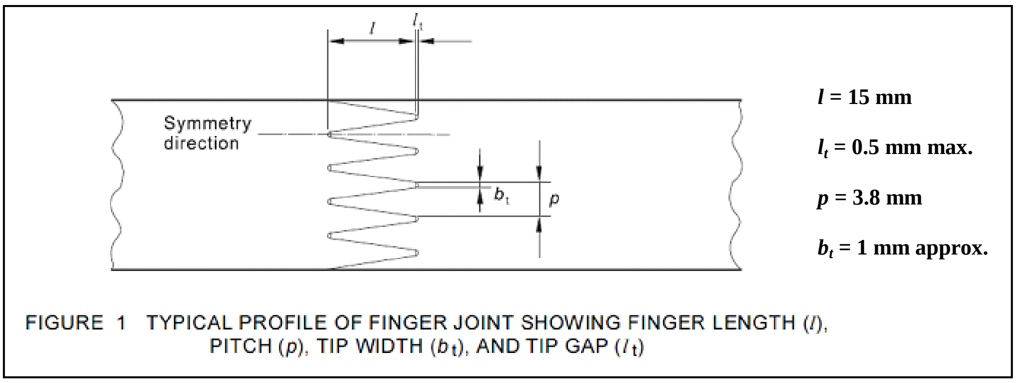


Figure 3.3 – Dimensions of Finger Joint Used

The pressure used to close the joints was appropriate for the 90 x 35 mm timber cross section, and in accordance with the adhesive manufacturer's recommendations. More than 100 finger jointed boards, 5.4 metres in length, were produced and allowed to cure for the appropriate period for the adhesive used. A number of these boards contained non-structural grade timber used when setting up the finger jointer. These boards were not tested as a part of this project. After full cure the finished boards were planed to remove any excess glue from the surface of the timber. The cross sectional dimensions of the timber remained as 90 x 35 mm. The finger jointed timber produced is shown in Figure 3.4, prior to planing.

Figure 3.4 – Finger Jointed Timber Before Planing

As a means of ensuring that finger jointed timber is produced with adequate strength properties, proof loading is often conducted as a part of the manufacturing process. All boards produced as a part of this project were subjected to an appropriate proof load applied in tension. The minimum load required to achieve the target characteristic tension strength of 90 x35 mm MGP10 was applied to each board. The procedure used to calculate this load is contained in Appendix C.

Overall, 1 of the 96 boards tested failed under the applied proof load. This board failed in a low density section of clear timber. Details of the proof load applied to all pieces are contained in Appendix D.

On completion of the manufacture process 95 pieces of 90 x 35 mm finger jointed timber, 5.4 m long, were available for testing as a part of this project.

Chapter 4

Methods of Testing and Assessment

4.0 Introduction

Finger jointed timber has been identified as a potential feedstock for nail plated roof truss fabrication. Before it can be adopted for use its ability to perform adequately must be investigated. A literature review identified the critical criteria for which the performance of finger jointed timber must be measured, and benchmark values against which this performance can be compared. This chapter presents details of the physical testing conducted to measure performance. It also describes in detail how the appropriate benchmark values were obtained, and how performance was assessed against them.

4.1 Mechanical Properties

This section outlines the methods used to test and assess the critical mechanical properties of finger jointed timber, with regards to its potential use in nail plated roof trusses.

4.1.1 Assessment

As identified in the literature review, finger jointed timber will be considered to possess adequate mechanical properties if it achieves the values specified for standard MGP10 framing in Australian Standard AS1720.1 (2010).

Assessment involved simply comparing the results of testing conducted, and analysed, in accordance with AS/NZS4063 (2010), with the standard values. This assessment process was appropriate for all mechanical properties considered.

4.1.2 Testing and Analysis Methods

4.1.2.1 Bending Strength and Stiffness

Testing of 30 samples of finger jointed timber was completed in Hyne and Son's Tuan test rig, shown in Figure 4.1. The samples were cut from separate, randomly selected full-length boards, and contained finger joints at random locations. Each sample was weighed before testing and its density determined.

Figure 4.1 – Hyne & Son's Tuan Bending Rig

All samples were subjected to four point loading, in the configuration required by AS/NZS 4063.1 (2010), as shown in Figure 4.2. All specimens tested were 90 x 35 mm in section.

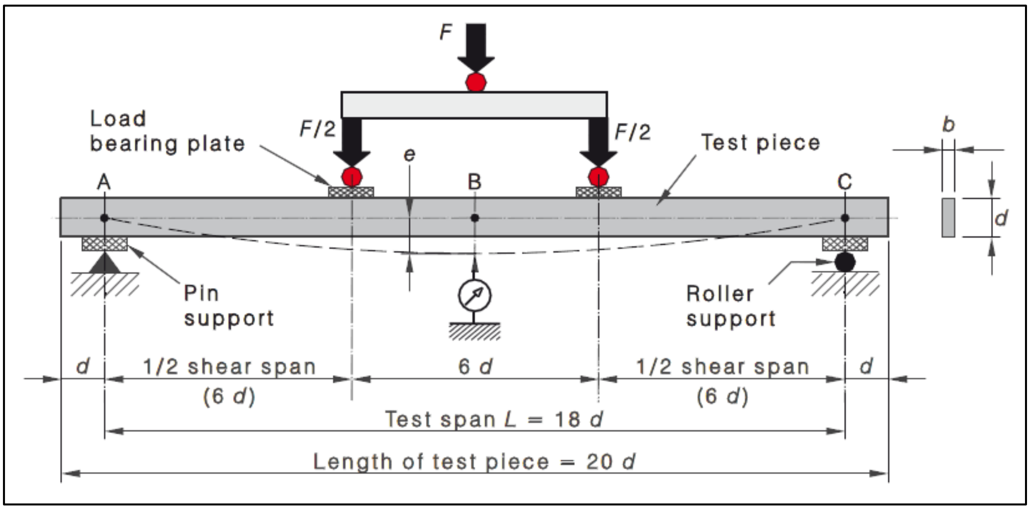


Figure 4.2 – AS/NZS4063 Bending Test Set-up

Load was applied to the test sample via a spreader beam driven by an Enerpac 10 ton hydraulic ram. The applied load was measured by a Kelba 10 ton S-type load cell, and the resulting deflection at centre span by a Mitutoyo ID-C1050XB digital indicator. As no data logging system was available corresponding values of load and deflection were recorded at two points within the elastic range of the timber, to allow the slope of the load-deflection curve to be calculated. The applied load at failure of the test sample was recorded, along with the failure source and location, measured from the mid-point of the test span.

The recorded data was used with Equation (4.1) to determine the Modulus of Elasticity (bending stiffness), *E*, of each sample.

$$E = \frac{23}{108}\left(\frac{L}{d}\right)^3\left(\frac{F_2-F_1}{e_2-e_1}\right)\frac{1}{b} \qquad \textbf{(4.1)}$$

Where

L = The test span

d = The depth of the test specimen

b = The breadth of the test specimen

F_1 = The lower of the loads recorded in the elastic zone

F_2 = The higher of the loads recorded in the elastic zone

e_1 = The deflection corresponding to F_1

e_2 = The deflection corresponding to F_2

If failure of the test specimen occurred between the loading points, the recorded failure load was used with Equation (4.2) to determine the bending strength, f_b, of each test sample.

$$f_b = \frac{F_{ult}L}{bd^2} \qquad \textbf{(4.2)}$$

Where

F_{ult} = The recorded failure load

If failure of the test specimen occurred between a loading point and adjacent support, the recorded failure load, and failure location, was used with Equation (4.3) to determine the bending strength, f_b, of each test sample.

$$f_b = \frac{3F_{ult}(L - 2L_v)}{2bd^2} \tag{4.3}$$

Where

L_v = The horizontal distance from the point of failure to the centre of the test span

The characteristic value for Modulus of Elasticity, E, of the finger jointed timber was then calculated using the bending stiffness test results, by the method shown in Appendix E, extracted from AS/NZS4063.2 (2010).

The characteristic value for Bending Strength, f_b, of the finger jointed timber was then calculated using the bending strength test results, by the method shown in Appendix F, extracted from AS/NZS4063.2 (2010).

4.1.2.2 Tension Strength

Testing of 30 samples of finger jointed timber was completed in Hyne and Son's tension test rig, shown in Figure 4.3. The samples were cut from separate, randomly selected full-length boards, and contained finger joints at random locations. Each sample was weighed before testing and its density determined.

Figure 4.3 – Hyne & Son's Tension Test Rig

All samples were subjected to axial loading, in the configuration required by AS/NZS 4063.1 (2010), as shown in Figure 4.4. All specimens tested were 90 x 35 mm in section, and the actual test span used was 2800 mm.

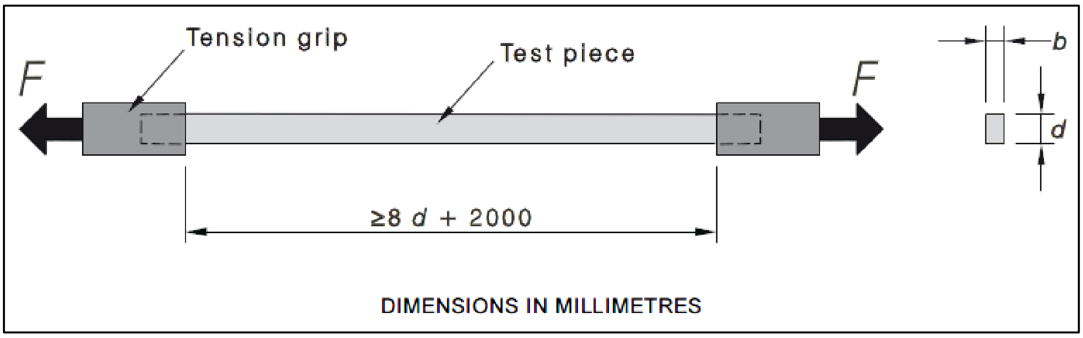


Figure 4.4 – AS/NZS4063 Tension Test Set-up

Load was applied to the test sample via steel jaws driven by an Enerpac 12 ton hydraulic ram. The applied load was measured by a Precision Transducers PT-LPX5000 5 ton compression type load cell. The jaw, load application, and load measurement arrangements are shown in detail in Figures 4.5, 4.6 and 4.7 respectively. The applied load at failure of the test sample was recorded, along with the failure source, be it a finger joint or naturally occurring defect.

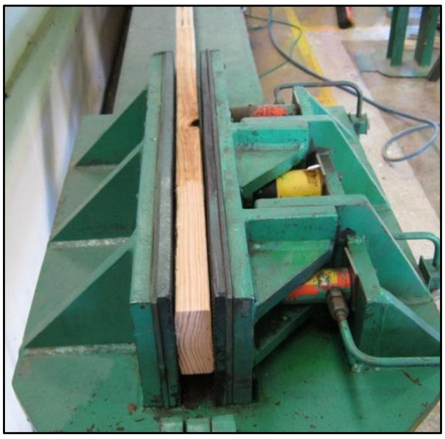


Figure 4.5 – Tension Testing Rig Jaw Arrangement

Figure 4.6 – Tension Testing Rig Load Application Arrangement

Figure 4.7 – Tension Testing Rig Load Measurement Arrangement

The recorded failure load was used with Equation (4.4) to determine the tension strength parallel to grain, $f_{t,0}$, of each test sample.

$$f_{t,0} = \frac{F_{ult}}{bd} \tag{4.4}$$

Where

F_{ult} = The recorded failure load

d = The depth of the test specimen

b = The breadth of the test specimen

The characteristic value for Tension Strength, $f_{t,0}$, of the finger jointed timber was then calculated using the tension strength test results, by the method shown in Appendix F, extracted from AS/NZS4063.2 (2010).

4.1.2.3 Shear Strength

A total of 62 samples of finger jointed timber were tested in Hyne and Son's Tuan bending rig, adjusted for shear testing as shown in Figure 4.8. The samples were sourced from off-cuts of the randomly selected full-length boards used for the bending tests, and contained finger joints at random locations. Each sample was weighed before testing and its density determined.

Figure 4.8 – Hyne & Son's Tuan Bending Rig Adjusted for Shear Testing

All samples were subjected to three point loading, in the configuration required by AS/NZS 4063.1 (2010), as shown in Figure 4.9. All specimens tested were 90 x 35 mm in section.

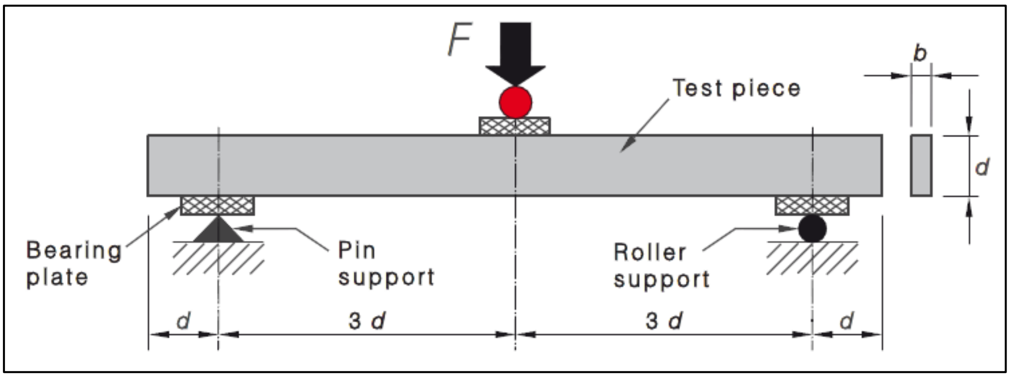


Figure 4.9 – AS/NZS4063 Shear Test Set-up

Load was applied to the test sample via a spreader beam driven by an Enerpac 10 ton hydraulic ram. The applied load was measured by a Kelba 10 ton S-type load cell. The applied load at failure of the test sample was recorded, along with the failure mode and source.

The recorded failure load was used with Equation (4.5) to determine the shear strength, f_v, for test samples that were considered to have failed in shear.

$$f_v = \frac{0.75F_{ult}}{bd} \tag{4.5}$$

Where

F_{ult} = The recorded failure load

d = The depth of the test specimen

b = The breadth of the test specimen

The characteristic value for Shear Strength, f_v, of the finger jointed timber was then calculated using the test results of samples that failed in shear, by the method shown in Appendix F, extracted from AS/NZS4063.2 (2010).

4.1.2.4 Compression Strength

Testing of 30 samples of finger jointed timber was completed in Hyne and Son's compression test rig, shown in Figure 4.10. The samples were sourced from off-cuts of the randomly selected full-length boards used for the bending and shear tests, and contained finger joints at random locations. Each sample was weighed before testing and its density determined.

Figure 4.10 – Hyne & Son’s Compression Test Rig

All samples tested were 90 x 35 mm in section. The AS/NZS 4063.1 (2010) compression test configuration, shown in Figure 4.11, indicates that a minimum sample length of 2720 mm is required for this section size. Due to limitations of the test rig, the maximum specimen length that could be tested was 2400 mm. With the exception of sample length, all other requirements of AS/NZS 4063.1 (2010) for compression testing were met.

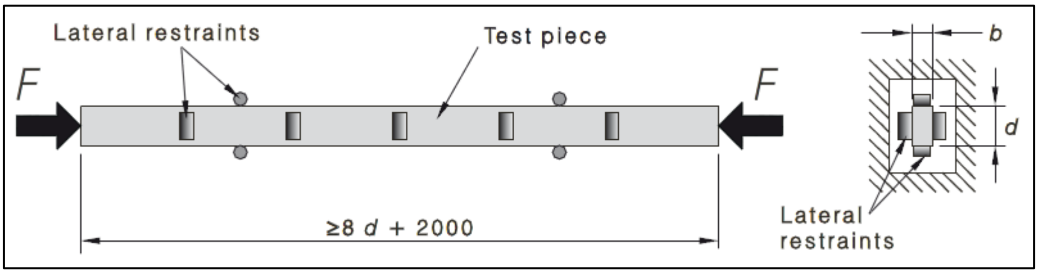


Figure 4.11 – AS/NZS4063 Compression Test Set-up

Load was applied to the test sample via a steel plate connected to an Enerpac 60 ton hydraulic ram. The applied load was measured by a Precision Transducers LPX25000 25 ton compression type load cell. The load application, and load measurement arrangements are shown in detail in Figures 4.12 and 4.13 respectively. The applied load at failure of the test sample was recorded, along with the failure source, be it a finger joint or naturally occurring defect.

Figure 4.12 – Compression Testing Rig Load Application Arrangement

Figure 4.13 – Compression Testing Rig Load Measurement Arrangement

The recorded failure load was used with Equation (4.6) to determine the compression strength parallel to grain, $f_{c,0}$, of each test sample.

$$f_{c,0} = \frac{F_{ult}}{bd} \tag{4.6}$$

Where

F_{ult} = The recorded failure load

d = The depth of the test specimen

b = The breadth of the test specimen

The characteristic value for Compression Strength, $f_{c,0}$, of the finger jointed timber was then calculated using the compression strength test results, by the method shown in Appendix F, extracted from AS/NZS4063.2 (2010).

4.2 Truss Joints and Connections

This section outlines the methods used to test and assess the effect of finger joints on the nail plated connection of truss members, and the connection of trusses to other structural elements, identified in the literature review.

4.2.1 Assessment

As previously identified, finger jointed timber will be considered to perform adequately in truss joints and connections if no significant difference in the performance of test joints constructed from finger jointed timber, and standard framing timber, is observed.

Assessment of the strength of all identified joints and connections involved the testing of sample joints manufactured from standard framing timber and finger jointed timber. Samples of the latter were biased so that a finger joint was located directly within the joint or connection. The test results were compared using a standard statistical test for assessing the significance of the difference of means of small populations. This test is based on the Student's *t* Distribution, and is described in Spiegel (1982). A two-tailed test was conducted.

An assessment of the deformation exhibited by end joints loaded parallel to the timber grain was also conducted. Testing was performed to measure the stiffness across each joint type, as shown in Figure 4.14. The test results were compared by the same statistical test for assessing the significance of the difference of means of small populations, used to compare the joint strength values.

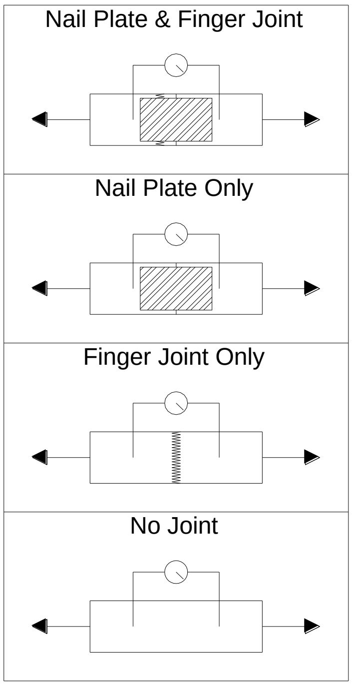


Figure 4.14 – Joint Types for Stiffness Testing

4.2.2 Testing and Analysis Methods

4.2.2.1 Nail Plate Parallel to Timber Grain – Stiffness and Strength

Samples for testing nail plated joints were fabricated to meet the dimensional requirements of AS1649 (2001). The fixing of nail plates was performed by Sid's Place using a rolling press. No teeth were removed from the plates. Prior to joining, the timber components were weighed to ensure a relatively even wood quality across the joint. Twenty samples were produced from both finger jointed timber and standard MGP10 timber. The finger jointed timber was sourced randomly from the material manufactured for the project, and the standard MGP10 framing from an ordinary Hyne and Son production run. The dimensions of the samples, and location of finger joints, are shown in Figure 4.15.

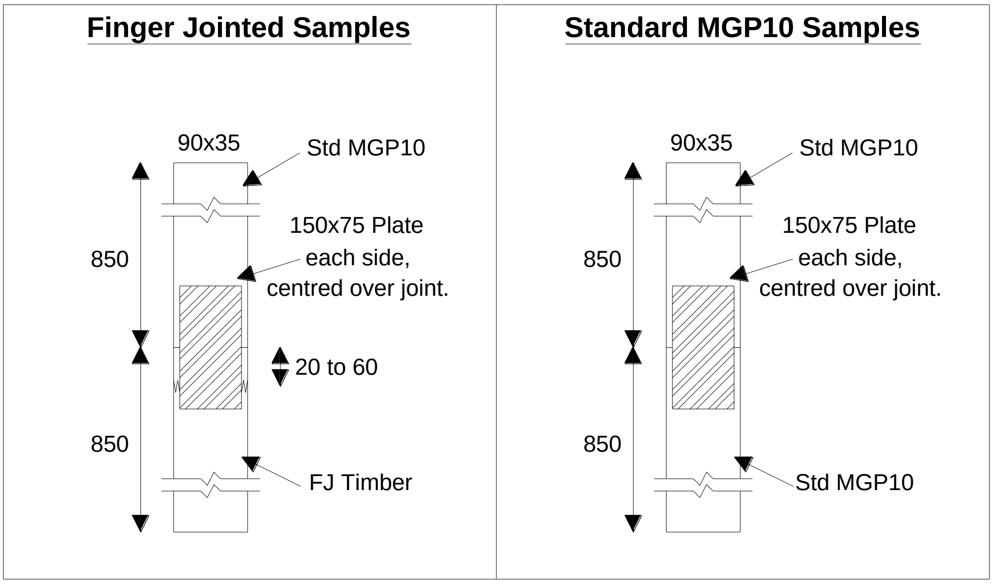


Figure 4.15 – Nail Plate Parallel to Grain Sample Dimensions

A further 10 samples of the same overall length were cut from both finger jointed timber and standard MGP10 framing. The finger jointed samples were cut so that a finger joint was located at the specimen's mid-point. No joining of these samples was required.

Testing was conducted on Hyne and Son's tension test rig. Axial load was applied over a 500 mm span, with deformation of the sample measured longitudinally over 205mm at centre span. The test set-up is shown in Figures 4.16 and 4.17.

Figure 4.16 – Joint Deformation Measuring – Front View

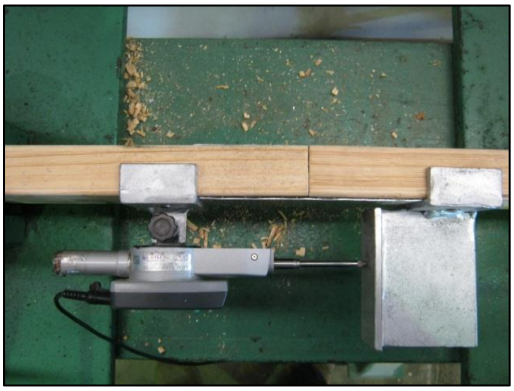


Figure 4.17 – Joint Deformation Measuring – Top View

Load was applied and measured as previously described for tension strength testing. The joint deformation was measured using a Mitutoyo ID-F150 digital indicator. No data logging system was available so corresponding values of applied load, and joint deformation, were recorded at regular intervals. The applied load at failure of the test sample was recorded, along with the failure mode.

Equation (4.7) was used to convert the recorded loads to stress values, σ_i.

$$\sigma_i = \frac{F_i}{bd} \tag{4.7}$$

Where

F_i = The recorded load

d = The depth of the test specimen

b = The breadth of the test specimen

Equation (4.8) was used to convert the recorded joint deformations to strain values, δ_i.

$$\delta_i = \frac{e_i}{205} \tag{4.8}$$

Where

e_i = The recorded joint deformation

A stress-strain curve was then plotted for each sample, with the slope of the linear portion of this graph representing the stiffness of the joint. Load carrying capacity was the parameter used to describe the strength of the joints. No calculations were required with the joint capacity being simply the ultimate failure load.

All nail plated joint samples were loaded to failure and had their strength value determined. Only 10 of each of those produced from finger jointed timber and standard MGP10 had intermittent loads and deformations recorded, and the joint stiffness calculated. Samples produced from finger jointed timber and standard MGP10 without nail plates were not taken to failure and only had the information required for determining stiffness recorded and analysed.

4.2.2.2 Nail Plate Perpendicular to Timber Grain

Samples for testing nail plated joints perpendicular to the grain of the timber were fabricated to meet the dimensional requirements of AS1649 (2001). The fixing of nail plates was performed by Sid's Place using a rolling press. No teeth were removed from the plates. Prior to joining, the timber components were weighed to ensure a relatively even wood quality across the joint. Twenty samples were produced from both finger jointed timber and standard MGP10 timber. The finger jointed timber was sourced randomly from the material manufactured for the project, and the standard MGP10 framing from an ordinary Hyne and Son production run. The dimensions of the samples, and location of finger joints, are shown in Figure 4.18.

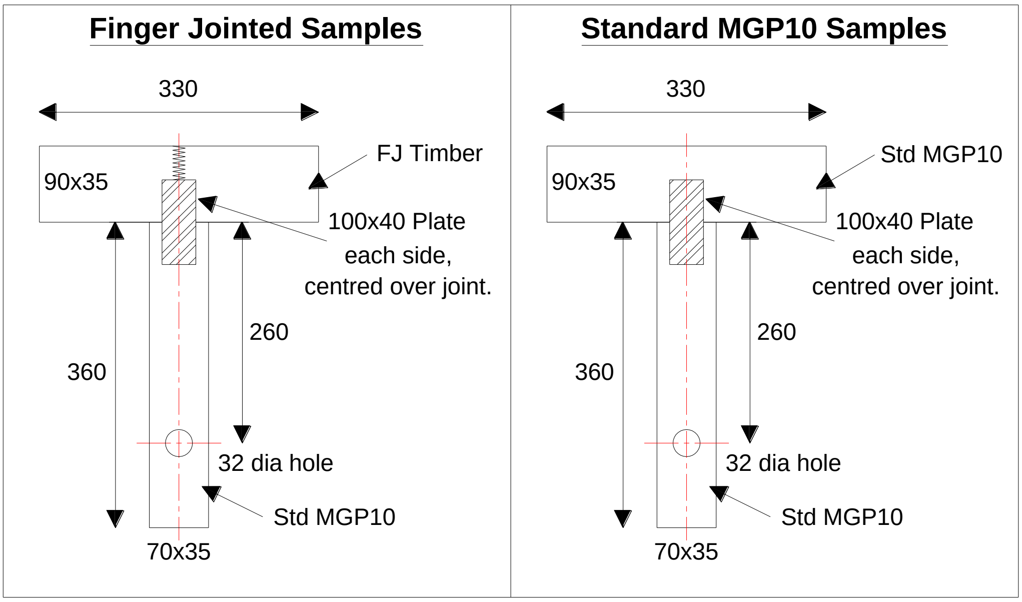


Figure 4.18 – Nail Plate Perpendicular to Grain Sample Dimensions

Testing was conducted on Hyne and Son's vertical test rig, shown in Figure 4.19. Tensile load was applied by anchoring the sample with a pin through the hole in the vertical leg, and pulling upwards at the ends of the horizontal branch. A clear span of 210 mm was maintained between the loading points.

Figure 4.19 – Hyne & Son's Vertical Test Rig

Load was applied to the test sample via a spreader frame driven by an Enerpac 30 ton hydraulic ram. The applied load was measured, via a lever arm, by a Precision Transducers 5 ton compression-type load cell. The measured load at failure of the test sample was recorded, along with the failure mode.

Equation (4.9) was used to apply the effects of the lever arm to the measured loads, and calculate the ultimate failure loads, F_i.

$$F_i = \frac{750 f_i}{300} \tag{4.9}$$

Where

f_i = The measured load at failure

Load carrying capacity was the parameter used to describe the strength of the joints. No calculations were required with the joint capacity being simply the ultimate failure load. All samples were loaded to failure and had their ultimate failure load determined.

4.2.2.3 Batten Screw Connection of Roof Batten to Truss Chord

Samples for testing axially loaded batten screw connections were fabricated to replicate the connection in service. The dimensions of the sample were selected to meet the limitations of the available test equipment. The initial test sample design is shown in Figure 4.20.

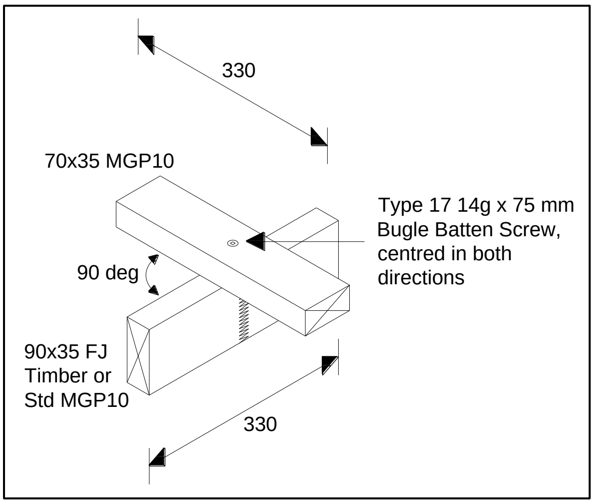


Figure 4.20 – Batten Screw Test Sample Initial Design

Advice was sought from an experienced builder and it was suggested that this assembly was likely to fail by the screw head pulling through the batten. This failure mode was considered unsatisfactory for assessing the effect on the connection of finger joints in the truss chord. Prototype testing was conducted and the samples were found to regularly fail in this manner. Hardwood battens were adopted to minimise the chances of this failure mode occurring.

Ten samples were produced with finger jointed and standard MGP10 truss chords, both with hardwood battens. The finger jointed timber was sourced randomly from the material manufactured for the project. The standard MGP10 framing was collected from an ordinary Hyne and Son production run, and the hardwood was supplied by the Hyne and Son laminated beam plant. The truss chord component of each sample was weighed before joining, and its density determined. The batten screws were driven until the heads were flush with the surface of the timber to ensure equal penetration for all tests. The dimensions and finger joint locations of the samples adopted for testing are shown in Figure 4.21.

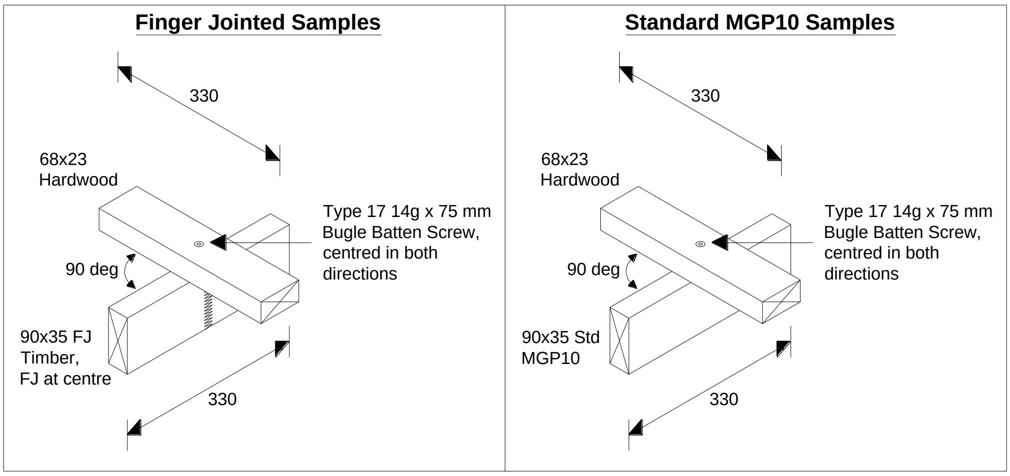


Figure 4.21 – Batten Screw Connection Sample Dimensions

Testing was conducted on Hyne and Son's vertical test rig with appropriate attachments, as shown in Figure 4.22. Axial load, with regards to the batten screws withdrawal from the truss chord, was applied by anchoring the sample at the ends of the batten, and pulling upwards at the ends of the truss chord. A clear span of 210 mm was maintained between the loading points, and between the anchor points.

Figure 4.22 – Hyne & Son's Vertical Test Rig – Batten Screw Test Set-up

Load was applied and measured as previously described for nail plate testing perpendicular to the timber grain. The measured load at failure of the test sample was recorded, along with the failure mode.

Equation (4.9) was used to apply the effects of the lever arm to the measured loads, and calculate the ultimate failure loads, F_i, as described previously.

Load carrying capacity was the parameter used to describe the strength of the joints. No calculations were required with the joint capacity being simply the ultimate failure load. All samples were loaded to failure and had their ultimate failure load determined.

4.2.2.4 MultiGrip Connection of Roof Truss to Supporting Wall

Samples for testing MultiGrip tie down connections were fabricated to replicate the connection in service. The dimensions of the sample were selected to meet the limitations of the available test equipment. Normally, a single MultiGrip would be used to connect a truss to the supporting wall. The equipment available requires a balanced joint for testing to avoid inducing eccentric loading. Test samples were prepared using two multigrips to meet this requirement. The dimensions of the samples, and location of finger joints, are shown in Figure 4.23.

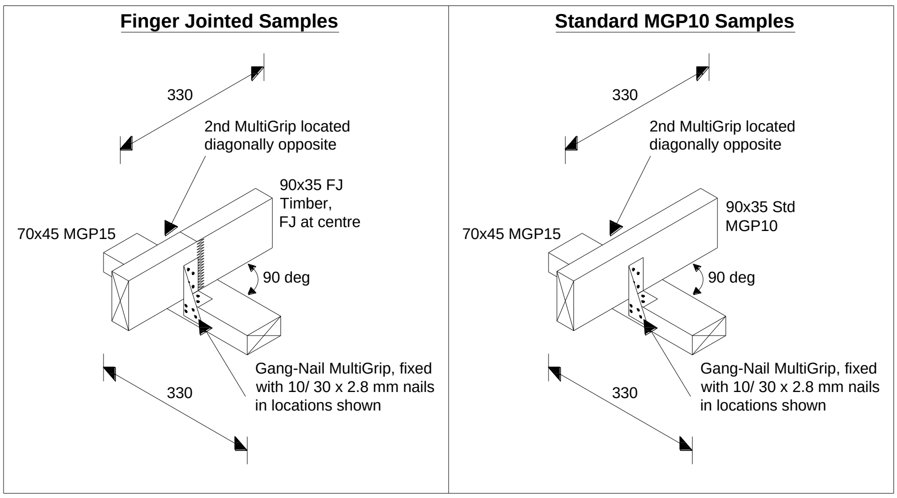


Figure 4.23 – MultiGrip Connection Sample Dimensions

Ten samples were produced with finger jointed and standard MGP10 truss chords, and 70 x 45 MGP15 wall top plates. The finger jointed timber was sourced randomly from the material manufactured for the project. The standard MGP10 and MGP15 framing were collected from ordinary Hyne and Son production runs. The truss chord component of each sample was weighed before joining, and its density determined. All nails were driven until their heads were seated against the surface of the MultiGrips to ensure equal penetration for all tests.

Testing was conducted on Hyne and Son's vertical test rig with appropriate attachments, as shown in Figure 4.24. Lateral load was applied to the nails penetrating the truss chord by anchoring the sample at the ends of the top plate, and pulling upwards at the ends of the truss chord. A clear span of 210 mm was maintained between the loading points, and between the anchor points.

Figure 4.24 – Hyne & Son's Vertical Test Rig – MultiGrip Test Set-up

Load was applied and measured as previously described for batten screw connection testing. The measured load at failure of the test sample was recorded, along with the failure mode.

Equation (4.9) was used to apply the effects of the lever arm to the measured loads, and calculate the ultimate failure loads, F_i, as described previously.

Load carrying capacity was the parameter used to describe the strength of the joints. No calculations were required with the joint capacity being simply the ultimate failure load. All samples were loaded to failure and had their ultimate failure load determined.

4.2.2.5 Screw Connection of Girder Bracket to Truss Chord

This connection type involves fixing a bracket, as shown in Figure 2.10, to the truss chord rather than connecting 2 timber members. This connection was replicated by fabricating an attachment for Hyne and Son's vertical test rig, to which a truss chord could be attached for testing. The literature review identified that groups of 4 screws are commonly used to attach brackets to truss chords. In practice these screws penetrate the truss chord from the same side. To provide the balanced joint required by the test rig to avoid eccentric loading, the attachment provided locations for the insertion of 2 screws from each side. Figure 4.25 shows the test rig operating with the attachment.

Figure 4.25 – Hyne & Son's Vertical Test Rig – Girder Bracket Test Set-up

Ten samples were produced from finger jointed timber and standard MGP10 framing. The finger jointed timber was sourced randomly from the material manufactured for the project. The standard MGP10 was collected from an ordinary Hyne and Son production run. Each sample was weighed before testing, and its density determined. Once the samples were placed in the test rig, screws were driven into the timber until their heads were seated against the surface of the girder bracket attachment to ensure equal penetration for all tests. The dimensions of the samples, and location of finger joints, are shown in Figure 4.26.

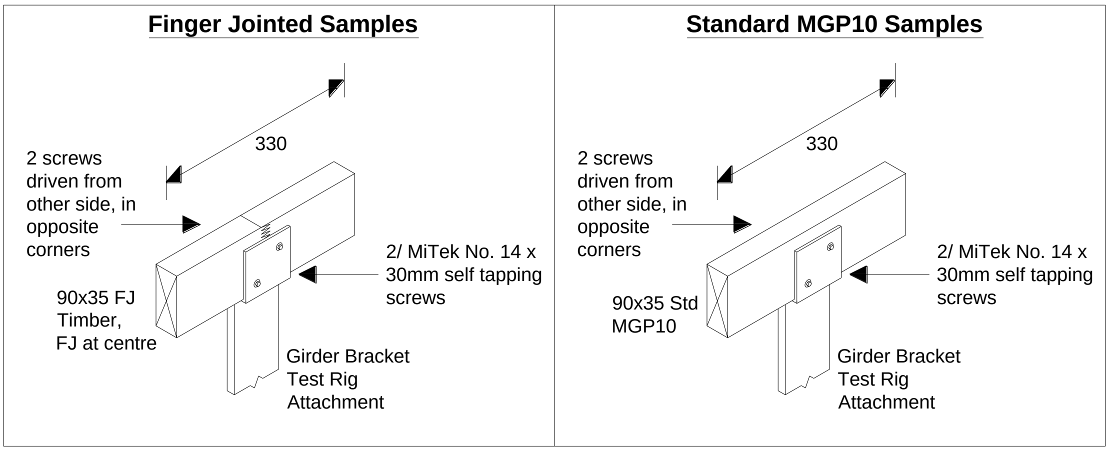


Figure 4.26 – Girder Bracket Connection Sample Dimensions

Lateral load was applied to the screws penetrating the truss chord by pulling upwards at the ends of the truss chord. A clear span of 210 mm was maintained between the loading points.

Load was applied and measured as previously described for batten screw connection testing. The measured load at failure of the test sample was recorded, along with the failure mode.

Equation (4.9) was used to apply the effects of the lever arm to the measured loads, and calculate the ultimate failure loads, F_i, as described previously.

Load carrying capacity was the parameter used to describe the strength of the joints. No calculations were required with the joint capacity being simply the ultimate failure load. All samples were loaded to failure and had their ultimate failure load determined.

4.3 Fabrication Issues

This section outlines the testing and assessment methods used to determine the probability of finger jointed timber boards breaking at a finger joint during the fabrication process, when handled by the techniques identified in the literature review.

4.3.1 Assessment

Finger jointed timber contains glued connections at which a board could potentially break. These connections occur regularly, with their location depending upon the length off-cuts used for manufacture. This assessment involved determining the probability of boards breaking at finger joints, under various scenarios, to provide information that enables end users to establish suitable handling practices.

A board will fail at a finger joint if, a large enough stress is applied to the board, and, a finger joint with inadequate capacity to support this stress occurs, and, this finger joint occurs in the appropriate location. From this statement it can be seen that the overall probability of a board failing is a combination of the probabilities of each of the three individual events occurring. This is represented by Equation (4.10).

$$Prob_{OA} = Prob_{STR} \times Prob_{CAP} \times Prob_{LOC} \qquad \textbf{(4.10)}$$

Where

$Prob_{OA}$ = The overall probability of a board breaking at a finger joint

$Prob_{STR}$ = The probability of a stress capable of breaking the board being applied

$Prob_{CAP}$ = The probability of a finger joint with inadequate capacity to support the applied stress occurring

$Prob_{LOC}$ = The probability of this finger joint occurring in the appropriate location

The stresses applied to a board during handling are dependent upon the weight of the board and can be modelled using static engineering principles. For this assessment the weights of a representative sample of finger joint boards were obtained from the measured densities of the specimens used for bending strength, tension strength and compression strength testing. The stresses that would be applied at a specified location during handling were then modelled for each board using the methods shown in Section 4.3.2.

It was found that the distribution of the sample board densities, and hence the stresses applied, could be estimated as log-normal. A cumulative frequency distribution was then applied to the calculated stresses to determine the probability of occurrence of an applied stress exceeding a nominated value. The cumulative frequency distribution is described by Equation (4.11). A typical cumulative frequency distribution for the applied stresses is shown in Figure 4.27.

$$M_i = \exp(\widehat{Y} - z_i S_y) \tag{4.11}$$

Where

M_i = The i-th percentile value of applied stress

$\hat{Y}$ = The mean of the natural logarithms of the modelled stresses

z_i = The z-score corresponding to the probability i, calculated using the NORMSINV function of Microsoft Excel

S_y = The standard deviation of the natural logarithms of the modelled stresses

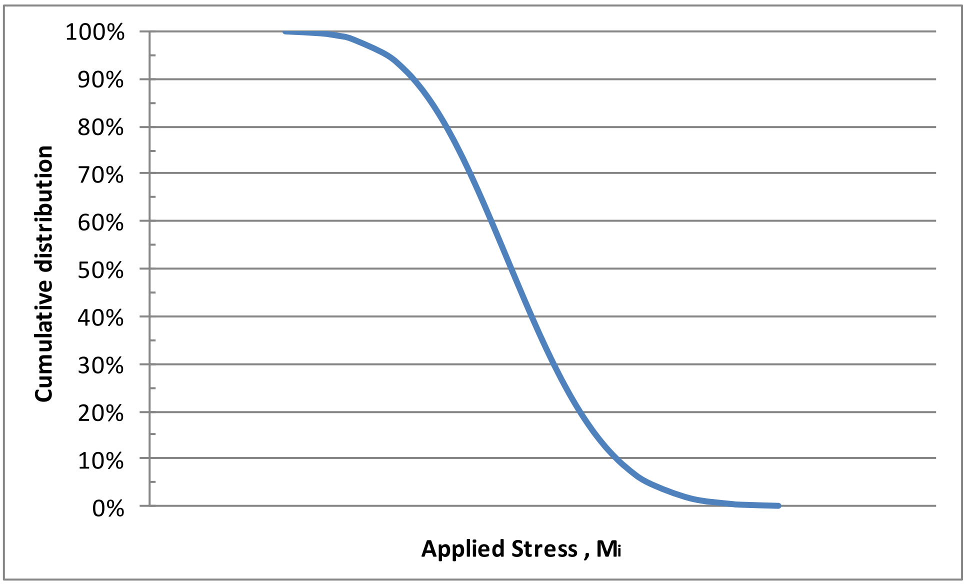


Figure 4.27 – Typical Cumulative Frequency Distribution for Applied Stress

For this assessment the capacities of a representative sample of finger joints were determined from testing. The testing was conducted using the method shown in Section 4.3.3.

The distribution of the finger joint capacity test results was also found to be approximately log-normal. A cumulative frequency distribution was then applied to the test results to determine the probability of occurrence of a finger joint below a nominated capacity. The cumulative frequency distribution is described by Equation (4.12). A typical cumulative frequency distribution for the finger joint capacities is shown in Figure 4.28.

$$M_{FW_i} = \exp(\hat{Y} + z_i S_y) \quad \textbf{(4.12)}$$

Where

$M_{FW\,i}$ = The i-th percentile value of finger joint capacity

$\hat{Y}$ = The mean of the natural logarithms of the test results

z_i = The z-score corresponding to the probability i, calculated using the NORMSINV function of Microsoft Excel

S_y = The standard deviation of the natural logarithms of the test results

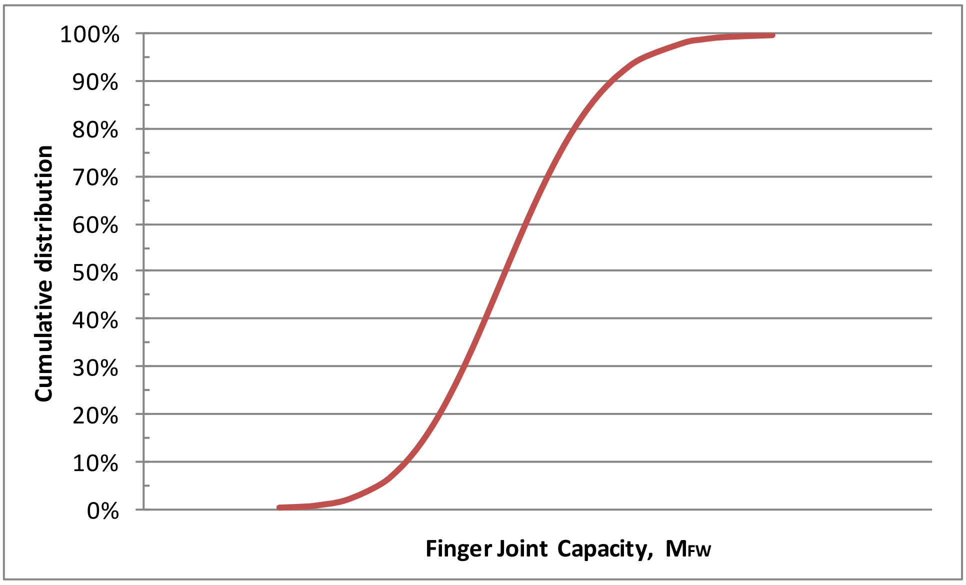


Figure 4.28 – Typical Cumulative Frequency Distribution for Finger Joint Capacity

The frequency distributions for applied stress and finger joint capacity were then plotted on the same graph. A typical graph of this type is shown in Figure 4.29. The y-axis value corresponding to the point at which the distributions intersect was taken to be the probability of the applied stress exceeding the capacity of the finger joint, $Prob_{STR}$, and, the probability of the capacity of the finger joint being inadequate to support the applied stress, $Prob_{CAP}$. The probability of the finger joint breaking under the stress applied at the specified location in the board, $Prob_{BREAK}$, was then calculated using Equation (4.13).

$$Prob_{BREAK} = Prob_{STR} \times Prob_{CAP} \tag{4.13}$$

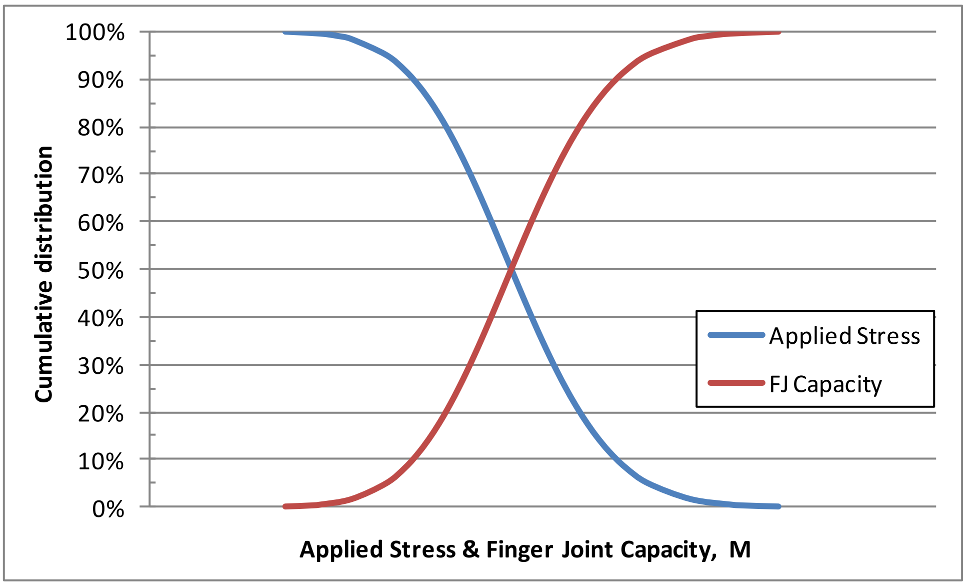


Figure 4.29 – Intersection of Applied Stress and Finger Joint Capacity Distributions

The probability of a finger joint occurring at this specific location then needed to assessed, to determine the overall probability of a board breaking at a finger joint during handling. It was considered that the length of the shortest off-cut likely to be used when manufacturing finger jointed timber is 450 mm. This results in a finger joint always occurring within 225 mm of the maximum moment location in a board. This region was divided into 5 equal zones, arranged concentrically about the maximum moment location, as shown in Figure 4.30. It was assumed that there was an equal possibility of a finger jointing being located in each of the 5 zones.

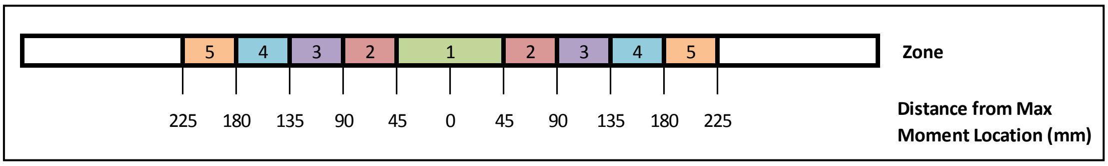


Figure 4.30 – Bending Moment Zones

The probability of the finger joint breaking, $Prob_{BREAK}$, was calculated at the boundaries of each zone, by the procedure described previously in this section, and the minimum and maximum value for each zone identified. The minimum, maximum, and average overall probability of a board breaking at a finger joint during handling was then calculated using Equations (4.14), (4.15), and (4.16), respectively.

$$Prob_{OA_{min}} = \frac{1}{5} \times \sum \left(Prob_{BREAK_{min}}\right)_i \qquad \textbf{(4.14)}$$

Where

$Prob_{OA_{min}} =$	The minimum overall probability of a board breaking at a finger joint during handling
$\left(Prob_{BREAK_{min}}\right)_i =$	The minimum probability of the finger joint breaking under the applied stress in zone *i*

$$Prob_{OA_{max}} = \frac{1}{5} \times \sum \left(Prob_{BREAK_{max}}\right)_i \qquad \textbf{(4.15)}$$

Where

$Prob_{OA_{max}} =$	The maximum overall probability of a board breaking at a finger joint during handling
$\left(Prob_{BREAK_{max}}\right)_i =$	The maximum probability of the finger joint breaking under the applied stress in zone *i*

$$Prob_{OA_{avg}} = \frac{1}{2} \times \left(Prob_{OA_{min}} + Prob_{OA_{max}}\right) \quad \textbf{(4.16)}$$

Where

$Prob_{OA_{avg}} =$ The average overall probability of a board breaking at a finger joint during handling

This assessment process was repeated for boards of various lengths, handled by each of the identified techniques. The results were collated and presented as design charts.

4.3.2 Modelling of Handling Stresses

The stresses applied to finger jointed boards during handling were modelled using static engineering principles. The following sections contain the appropriate loads and equations for calculating bending moment, for each handling technique.

4.3.2.1 Levering

The loads applied to a board when levering were identified in the literature review and are shown again in Figure 4.31.

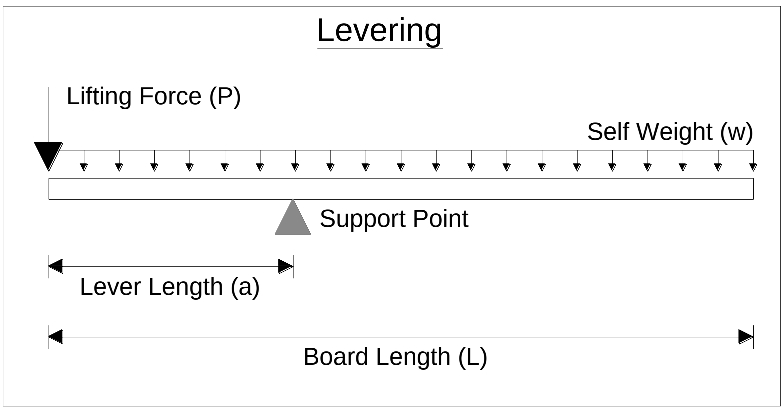


Figure 4.31 – Levering Loads

It was found from physical experimentation that the force required to raise a board by levering is only minimally larger than the force required to hold the board in balance. It is assumed that there is no residual moment acting on a board when it is in balance. As a result, the balancing force can be calculated relatively simply by summing the moments about the support point. The calculated balancing force, F_B, is shown in equation (4.17). This balancing force was adopted as an approximation of the Lifting Force, *P*.

$$F_B = \frac{wL(L-2a)}{2a} \tag{4.17}$$

Where

w = The self weight of the board (Density x Cross Sectional Area)

L = The length of the board

a = The length from the handled end of the board to the support point

The bending moment for this loading arrangement was approximated by combining the bending moment diagrams of 3 simple loading scenarios. The simple loading scenarios used, and their bending moment diagrams, are shown in Figure 4.32.

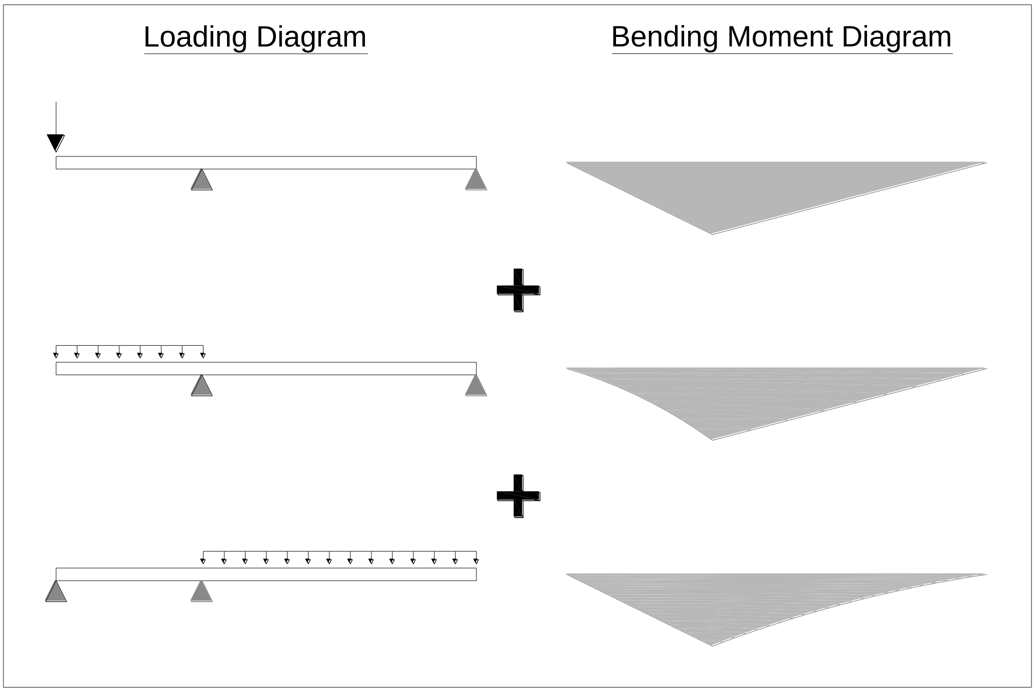


Figure 4.32 – Simplification of Levering Loads

The bending moment diagram for the overall load arrangement, determined by adding those shown in Figure 4.32, is shown in Figure 4.33.

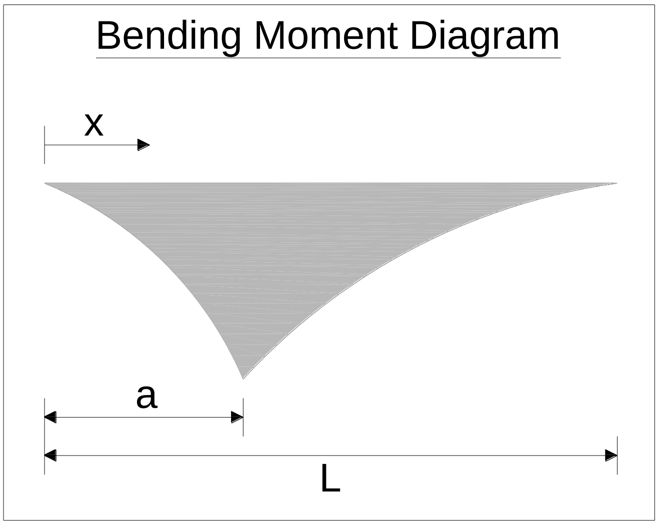


Figure 4.33 – Bending Moment Diagram of Levered Board

The bending moment, M_i, at any point in a levered board, x, as shown by the bending moment diagram in Figure 4.33, can be calculated by Equation (4.18), and Equation (4.19).

When x ≤ a,

$$M_i = \frac{wx}{2}\left(\frac{2}{a}(L-a)^2 + x - a\right) \tag{4.18}$$

When x > a,

$$M_i = \frac{w}{2}(L-x)(2L-x-a) \tag{4.19}$$

Where

w = The self weight of the board (Density x Cross Sectional Area)

x = The distance from the handled end of the board

L = The length of the board

a = The length from the handled end of the board to the support point

4.3.2.2 Two Man Lift

The loads applied to a board when lifted by both ends were identified in the literature review and are shown again in Figure 4.34.

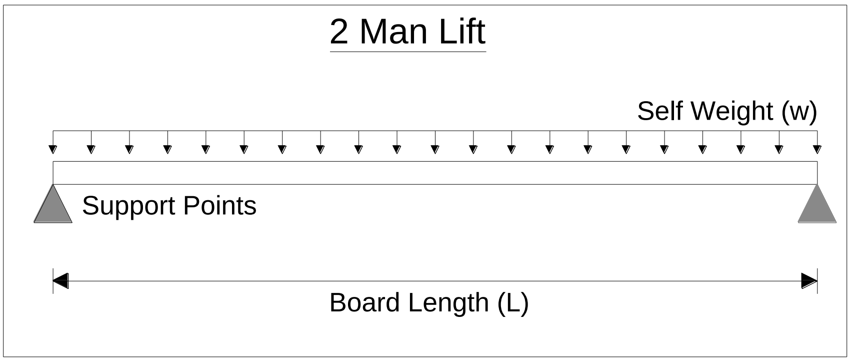


Figure 4.34 – 2 Man Lift Loads

This arrangement is a simply supported beam. The bending moment diagram and equation were sourced from American Wood Council (2007), and are shown in Figure 4.35, and Equation (4.20), respectively.

$$M_i = \frac{wx}{2}(L - x) \qquad \textbf{(4.20)}$$

Where

w = The self weight of the board (Density x Cross Sectional Area)

x = The distance from the end of the board

L = The length of the board

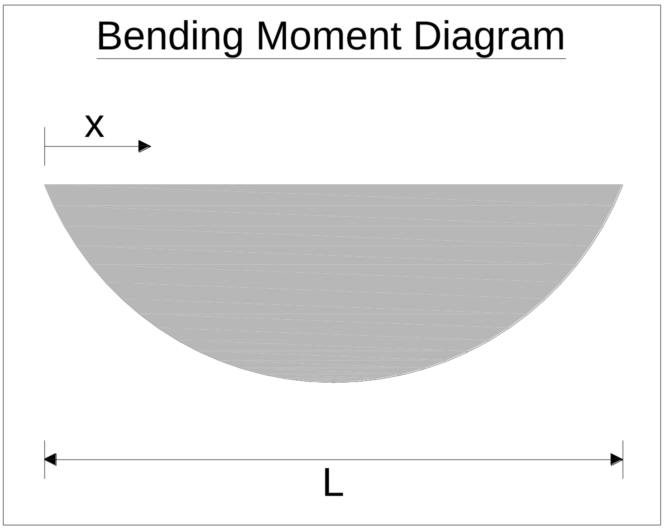


Figure 4.35 – Bending Moment Diagram of 2 Man Lifted Board

4.3.2.3 Fork Lifted Board

The loads applied to a board when lifted by a fork lift were identified in the literature review and are shown again in Figure 4.36.

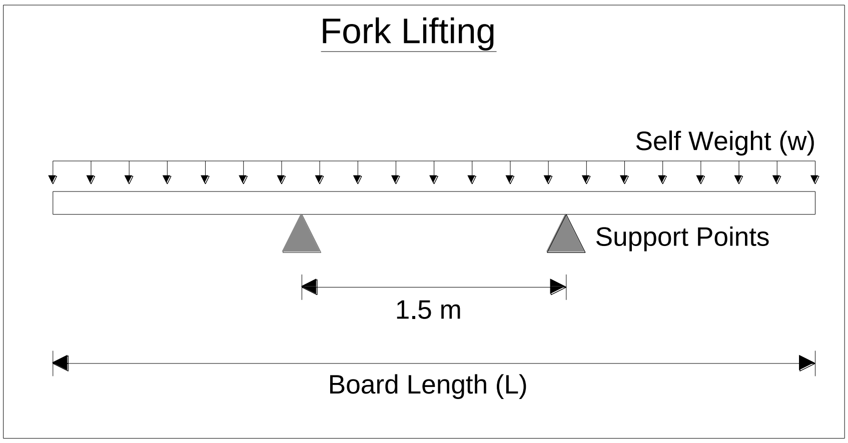


Figure 4.36 Fork Lifting Loads

This is a standard arrangement contained in American Wood Council (2007). The bending moment diagram is shown in Figure 4.37.

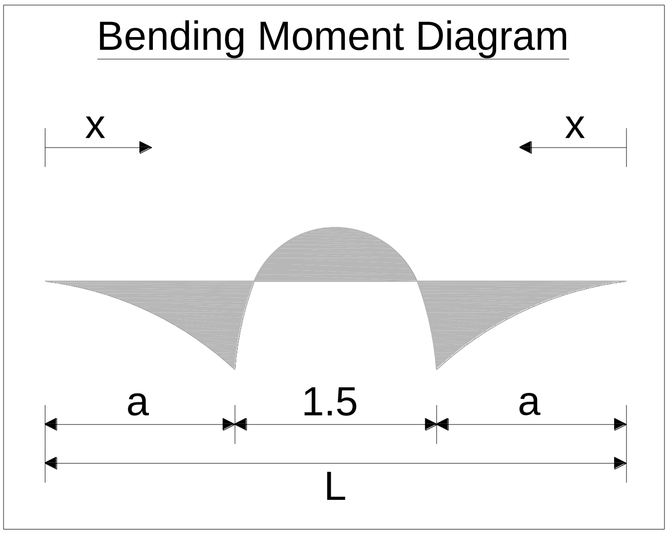


Figure 4.37 – Bending Moment Diagram of Fork Lifted Board

The standard fork lift support spacing of 1.5 metres was substituted into the standard bending moment formula for this arrangement. The bending moment, M_i, at any point in a fork lifted board, x, as shown by the bending moment diagram in Figure 4.37, could then be calculated by Equation (4.21), and Equation (4.22).

When x ≤ a,

$$M_i = \frac{-wx^2}{2} \tag{4.21}$$

When a < x ≤ L/2,

$$M_i = \frac{wL}{3}(L - 2a)(x - a) - \frac{wx^2}{2} \tag{4.22}$$

Where

w = The self weight of the board (Density x Cross Sectional Area)

x = The distance from either end of the board

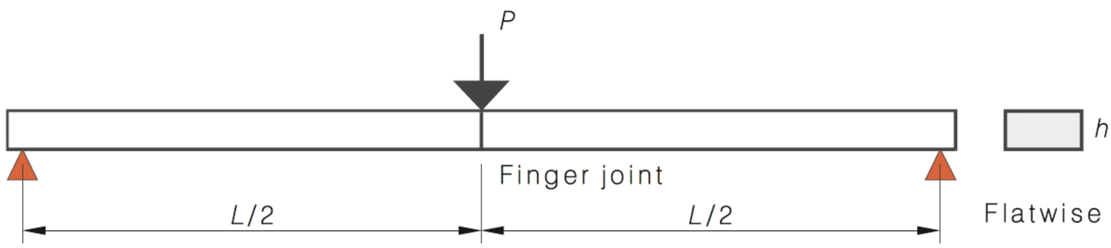
L = The length of the board

a = The length from the end if the board to the adjacent support point (a= 0.5(L - 1.5))

4.3.3 Test Method

Testing of 30 samples of finger jointed timber was completed in Hyne and Son's Tuan test rig, modified to perform three point loading, as shown previously in Figure 4.8. The samples were cut randomly from the finger jointed timber produced for this project, with a finger joint at the mid-point. Each sample was weighed before testing and its density determined.

All samples were subjected to three point loading, in the configuration required by AS5068 (2006), as shown in Figure 4.38. All specimens were 90 x 35 mm in section, 650mm long, and were tested over a span of 540mm.



NOTES:

1 Span-depth ratio $L/h \geq 12$.

2 Finger joint orientation may be face-to-face, as shown, or edge-to-edge.

Figure 4.38 – AS5068 3-point Flatwise Test Set-up

Load was applied to the test sample via a spreader beam driven by an Enerpac 10 ton hydraulic ram. The applied load was measured by a Kelba 10 ton S-type load cell. The applied load at failure of the test sample was recorded, along with the failure mode as described by AS5068 (2006). A copy of the AS5068 (2006) failure mode classifications is contained in Appendix G.

The recorded failure load was used with Equation (4.23) to determine the flatwise bending moment capacity, M_{FW}, of each sample.

$$M_{FW} = \frac{PL}{4} \tag{4.23}$$

Where

P = The recorded failure load

L = The test span

4.4 Truss Erection Issues

This section outlines the testing and assessment methods used to determine the probability of finger jointed timber truss chords breaking at a finger joint, when subjected to the temporary construction loads identified in the literature review.

4.4.1 Assessment

Finger jointed timber truss chords contain glued connections at which they could potentially fail. These connections occur regularly, with their location depending upon the length off-cuts used for manufacture. This assessment involves determining the probability of truss chords breaking at finger joints, under various scenarios, to provide information that enables end users to manage any associated risk.

The assessment was conducted by adopting the same overall process that was used for assessing fabrication issues in Section 4.3.1. The stresses applied to the truss chords are dependent upon the weight of the builders standing upon them, and, as for handling stresses, were modelled using static engineering principles. The weights of builders used in this assessment were based on statistical data for the general population of Australian adult males in McLennan and Podger (1995). Average and standard deviation values were sourced and, by considering the data to be normally distributed, converted to a cumulative frequency distribution using Equation (4.24).

$$P_i = \hat{Y} - z_i S_y \tag{4.24}$$

Where

P_i = The i-th percentile value of builder's mass

$\hat{Y}$ = The mean body weight value from McLennan and Podger (1995)

z_i = The z-score corresponding to the probability i, calculated using the NORMSINV function of Microsoft Excel

S_y = The standard deviation body weight value from McLennan and Podger (1995)

The stresses in a truss chord subjected to a builder's weight were modelled, at specified locations, using the methods described in Section 4.4.2. The stress modelling results presented values that could be described by the same frequency distribution as the builder's weights. When attributed to the stresses, Equation (4.25) describes the frequency distribution.

$$M_i = \hat{Y} - z_i S_y \tag{4.25}$$

Where

M_i = The i-th percentile value of stress in the truss chord

$\hat{Y}$ = The mean value of the modelled stresses

z_i = The z-score corresponding to the probability i, calculated using the NORMSINV function of Microsoft Excel

S_y = The standard deviation of the modelled stresses

The capacities of a representative sample of finger joints were again determined by testing. The testing was conducted using the method shown in Section 4.4.3. A cumulative frequency distribution was applied to the test results in an identical means to Section 4.3.1.

The balance of the assessment was then carried out exactly as it was for handling loads, refer Section 4.3.1 for details. The assessment process was repeated for both loading situations identified. A number of truss spans and eave widths were assessed. The results were collated and presented as design charts.

4.4.2 Modelling of Handling Stresses

The stresses applied to finger jointed truss chords subject to temporary construction loads were modelled using static engineering principles. The following sections contain the appropriate equations for calculating bending moment, for chords loaded at the end of overhangs, and at the mid-point of panels.

4.4.2.1 Loads on Truss Overhangs

The critical loading location, representing a builder standing on a truss overhang, was identified in the literature review and is shown again in Figure 4.39.

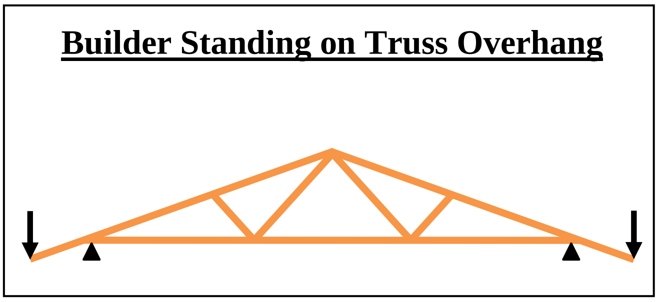


Figure 4.39 – Truss Overhang Loads

This loading arrangement was approximated by considering each top chord of the truss as a separate, simply supported beam with overhang. The simple span represents the panel of the truss chord closest to the supporting wall, and a nominal span of 2.4 m was used. The self weight of the truss chord was considered to have minimal effect when combined with the builders mass. As a result, the point load only was used for modelling the stresses applied to the truss chord. The loading arrangement used for modelling is shown in Figure 4.40.

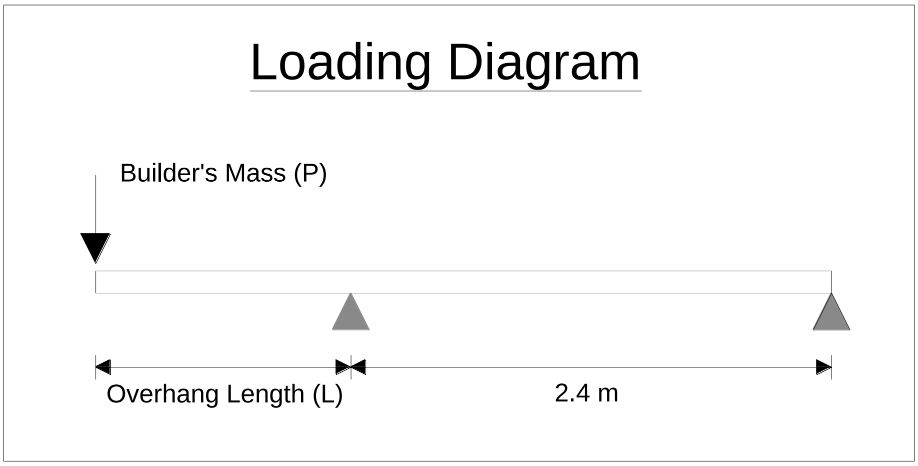


Figure 4.40 – Simplification of Overhang Loads

The overhang length, L, is dependent upon the eave width of the building. When considering standard trusses, which run perpendicular to the supporting walls, as shown in Figure 4.41, the overhang length is simply the eave width. When considering hip trusses, which run at 45^{o} to the supporting walls, also shown in Figure 4.41, Equation (4.26) is used to calculate the overhang length, L.

$$L = \sqrt{2(W_E)^2} \tag{4.26}$$

Where

W_E = The eave width of the building

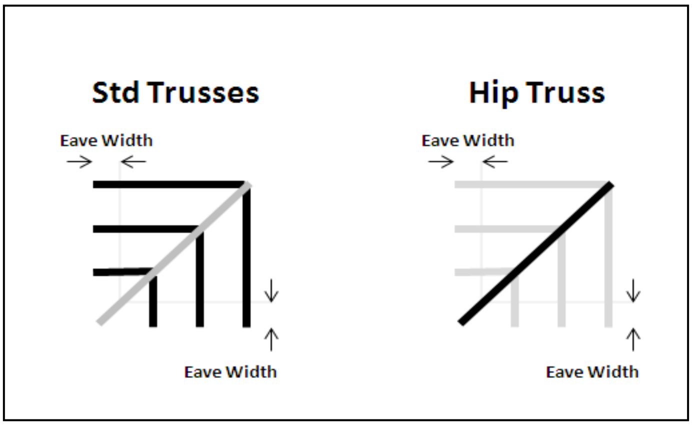


Figure 4.41 – Orientation of Standard and Hip Trusses

The loading arrangement used is a standard configuration contained in American Wood Council (2007). The bending moment diagram is shown in Figure 4.42.

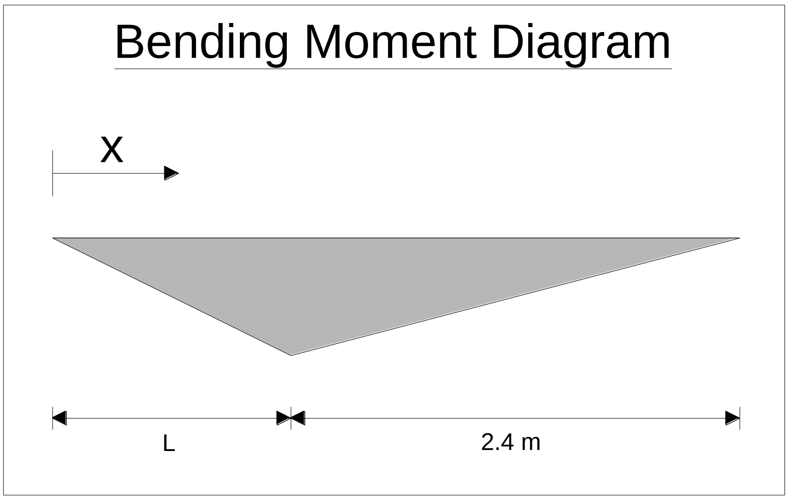


Figure 4.42 – Bending Moment Diagram of Truss Overhang

The adopted simple span of 2.4 metres was substituted into the standard bending moment formula for this arrangement. The bending moment, M_i, at any point in the truss chord, x, as shown by the bending moment diagram in Figure 4.42, could then be calculated by Equation (4.27), and Equation (4.28).

When x ≤ L,

$$M_i = Px \quad \textbf{(4.27)}$$

When x > L,

$$M_i = \frac{PL}{2.4}(L + 2.4 - x) \quad \textbf{(4.28)}$$

Where

P = The weight of the builder

x = The distance from the end of the overhang

L = The overhang length

4.3.2.2 Loads on Bottom Chord Panels

The critical loading locations, representing a builder standing on a truss bottom chord, were identified in the literature review and are shown again in Figure 4.43.

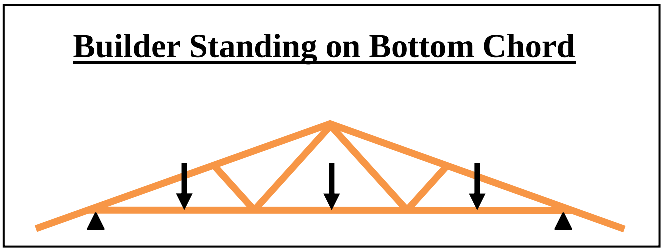


Figure 4.43 – Truss Bottom Chord Loads

The bottom chord was considered as a continuous beam, consisting of three equal spans, for modelling the bending moment. The self weight of the truss chord was considered to have minimal effect when combined with the builders mass. As a result, the point load only was used for modelling the stresses applied to the truss chord. The literature review identified Clapeyron's Theorem of Three Moments as the appropriate method for modelling this configuration. Initial calculations using Clapeyron's Theorem showed that more severe moments occur when a point load is applied to one of the end spans, and this load location was adopted. The loading arrangement used for modelling is shown in Figure 4.44.

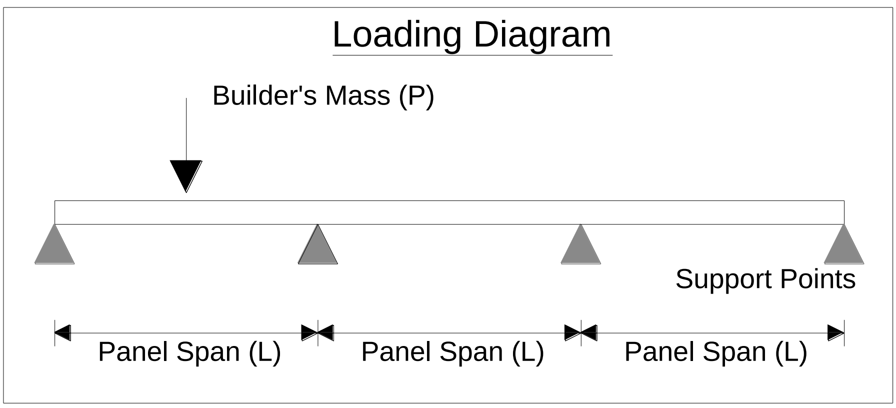


Figure 4.44 – Bottom Chord Loading Diagram

Clapeyron's Theorem was used, in conjunction with similar triangles, to determine the bending moment diagram, and bending moment formula, for the arrangement. The resulting moment diagram is shown in Figure 4.45.

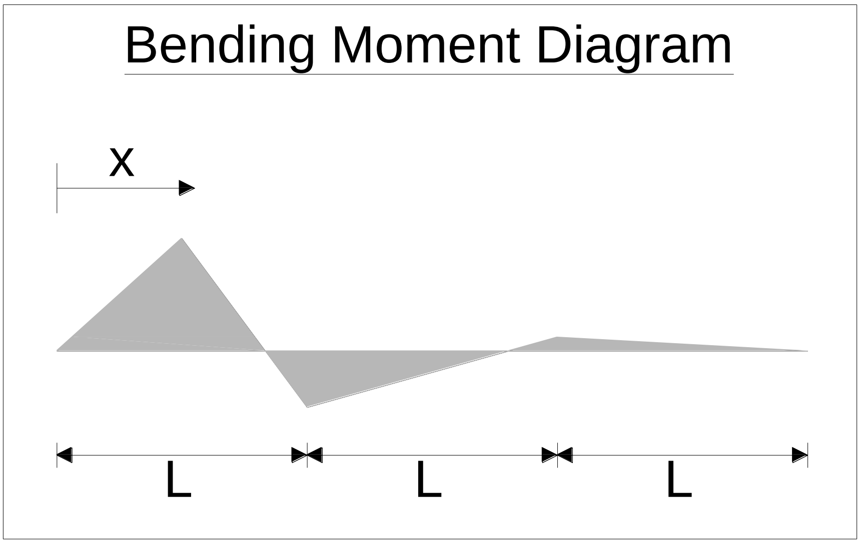


Figure 4.45 – Bending Moment Diagram of Bottom Chord

The bending moment, M_i, at any point in the truss chord, x, as shown by the bending moment diagram in Figure 4.45, could then be calculated by Equations (4.29), (4.30), (4.31) and (4.32).

When $x \leq L/2$,

$$M_i = \frac{2Px}{5} \tag{4.29}$$

When $L/2 < x \leq L$,

$$M_i = \frac{P}{2}\left(L - \frac{6x}{5}\right) \tag{4.30}$$

When $L < x \leq 2L$,

$$M_i = \frac{P}{8}\left(x - \frac{9L}{5}\right) \tag{4.31}$$

When $2L < x \leq 3L$,

$$M_i = \frac{P}{40}(3L - x) \tag{4.32}$$

Where

P = The weight of the builder

x = The distance from the end of the truss adjacent to the load

L = The panel span

4.4.3 Test Method

Testing of 20 samples of finger jointed timber was completed in Hyne and Son's Tuan test rig, modified to perform three point loading, as shown in Figure 4.46. The samples were cut randomly from the finger jointed timber produced for this project, with a finger joint at the mid-point. Each sample was weighed before testing and its density determined.

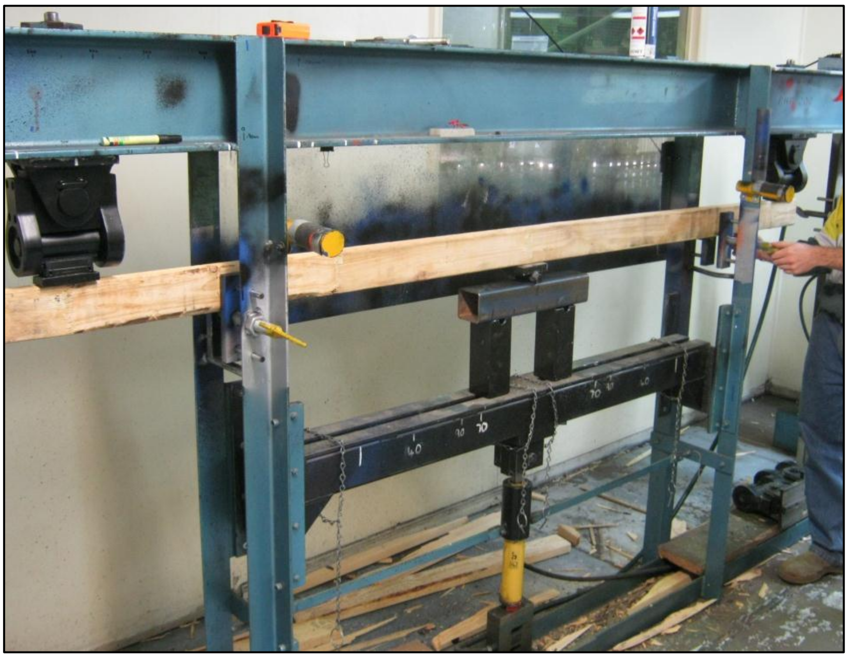


Figure 4.46 – Hyne & Son's Tuan Bending Rig Adjusted for 3-point testing

All samples were subjected to three point loading, in the configuration required by AS5068 (2006), as shown in Figure 4.47. All specimens were 90 x 35 mm in section, 2600mm long, and were tested over a span of 2320mm, to more accurately replicate in-service conditions.

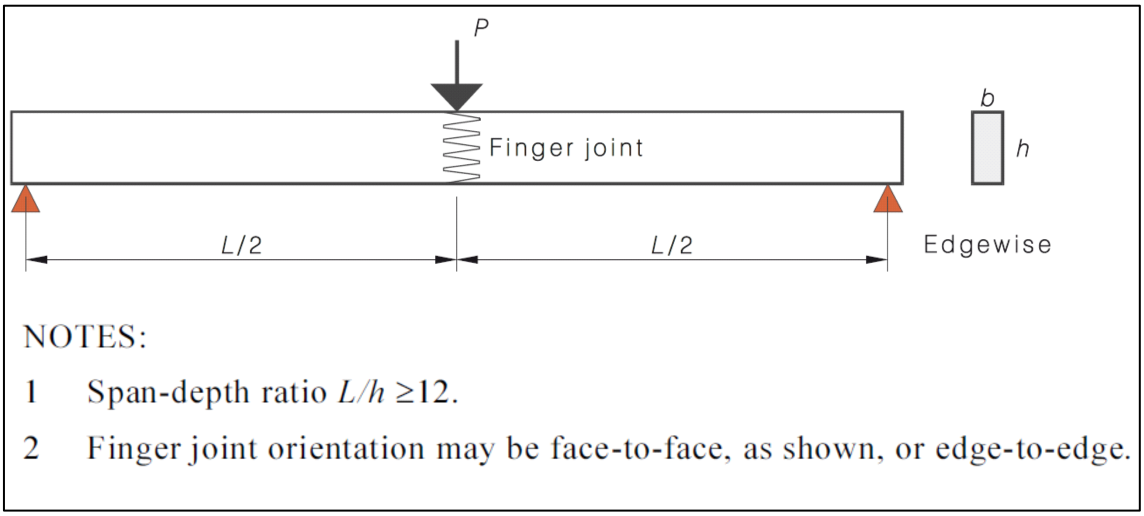


Figure 4.47 – AS5068 3-point Edgewise Test Set-up

Load was applied to the test sample via a spreader beam driven by an Enerpac 10 ton hydraulic ram. The applied load was measured by a Kelba 10 ton S-type load cell. The applied load at failure of the test sample was recorded, along with the failure source and location, measured from the centre of the test span.

The recorded failure load was used with Equation (4.33) to determine the edgewise bending moment capacity, M_{EW}, of each sample.

$$M_{EW} = \frac{P\left(\frac{L}{2}-L_v\right)}{2} \tag{4.33}$$

Where

P = The recorded failure load

L = The test span

L_v = The horizontal distance from the point of failure to the centre of the test span

Chapter 5

Test Results and Discussion

5.0 Introduction

The performance criteria, critical in determining the suitability of finger jointed timber for use in nail plated roof trusses, were highlighted in the literature review. Methods to measure this performance were also identified. The application of these test methods, and the process for analysing the subsequent results, was discussed in detail in the previous chapter.

This chapter outlines the results that were obtained from the performance testing. The data measured, and observations made throughout testing, are discussed. The outcomes obtained from assessing the performance of finger jointed timber against appropriate benchmarks are also presented.

5.1 Mechanical Properties

This section presents the results, and assessment, of testing conducted on the mechanical properties of finger jointed timber using the methods contained in Section 4.1. The results for all properties tested are presented initially, followed by an individual discussion for each series of tests.

5.1.1 Overview of Results

Table 5.1 presents the results of testing conducted on 90 x 35 mm finger jointed timber for Bending Stiffness, Bending Strength, Tension Strength, Shear Strength and Compression Strength. It also shows the target value for each, as identified in the literature review.

Mechanical Property	No. of Samples	Average Density (kg/m^3)	FJ Timber Calculated Characteristic Value (MPa)	Target MGP10 Characteristic Value (MPa)
Modulus of Elasticity, E	30	578	10 155	10 000
Bending Strength, f_b	30	578	21.54	17.0
Tension Strength, f_t	30	585	13.05	7.7
Shear Strength, f_s	62 (18)[1]	596 (636)[2]	3.02	2.6
Compression Strength, f_c	30	580	21.87	18.0

Notes: [1] – Analysis based on 18 samples that exhibited shear failure from a total of 62 tested

[2] – Bracketed value indicates average density of 18 samples exhibiting shear failure only

Table 5.1 – Summary of Mechanical Property Test Results

The consistency in the average density measured for each test type indicates that a representative sample of finger jointed timber was tested in each case. It can be noted from Table 5.1 that, for each property tested, the characteristic value calculated from test results exceeds the characteristic value for standard 90 x 35 mm MGP10, defined by AS1720.1 (2010).

As a result of this testing it is considered that the 90 x 35 mm finger jointed timber produced for this trial could be directly substituted for standard MGP10 framing, from a mechanical property perspective.

5.1.2 Bending Stiffness

The characteristic Modulus of Elasticity of the finger jointed timber tested was determined to be 10155 MPa, as shown in Table 5.1. A detailed record of the testing data and analysis used to calculate this value is contained in Appendix H.1.

Investigation of the detailed results shows the coefficient of variation for the stiffness of individual samples to be 21.4%. This value is similar to the coefficient of variation of 18% achieved during the Quality Control testing of standard 90 x 35 MGP10 at Hyne and Son's Tuan Mill, in the last year.

Testing regularly indicates a reasonably strong relationship between the density and stiffness of timber. A comparison of density and Modulus of Elasticity for each sample of finger jointed timber tested is shown in Figure 5.1.

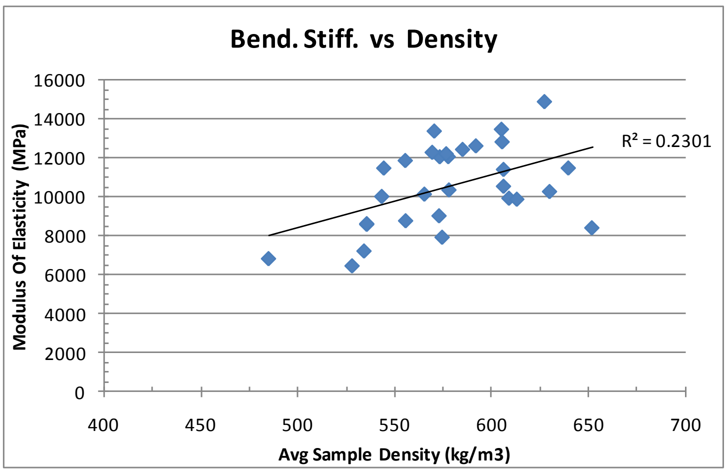


Figure 5.1 – Relationship between Bending Stiffness and Average Sample Density

The relationship displayed in Figure 5.1 is not as strong as expected. This is most likely a result of the variation in density that can occur between off-cuts contained in the same test sample. The average density may be influenced by an off-cut occurring outside the centrally located, maximum moment zone responsible for the majority of deflection in a four point bending test. A comparison of density at mid-span and Modulus of Elasticity for each sample tested is shown in Figure 5.2

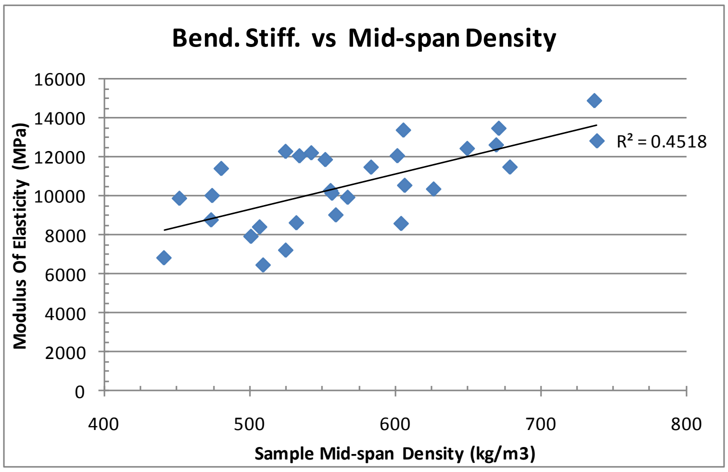


Figure 5.2 – Relationship between Bending Stiffness and Sample Mid-span Density

Figure 5.2 shows a much stronger relationship when the density at mid-span is considered. This indicates that bending stiffness is influenced more by the local density at critical locations, than by the overall density of the board.

Although the grading of off-cuts conducted as a part of this project was proven to be adequate by the test results, it is likely that improved bending stiffness could be attained for finger jointed timber if lower density off-cuts were minimised as a part of the manufacture process.

5.1.3 Bending Strength

The characteristic Bending Strength of the finger jointed timber tested was determined to be 21.54 MPa, as shown in Table 5.1. A detailed record of the testing data and analysis used to calculate this value is contained in Appendix H.1.

Investigation of the detailed results shows the coefficient of variation for the stiffness of individual samples to be 22.4%. This value is far less than the coefficient of variation of 36% achieved during the Quality Control testing of standard 90 x 35 MGP10 at Hyne and Son's Tuan Mill, in the last year. The greater uniformity in test results is thought to be due to a combination of, reducing the number of naturally occurring defects through grading of the off-cuts, and, introducing a more predictable failure source in the form of finger joints.

The mode by which the samples failed was monitored as a part of testing. Typically, failure initiated at a finger joint or knot, near the tension edge, in the centrally located, maximum moment zone. When failure was initiated by a finger joint a brittle bending failure generally occurred with the fracture propagating directly from the tension edge to the compression edge. This failure type is shown in Figure 5.3. In samples which initially fractured at knots, tensile stresses perpendicular to the grain appeared to be induced in the reduced section, and the fracture propagated longitudinally through the board, as shown in Figure 5.4.

Figure 5.3 – Typical Bending Failure at Finger Joint

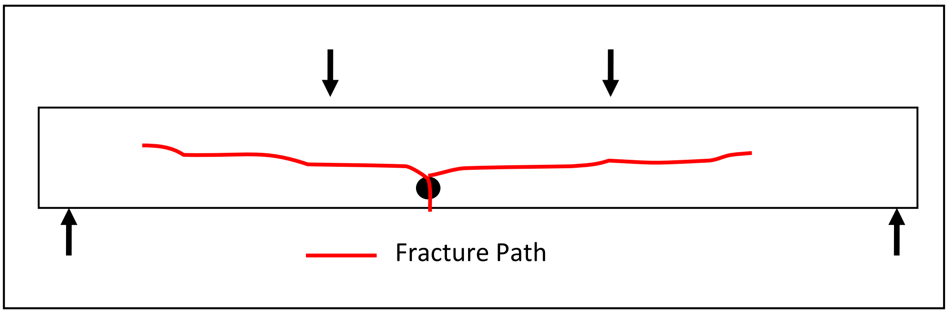


Figure 5.4 – Typical Bending Failure at Knot

A total of 30 samples were tested, of which, 26 failed at finger joint, including the 6 lowest results. This indicates that maintaining a high quality finger joint is critical in producing finger jointed timber with adequate bending strength.

5.1.4 Tension Strength

The characteristic Tension Strength of the finger jointed timber tested was determined to be 13.05 MPa, as shown in Table 5.1. A detailed record of the testing data and analysis used to calculate this value is contained in Appendix H.2.

Investigation of the detailed results shows the coefficient of variation for the strength of individual samples to be 21.8%. This value is similar to the coefficient of variation of 19% reported for 90 x 35 mm F5 in a confidential report on timber properties prepared in 1993 by CSIRO.

The mode by which the samples failed was again monitored as a part of testing. Typically, brittle failure occurred at finger joints or knots, or a combination of both. A typical finger joint, knot and combination failure is shown in Figures 5.5, 5.6 and 5.7, respectively.

Figure 5.5 – Typical Tension Failure at Finger Joint

Figure 5.6 – Typical Tension Failure at Knot

Figure 5.7 – Typical Tension Failure at Finger Joint and Knot

A total of 30 samples were tested, of which, 18 failures contained knots, either alone or in combination with a finger joint. Included in these were 14 of the 16 lowest test results. The test results indicate that limiting the size of knots, and their location with regards to finger joints, are important measures in ensuring adequate tension strength in finger jointed timber.

5.1.5 Compression Strength

The characteristic Compression Strength of the finger jointed timber tested was determined to be 21.87 MPa, as shown in Table 5.1. A detailed record of the testing data and analysis used to calculate this value is contained in Appendix H.3.
Due to limitations in the available test equipment, the minimum test span recommended by AS/NZS 4063.1 (2010) could not be used. This Australian Standard recommends that an adjustment factor be applied to results obtained under non-standard test conditions. However, it does not provide methods for determining the required adjustment factor.

The 1992 version of this standard provides advice on adjusting test results for non-standard test spans. It indicates that an adjustment need not be applied to non-standard compression tests so long as “significant defects” are present within the tested sample. All samples tested as a part of this project were randomly selected, and contained multiple knots and finger joints. The samples were approximately 90% of the recommended length. It is considered highly likely, given the random nature of finger jointed timber, that the most “significant defects” have been included in the test samples.

As a result, it is considered that the characteristic value for compression strength obtained through testing is representative of the finger jointed material produced for the project, and has not been compromised by the non-standard test conditions.

Investigation of the detailed results shows the coefficient of variation for the strength of individual samples to be 12.5%. This value is similar to the coefficient of variation of 16% reported for 90 x 35 mm F5 in a confidential report on timber properties prepared in 1993 by CSIRO.

The mode by which the samples failed was again monitored as a part of testing. Typically, failure consisted of localised fibre buckling and splitting at finger joints or knots, or in low density clear wood. This failure mode is highlighted in Figures 5.8, 5.9 and 5.10, respectively.

Figure 5.8 – Typical Compression Failure at Finger Joint

Figure 5.9 – Typical Compression Failure at Knot

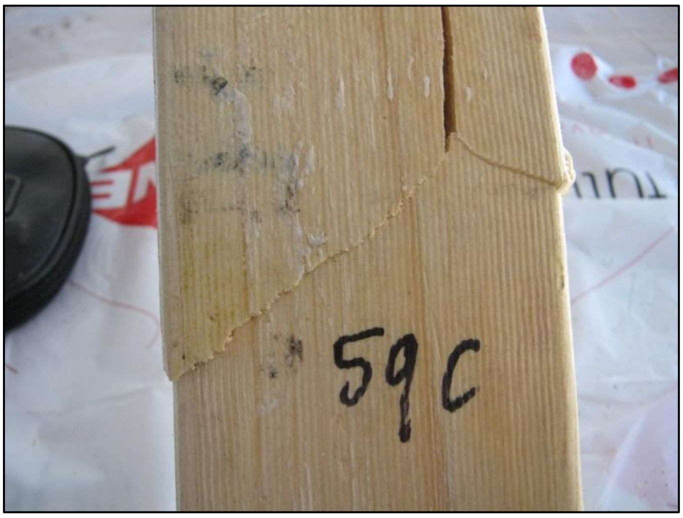


Figure 5.10 – Typical Compression Failure in Low Density Wood

A total of 30 samples were tested, of which, 20 failed at knots, including the 12 lowest results. Further analysis of the results indicated that failures at larger knots generally result in lower compression strengths. This indicates that limiting the size of knots is critical in producing finger jointed timber with adequate compression strength.

5.1.6 Shear Strength

Despite following the methods prescribed in AS/NZS 4063.1 (2010), inducing shear failure in the timber during testing proved extremely difficult. A total of 62 samples were tested with only 18 exhibiting shear-like failures.

Generally 30 samples are required to confidently determine a characteristic strength value using the method described in AS/NZS 4063.2 (2010). The characteristic Shear Strength of the finger jointed timber tested, shown in Table 5.1, has been calculated using this method, based on the 18 samples that failed in shear only. A detailed record of the testing data and analysis is contained in Appendix H.4.

The detailed data shows that the majority of samples failed in bending. This was observed to be particularly prevalent when a finger joint was located near mid-span. This failure type was shown previously in Figure 5.3. Bending failures were also common at knots and in clear wood at mid-span.

The 18 shear failures that did occur typically commenced with a fracture on the tension edge of a sample, at a finger joint or knot, and propagated horizontally through the sample. This failure mode is shown in Figure 5.11. The characteristic end grain "slip" associated with shear fractures was used to identify these failures. This characteristic is shown in Figure 5.12.

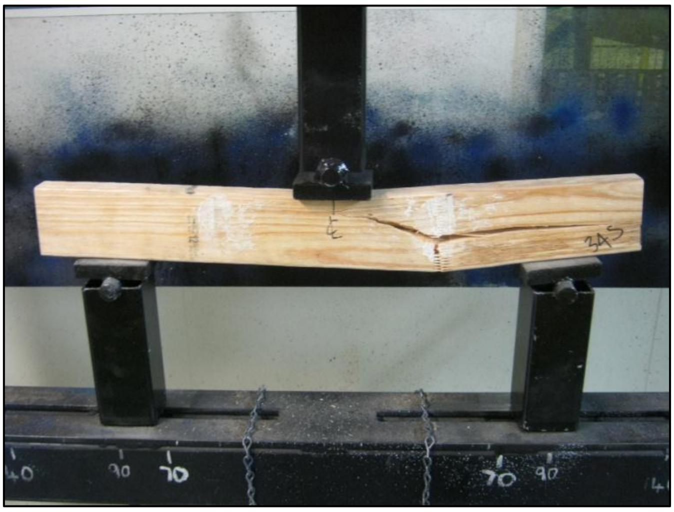


Figure 5.11 – Typical Shear-Like Failure Originating at Finger Joint

Figure 5.12 – Characteristic End Grain Slip of Shear Failures

The difficulties encountered in producing shear failures using this test method have been identified previously. Papers by Lavielle, Gibier and Stringer (1996) and Leicester and Breitinger (1992) highlight these problems and investigated other potential methods for testing the shear strength of beams, in a manner that reflects in-service performance. These methods include double-span testing with equal, and unequal, spans. Shear block testing, which is not particularly representative of in-service conditions, is also discussed in these papers.

An investigation into to the comparative performance of each of these methods, with the aim of identifying an improved method for testing beam shear in solid timber, is recommended. Based on the findings of such an investigation, further testing could be conducted which would allow a value of characteristic shear strength to be determined for finger jointed timber, with greater confidence.

5.2 Truss Joints and Connections

This section presents the results, and assessment, of testing conducted on truss joints and connections containing finger jointed timber and standard MGP10 framing, using the methods contained in Section 4.2. The results for all joint and connection types tested are presented initially, followed by an individual discussion for each series of tests.

5.2.1 Overview of Results

Table 5.2 presents the results of strength testing conducted on truss joints and connections constructed using 90 x 35 mm finger jointed timber, fastened with nail plates at different orientations, batten screws, Gang-Nail MultiGrips with nails, and girder bracket screws. It also shows the results of identical tests conducted on identical joints and connections constructed from standard 90 x 35 mm MGP10 framing.

The consistency in the average densities, measured for all joint types, indicates that a representative sample of both timber types was tested in each case. The similarities in the average density of finger jointed timber and standard MGP10 framing samples, when compared for each test type, suggest that any difference in the performance of the two is unlikely to be due to wood quality.

It can be noted from Table 5.2 that, for the joints and connections tested, the average joint capacity for finger jointed timber and standard MGP10 framing are within 10%, in all cases. Similar standard deviations were attained in all cases. The test results were compared using a standard statistical test for assessing the significance of the difference of means of small populations, as described in Section 4.2.1. The right hand column of Table 5.2 indicates that there was no significant difference in the performance of finger jointed timber and standard MGP10 framing for all of the joints and connections tested. As a result of this testing it is considered that the 90 x 35 mm finger jointed timber produced for this trial would perform equivalently to standard MGP10 framing, from a joint capacity perspective.

Joint Type	Finger Jointed Timber				Standard MGP10 Framing				Result of Statistical Significance Of Difference Test
	No. of Samples	Avg. Density (kg/m^3)	Joint Capacity (kN)		No. of Samples	Avg. Density (kg/m^3)	Joint Capacity (kN)		
			Avg.	Std. Dev			Avg.	Std. Dev	
Nail Plate Parallel to Grain	20 (18)[1]	569 (566)[2]	39.19	1.04	20 (19)[3]	525 (525)[4]	39.53	1.07	No Significant Difference
Nail Plate Perp. to Grain	20	581	7.51	1.15	20	561	7.02	1.29	No Significant Difference
Type 17 Batten Screw	10	575	5.90	1.09	10	574	5.33	1.07	No Significant Difference
MultiGrip with nails	10	569	4.48	1.13	10	563	4.26	1.22	No Significant Difference
No. 14 screws	10	560	10.54	1.23	10	552	10.56	1.12	No Significant Difference

Notes: [1] – Analysis based on 18 samples that exhibited failure at joint from 20 tested

[2] – Bracketed value indicates average density of 18 samples exhibiting joint failure only

[3] – Analysis based on 19 samples that exhibited failure at joint from 20 tested

[4] – Bracketed value indicates average density of 19 samples exhibiting joint failure only

Table 5.2 – Summary of Truss Joint and Connection Test Results

Table 5.3 presents the results of joint deformation testing conducted on 90 x 35 mm finger jointed timber and standard MGP10, splice joined using 150 x 75 mm Gang-Nail plates. It also shows the results of identical tests conducted on finger jointed timber and standard MGP10 framing without nail plated joints.

Joint Type	Finger Jointed Timber				Standard MGP10 Framing				Result of Statistical Significance Of Difference Test
	No. of Samples	Avg. Density (kg/m^3)	Joint Stiffness (GPa)		No. of Samples	Avg. Density (kg/m^3)	Joint Stiffness (GPa)		
			Avg.	Std. Dev			Avg.	Std. Dev	
Nail Plate Parallel to Grain	10	560	NMR[1]		10	553	NMR[1]		NMR[1]
Nail Plate Perp. to Grain	10	599	11.0	4.33	10	609	11.4	4.24	No Significant Difference

Notes: [1] – NMR indicates that no meaningful result was obtained

Table 5.3 – Summary of Joint Deformation Test Results

Table 5.3 shows that no meaningful results were obtained from the joint stiffness testing of nail plated splice joints in both finger jointed timber and standard MGP10 framing. This is the result of inadequacies in the test method adopted, and data recording errors. These will be discussed in more detail in Section 5.2.7.

Due to the inadequate test method, and data recording errors, no conclusion can be drawn regarding the performance of finger jointed timber, from a joint deformation perspective. It is recommended that the joint deformation testing be repeated, using techniques suggested in Section 5.2.7, so that the effect of finger joints on the stiffness of nail plated joints can be assessed.

Results were obtained for the tensile stiffness of finger jointed timber across a finger joint, and for standard MGP10 clear wood. As indicated in Table 5.3 the average sample density for both timber types was very similar, suggesting that any difference in the performance of the two is unlikely to be due to wood quality.

Table 5.3 also shows that the average, and standard deviation, of the measured tensile stiffness for each timber type were very similar. The test results were compared using a standard statistical test for assessing the significance of the difference of means of small populations, as described in Section 4.2.1. The right hand column of Table 5.3 indicates that there was no significant difference in the tensile stiffness of finger jointed timber and standard MGP10 framing for the samples tested.

As a result of this testing it is considered that the finger joints have no significant effect on the tensile stiffness of 90 x 35 mm structural timber. This also provides further confirmation of the results achieved in the bending stiffness testing of finger jointed timber.

5.2.2 Nail Plate Parallel to the Grain

No significant difference in joint capacity was observed between finger jointed timber and standard MGP10 framing connected by 150 x 75 mm nail plates, orientated parallel to the grain of the timber, as shown in Table 5.2. A detailed record of the testing data and assessment conducted is contained in Appendix I.1.

A total of 3 samples, from the 40 tested, were excluded from the analysis of test results. One sample constructed from each timber typed failed at a knot, located a significant distance from the nail plated joint, as shown in Figure 5.13. It was considered that this failure type was not related to the joint performance being assessed, and as a result it would be inappropriate to include the result in the performance comparison.

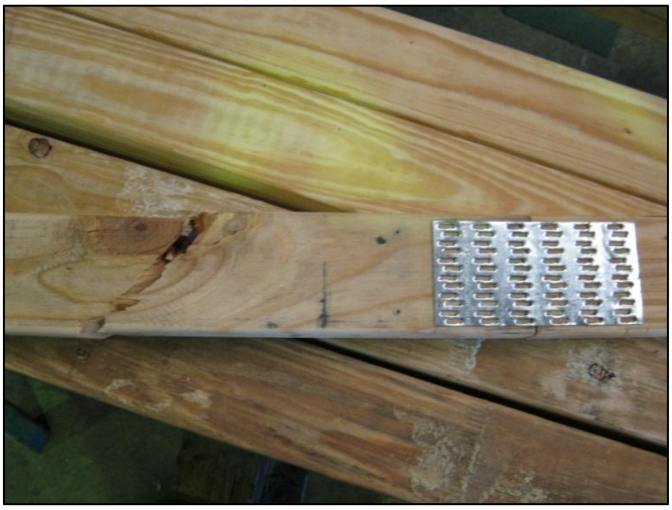


Figure 5.13 – Failure Unrelated to Nail Plated Joint

The third sample excluded was found to have a manufacture defect. The teeth of one nail plate had not been adequately embedded into one of the members being joined. Again, it was considered inappropriate to compare the result of this sample against correctly manufactured joints.

The balance of samples failed in modes related the nail plated connection. All failures exhibited one or more of the following characteristics:

- Tearing of steel nail plates
- Nail plate teeth pulled out of timber
- Timber breakage between nail plates.

Typical failure modes, combining the above characteristics, are shown in Figures 5.14, 5.15 and 5.16.

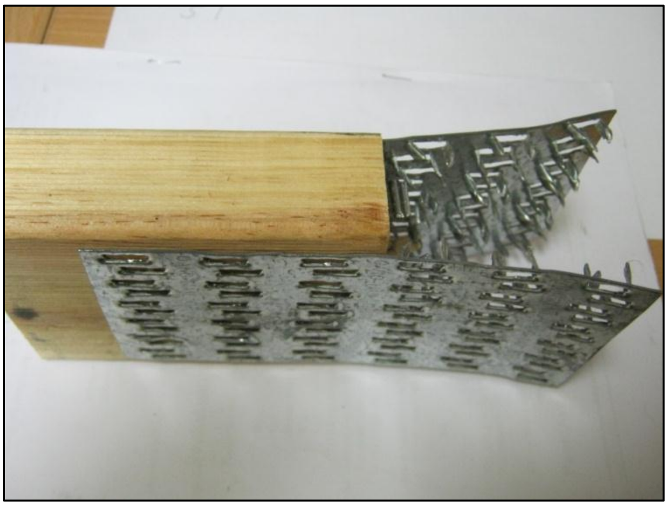


Figure 5.14 – Double Pull Out of Nail Plate Teeth

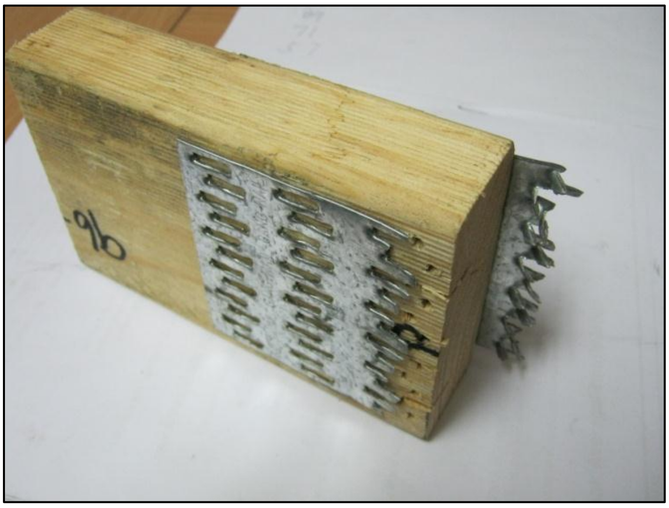


Figure 5.15 – Double Plate Tear

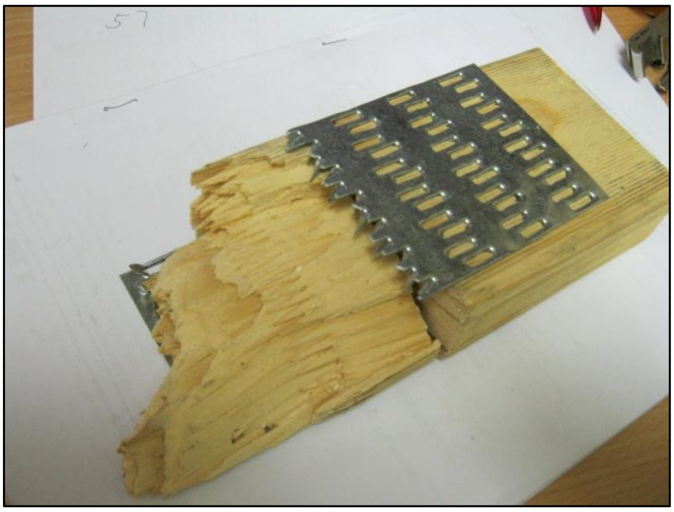


Figure 5.16 – Single Plate Tear and Wood Break

Several samples of both finger jointed timber and standard MGP10 failed by each of these means. There appeared to be no tendency for joints of either timber type to fail by a particular means. This indicates that the presence of a finger joint does not promote premature failure in a nail plated joint parallel to the grain.

5.2.3 Nail Plate Perpendicular to the Grain

No significant difference in joint capacity was observed between finger jointed timber and standard MGP10 framing connected by 100 x 40 mm nail plates, orientated perpendicular to the grain of the timber representing a truss chord, as shown in Table 5.2. A detailed record of the testing data and assessment conducted is contained in Appendix I.2.

All samples tested exhibited failure modes related to the nail plated joint. Two distinct failure modes were observed. The most prevalent mode involved the nail plate teeth withdrawing from the face of the truss chord component of the joint. This failure type is shown in Figure 5.17. The splitting of the timber chord in the sample shown was not a common occurrence. Withdrawal regularly occurred in plates located on both sides of the samples with regards to their position in the testing rig. This indicates that no eccentricity was being introduced during loading.

Figure 5.17 – Typical Plate Withdrawal Failure

The second failure mode displayed a fracture propagating from the location where the top row of nail plated teeth penetrated the truss chord component of the joint. This fracture is considered to be a result of tensile forces applied perpendicular to the grain of the truss chord. A typical failure of this type is shown in Figure 5.18.

Figure 5.18 – Typical Tension Perpendicular to Grain Failure at Nail Plate

Similar portions of the finger jointed timber, and standard MGP10, exhibited failure by each of these modes. There appeared to be no greater tendency for joints of either timber type to fail by a particular means. This indicates that the presence of a finger joint does not promote premature failure in a nail plated joint perpendicular to the grain of a truss chord.

5.2.4 Batten Screw Connection of Roof Batten to Truss Chord

No significant difference in joint capacity was observed between finger jointed and standard MGP10 truss chords penetrated by 75 mm batten screws, as shown in Table 5.2. A detailed record of the testing data and assessment conducted is contained in Appendix I.3.

All samples tested exhibited failure modes related to the batten screw connection. All 10 of the samples containing standard MGP10 truss chord components, along with 7 of the 10 finger jointed samples, failed when the thread of the batten screw pulled out of the truss chord. This failure mode is shown in Figure 5.19.

Figure 5.19 – Typical Batten Screw Connection Failure by Thread Pull Out

The remaining samples containing finger jointed truss chords failed in a significantly different manner that appears to be a direct result of the batten screw penetrating a finger joint. The failure appeared to initiate as a fracture on the tension edge of the chord at the finger joint. Tensile stresses perpendicular to the grain were then induced in the reduced section, and the fracture propagated longitudinally through the chord from the screw tip, as shown in Figure 5.20.

Figure 5.20 – Typical Batten Screw Connection Failure at Finger Joint

The cause of this different failure mode in finger jointed samples could not be identified with absolute confidence. The interlocking of grain at the finger joint, the variation in density across the finger joint, or a combination of the two, may be preventing the withdrawal of the screw thread in certain circumstances. Without a complete understanding of this failure type, a definite conclusion on the effect of finger joints on this connection type cannot be made.

However, given that testing was conducted on representative samples of both finger jointed timber, and standard MGP10, and no significant difference in joint capacity was observed, it is considered that finger jointed timber will perform adequately in this connection type.

5.2.5 MultiGrip Connection of Roof Truss to Supporting Wall

No significant difference in joint capacity was observed between finger jointed and standard MGP10 truss chords connected to wall plates with MultGrips and nails, as shown in Table 5.2. A detailed record of the testing data and assessment conducted is contained in Appendix I.4.

All samples tested exhibited failure modes related to the MultiGrip connection. Two distinct failure modes were observed. The most prevalent mode involved laterally loaded nails withdrawing from the face of the truss chord component of the sample, as shown in Figure 5.21. The withdrawal of nails regularly occurred from MultiGrips located on both sides of the samples with regards to their position in the testing rig. This indicates that no eccentricity was being introduced during loading.

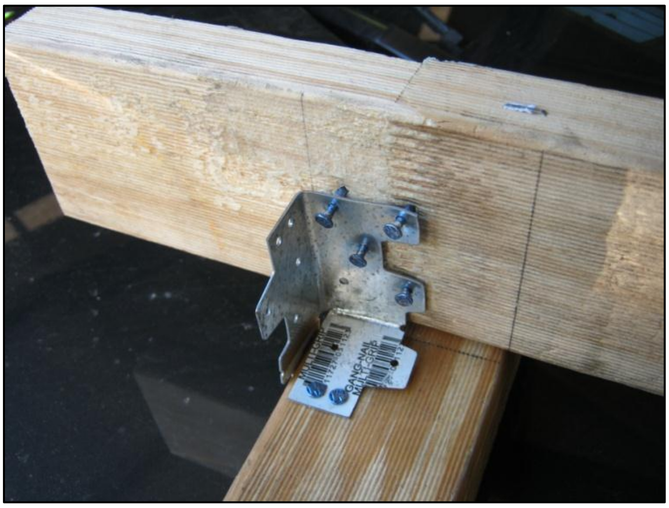


Figure 5.21 – Typical MultiGrip Connection Failure in Truss Chord

The second failure mode displayed laterally loaded nails withdrawing from the edge of the wall plate component of the sample, as shown in Figure 5.22.

Figure 5.22 – Typical MultiGrip Connection Failure in Wall Plate

Similar portions of the finger jointed timber, and standard MGP10, exhibited failure by each of these modes. There appeared to be no greater tendency for joints of either timber type to fail by a particular means. This indicates that the presence of a finger joint does not promote failure in a nailed MultiGrip connection.

5.2.6 Screw Connection of Girder Bracket to Truss Chord

No significant difference in joint capacity was observed between finger jointed and standard MGP10 truss chords penetrated by 30 mm girder bracket screws, as shown in Table 5.2. A detailed record of the testing data and assessment conducted is contained in Appendix I.5.

All samples tested exhibited failure modes related to the girder bracket screw connection. The majority of samples, of each timber type, failed in a similar mode. The standard MGP10 truss chords exhibited fibre crushing beneath the screw threads and longitudinal splitting, due to tensile stress perpendicular to the timber grain, propagating from the top row of screws. This failure mode is shown in Figure 5.23.

Figure 5.23 – Typical Girder Bracket Screw Connection Failure in MGP10

The finger jointed truss chords displayed identical failure characteristics, and additionally a fracture in the finger joint from the tension edge of the chord to the level of the bottom screws occurred. This failure mode is shown in Figure 5.24. Due to the enclosed nature of the testing bracket it is unclear whether the finger joint fracture, or the longitudinal splitting occurred first.

Figure 5.24 – Typical Girder Bracket Screw Connection Failure at FJ

A single sample of each timber type failed in a different mode. The standard MGP10 sample showed extreme fibre crushing beneath the screws with the resulting joint deformation causing the screws to yield, as shown in Figure 5.25. The finger jointed timber chord exhibited a bending type failure. A brittle fracture initiated on the tension edge of the sample at the finger joint and propagated to the compression edge via the screw locations, as shown in Figure 5.26.

Figure 5.25 – Failure due to Fibre Crushing and Screw Yield

Figure 5.26 – Bending Failure at Finger Joint

The cause of the additional fracture seen in the typical failure of finger jointed samples could not be identified. Without knowing whether it was a precursor to, or a result of, the longitudinal splitting in the sample, an absolute conclusion on the effect of finger joints on the failure of this connection type cannot be made.

However, given that testing was conducted on representative samples of both finger jointed timber, and standard MGP10, and no significant difference in joint capacity was observed, it is considered that finger jointed timber will perform adequately in this connection type.

5.2.7 Nail Plate Parallel to the Grain – Joint Deformation

Table 5.2 indicated that no meaningful results were obtained from the joint deformation testing conducted on timber spliced with 150 x 75 mm nail plates. However, the comparison testing conducted on finger jointed timber, and standard MGP10, without nail plated splices, yielded assessable results. A detailed record of the testing data and assessment conducted is contained in Appendix I.6.

5.2.7.1 Tensile Stiffness without Nail Plated Splice

The stress-strain curves produced from the recorded data, for both the finger jointed timber and standard MGP10, typically exhibited the expected shape. The curves for all samples of finger jointed timber and standard MGP10 are shown in Figures 5.27 and 5.28, respectively.

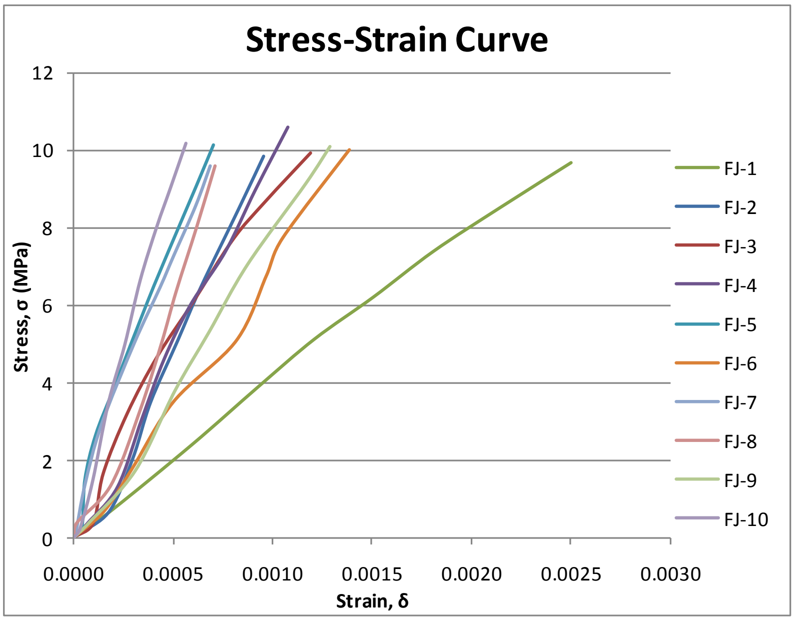


Figure 5.27 – Stress-Strain Curves of FJ Timber without Splice

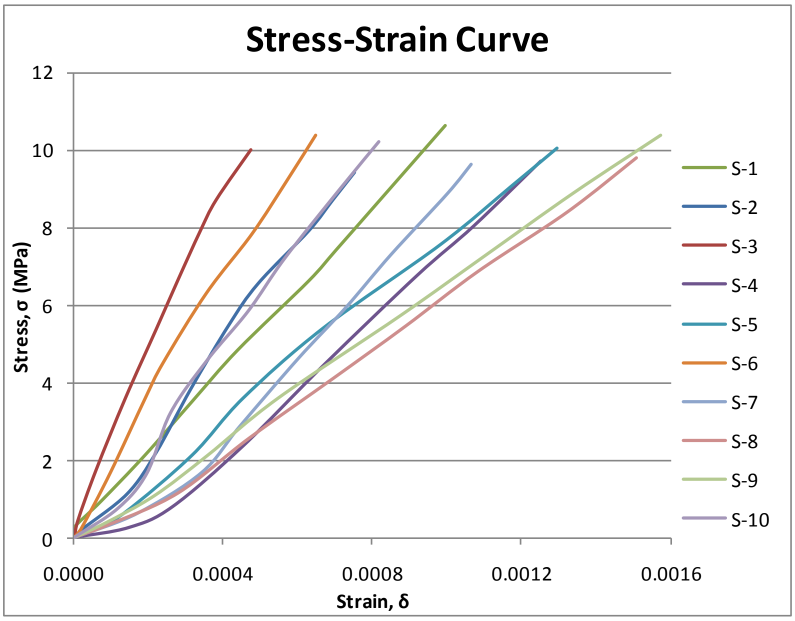


Figure 5.28 – Stress-Strain Curves of Standard MGP10 without Splice

Some minor deviations from the overall linear nature of the curves can be seen. This can most likely be attributed to the use of incremental, rather than continual, measurements. The linearity of the curves, along with the absence of disproportionate increases in strain at higher stresses, indicates that all measurements were made in the elastic range of the timber. As a result, the curves were deemed suitable for calculating tensile stiffness values.

The recorded data for all samples except "FJ-1" resulted in reasonably consistent tensile stiffness values, comparable to the results obtained for bending stiffness. Sample "FJ-1" returned a tensile stiffness of 3808 MPa, well below the range typically expected for MGP10 material. No manufacturing defects or errors in the testing process could be identified to explain this abnormal result. Therefore, the sample was not excluded when analysis and comparison was conducted.

5.2.7.2 Joint Stiffness of Nail Plated Splice

The stress-strain curves resulting from the testing of finger jointed timber with a nail plated splice showed 2 distinct shapes. Several samples displayed the shape typically expected, while others were completely incomparable. The different results can be seen clearly in Figure 5.29.

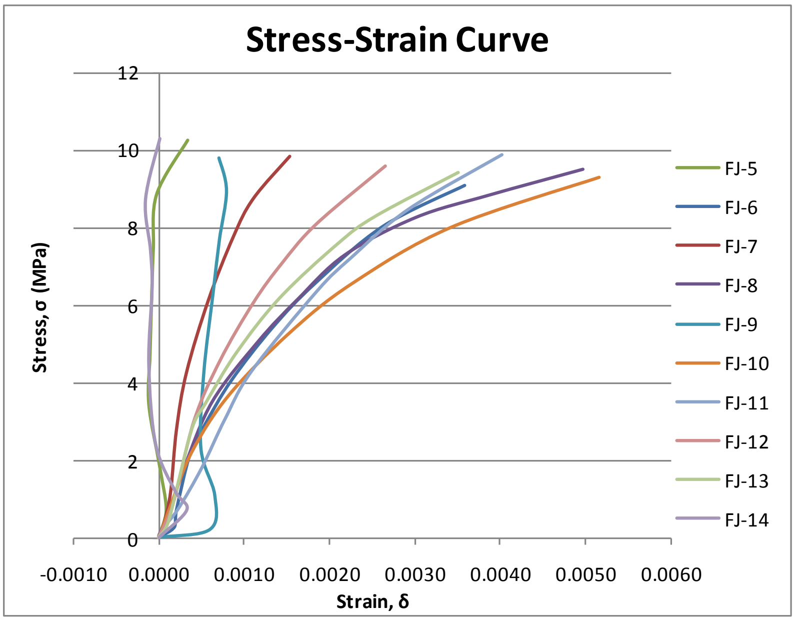


Figure 5.29 – Stress-Strain Curves of FJ Timber with Splice

The variation in results can be attributed to the use of an inadequate test method, which involved measuring the joint deformation on 1 face only, as shown previously in Figure 4.17. This test method was developed based on the assumption that the test samples would be symmetrical about all axes. However, all samples showed asymmetry of varying degrees. An exaggerated representation of this is shown in Figure 5.30.

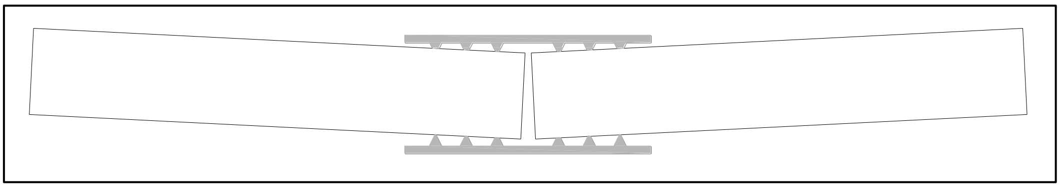


Figure 5.30 – Asymmetric Joint Deformation Test Sample

The asymmetry is due to the use a roller press to embed the nail plates during sample manufacture. The roller pushes down to embed the plate, and rotates to drive the sample longitudinally through the machine. When pressure is applied at the ends of short members being connected, the far ends of the members may be lifted causing an uneven gap on opposite sides of the joint, as shown in Figure 5.31.

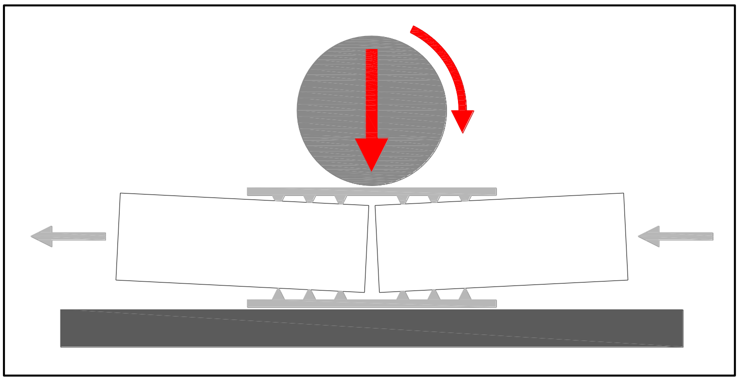


Figure 5.31 – Embedment of Nail Plates by Roller Press

The shape of the stress-strain curve obtained was dependent upon the orientation of the test sample in the test rig. The stress-strain curve exhibited by samples “FJ-5”, “FJ-9”, and “FJ-14”, as shown in Figure 5.29, occurred when the joint deformation was measured on the convex face of the sample. The curves exhibited by the remaining samples were a result of measuring the joint deformation on the concave face. The observed interaction between loading and deformation is explained in Figure 5.32.

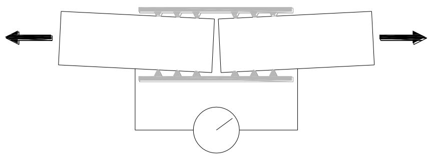
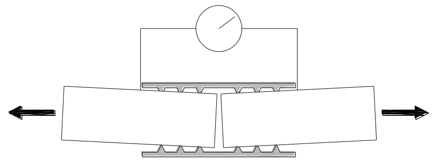
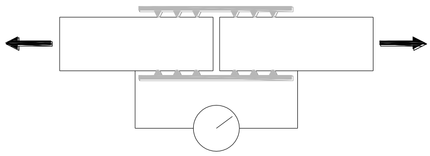
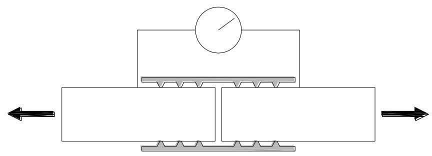
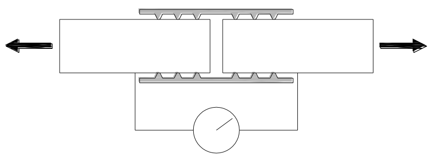
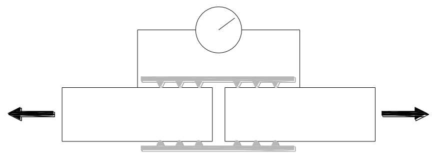
Loading Stage	Deformation Measured on Convex Face	Deformation Measured on Concave Face
Initial	 Initial elongation due to seating of teeth and stretching of fibres	 Initial elongation due to seating of teeth and stretching of fibres
Intermediate	 Shortening occurs as sample straightens under load	 Elongation continues as sample straightens under load
Final	 Elongation recommences as fibre stretches, plate yields and teeth tear through fibre	 Elongation continues as fibre stretches, plate yields and teeth tear through fibre

Figure 5.32 – Interaction of Loading and Deformation

The observed behaviour of the joint under load clearly indicates that a value of joint stiffness calculated from the recorded stress-strain curve is not representative of the overall performance of the joint. It is considered that a more accurate representation of a joint's performance would have been determined if deformation values were measured on both faces of the sample and averaged.

The samples of standard MGP10 with a nail plated splice, manufactured for testing, displayed the same asymmetrical characteristics as the finger jointed timber specimens. As a result they exhibited the same behaviour under load. The stress-strain curves for all samples are shown in Figure 5.33, and again 2 distinct shapes are evident. The results for these samples are further compromised by a data recording error. It was realised, after testing of the samples was complete, that all joint deformations had been recorded as absolute values.

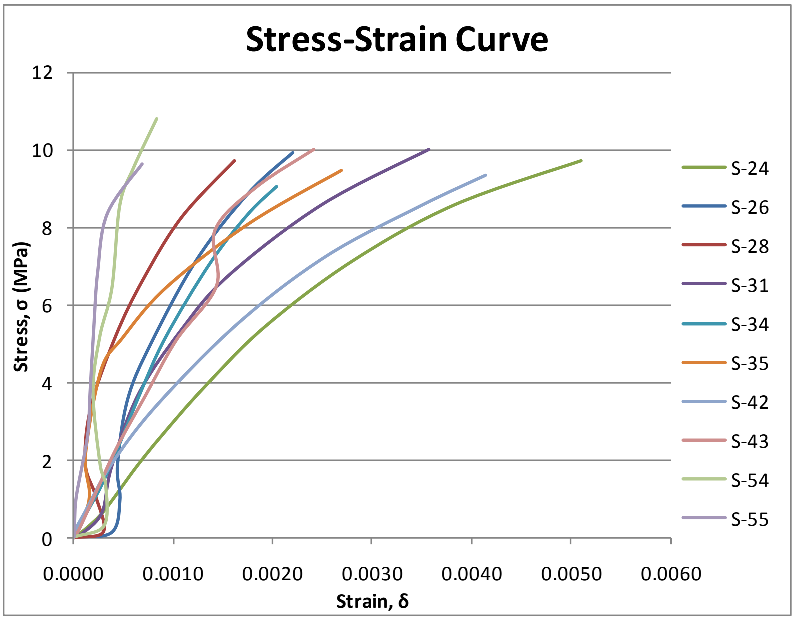


Figure 5.33 – Stress-Strain Curves of Standard MGP10 with Splice

Due to the joint deformation being measured on one face of the sample only, and the data recording error, the stress-strain curves could not be used to calculate an accurate value for joint stiffness. It is considered that a more accurate representation of a joint's performance would have been determined if deformation values were measured on both faces of the sample and averaged, as suggested previously for the finger jointed timber samples.

5.3 Fabrication Issues

This section presents the results of the assessment conducted on the probability of finger jointed timber boards breaking at a finger joint during the fabrication process, when handled by the techniques identified in the literature review. The process used for assessment is presented in Section 4.3.

The results, and a brief discussion, for each handling technique are presented in separate sub-sections.

5.3.1 Levering

The design chart in Figure 5.34 presents the probability of a finger jointed board breaking at a finger joint when levered. Probabilities are displayed for a range of board lengths and span configurations.

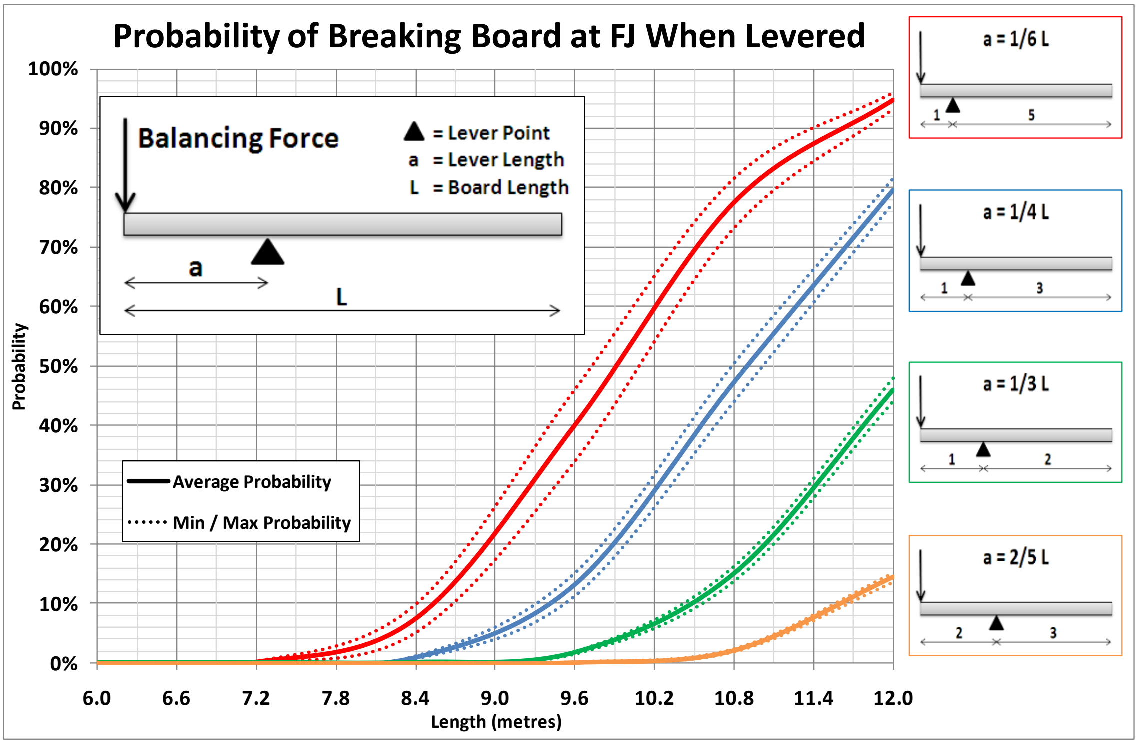


Figure 5.34 – Design Chart - Levering

Section 4.3.1 outlines the method used to determine the probability shown for each combination of board length and span configuration. This process required the testing of a representative sample of finger joints to determine their capacity. The testing was conducted in accordance with the method described in Section 4.3.3. Detailed results of the testing are contained in Appendix J.1.

The assessment process also required the modelling of stresses applied to the board during levering. The measured density of finger jointed timber samples, used for mechanical property testing, was analysed to provide a load distribution for this modelling. The details of the density analysis are included in Appendix J.2. The applied stresses were then modelled for each combination of board length and span configuration in accordance with Section 4.3.2.1. An example of the stress modelling, and probability calculation, for a given combination of board length and span configuration, is provided in Appendix J.3.

The assessment results, presented in Figure 5.34, indicate that there is a definite possibility of finger jointed boards breaking at a finger joint when levered. It can be noted from the design chart that the probability of failure occurring increases as the lever length decreases, and as the board length increases.

Anecdotal investigations, with timber production staff, indicate that it is highly unlikely that a single person could handle boards of these lengths with a lever less than one third of the board length. Therefore, it is considered that finger joint boards up to 9 metres in length can be levered with a negligible probability of breaking at a finger joint, under static loading.

5.3.2 Two Man Lift

The design chart in Figure 5.35 presents the probability of a finger jointed board breaking at a finger joint when lifted by its ends. Probabilities are displayed for a range of board lengths.

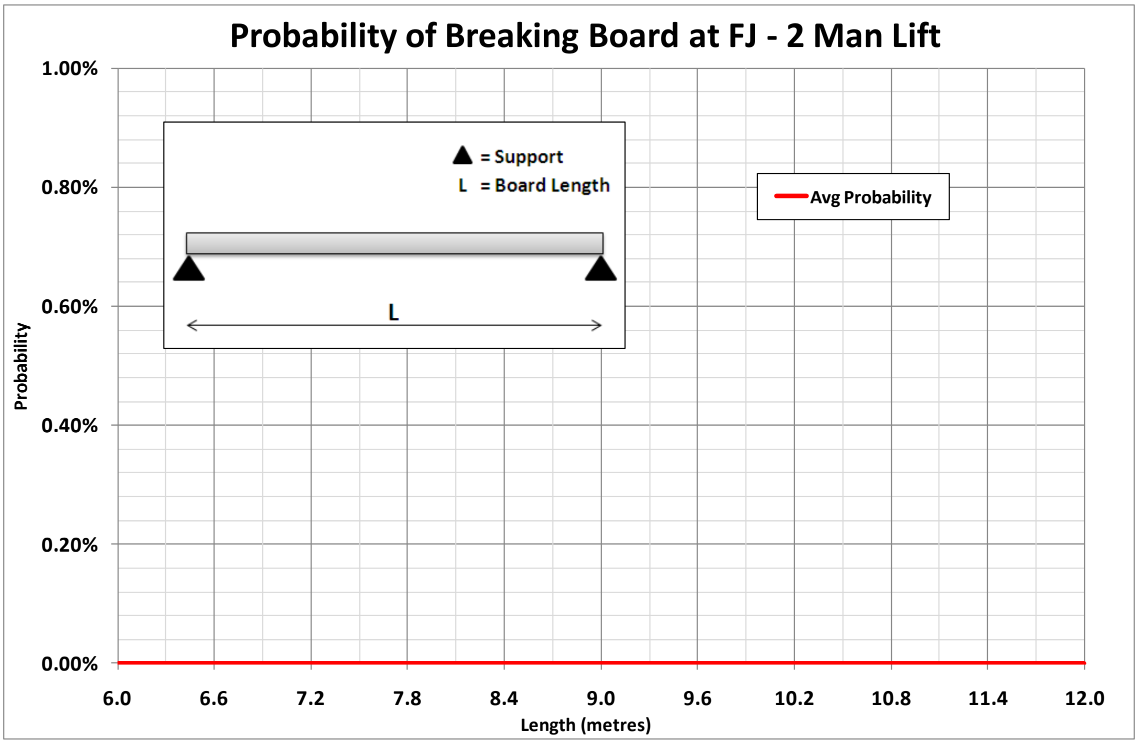


Figure 5.35 – Design Chart - 2 Man Lift

The same overall assessment process, as described in Section 4.3.1, was used to determine the probabilities shown. The finger joint capacity data in Appendix J.1, and the board density analysis in Appendix J.2, were used in the assessment, as they were for the levering assessment.

The required modelling of applied stresses was conducted in accordance with Section 4.3.2.2, for each board length. An example of the stress modelling, and probability calculation, for a given board length, is provided in Appendix J.4.

The assessment results, presented in Figure 5.35, indicate clearly, by their extremely low values, that there is a negligible probability of finger jointed boards, in lengths to 12 metres, breaking at a finger joint when lifted by their ends.

5.3.3 Fork Lift

The design chart in Figure 5.36 presents the probability of a finger jointed board breaking at a finger joint when lifted by a fork lift. Probabilities are displayed for a range of board lengths.

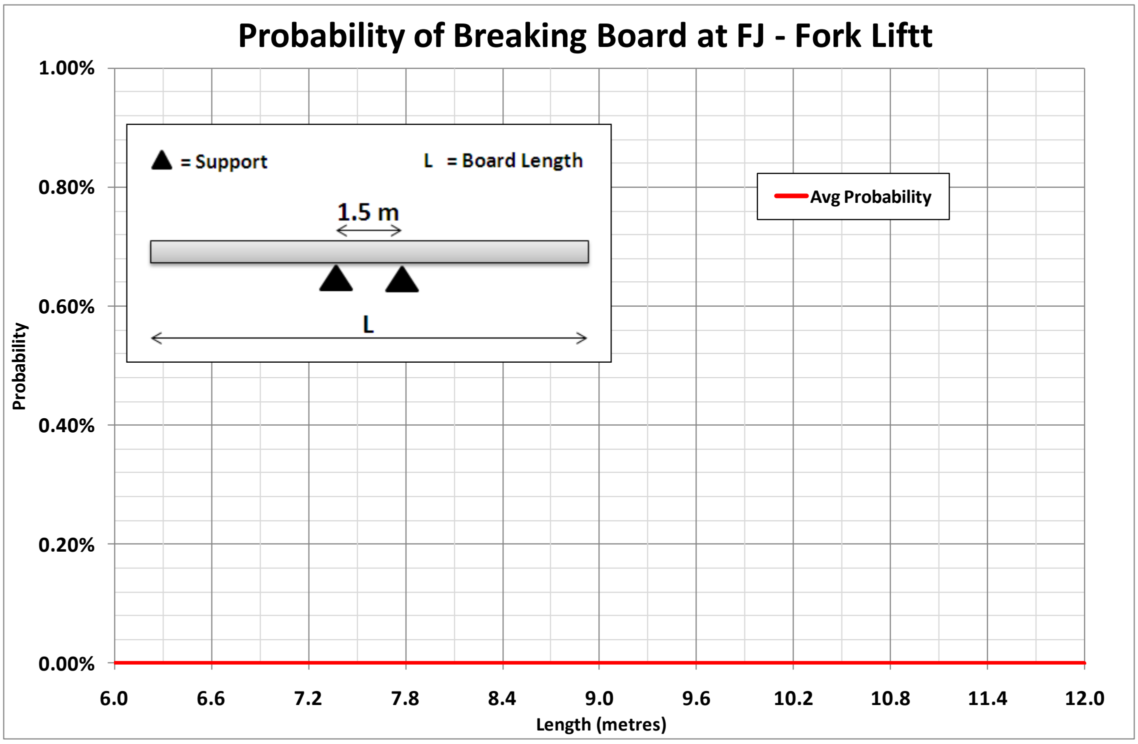


Figure 5.36 – Design Chart - Fork Lift

The same overall assessment process, as described in Section 4.3.1, was again used to determine the probabilities shown. The finger joint capacity data in Appendix J.1, and the board density analysis in Appendix J.2, were used in the assessment, as they were for the levering and 2 man lift assessments.

The required modelling of applied stresses was conducted in accordance with Section 4.3.2.3, for each board length. An example of the stress modelling, and probability calculation, for a given board length, is provided in Appendix J.5.

The assessment results, presented in Figure 5.36, indicate clearly, by their extremely low values, that there is a negligible probability of fork lifted finger jointed boards, in lengths up to 12 metres, breaking at a finger when static loads are considered. Anecdotal evidence exists suggesting that long length finger jointed boards can break when the ends "bounce" during fork lifting. This evidence, in combination with the results of the assessment conducted, indicates that dynamic loading effects may be critical in causing breakage in finger jointed timber handled by forklifts. The assessment of dynamic loading effects was outside the scope of this project.

5.4 Truss Erection Issues

This section presents the results of the assessment conducted on the probability of finger jointed timber truss chords breaking at a finger joint when subjected to point loads during the truss erection process. The process used for assessment is presented in Section 4.4.

The results, and a brief discussion, for each load location are presented in separate sub-sections.

5.4.1 Loads on Truss Overhangs

The design chart in Figure 5.37 presents the probability of a finger jointed truss chord failing at a finger joint when a builder stands at the end of the truss overhang. Probabilities are displayed for standard and hip trusses, for a range of building eave widths.

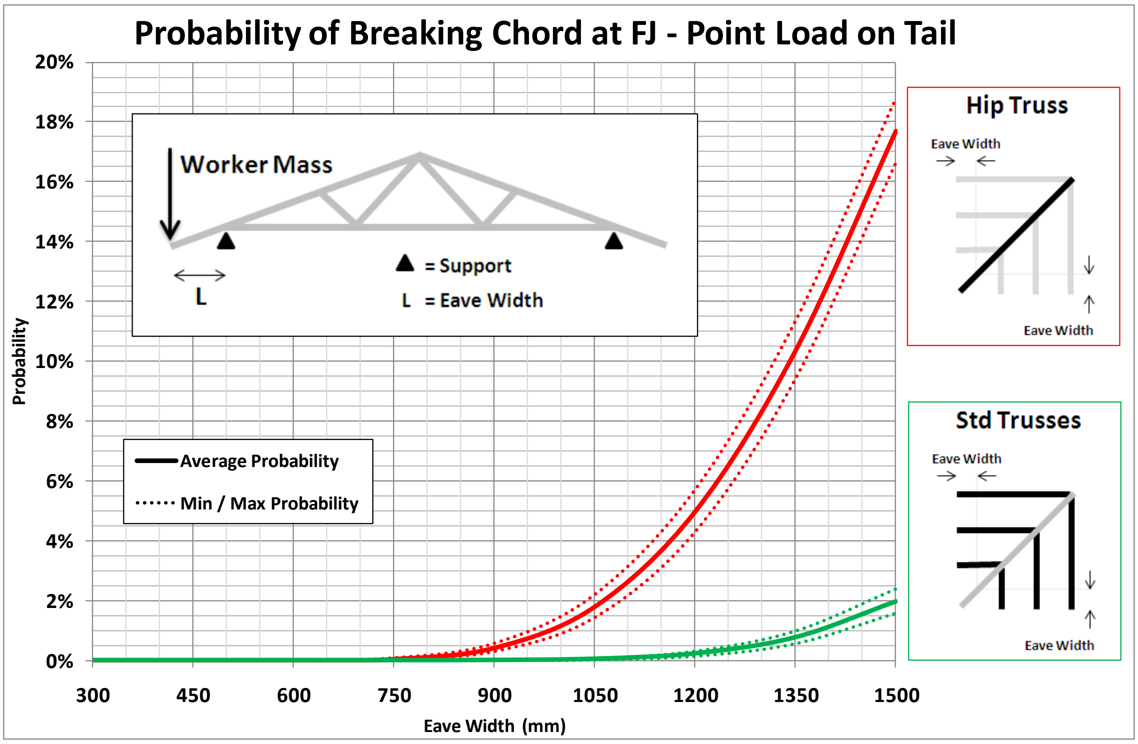


Figure 5.37 – Design Chart - Load on Truss Tail

Section 4.4.1 outlines the method used to determine the probability shown for each combination of truss type and eave width. This process required the testing of a representative sample of finger joints to determine their capacity. The testing was conducted in accordance with the method described in Section 4.4.3. Detailed results of the testing are contained in Appendix K.1.

The assessment process also required the modelling of stresses applied to the truss chord during loading. The applied stresses were modelled for each combination of truss type and eave width in accordance with Section 4.4.2.1. An example of the stress modelling, and probability calculation, for a standard truss and given eave width, is provided in Appendix K.2. A similar example, for a hip truss and given eave width, is provided in Appendix K.3.

The assessment results, presented in Figure 5.37, indicate that there is a possibility of finger jointed truss chords breaking at a finger joint if a builder stands on the end of an overhang. It can be noted from the design chart that the probability of failure is significantly greater for hip trusses, and increases as the eave width of the building increases.

The maximum eave width typically used in residential house construction is about 900 mm, with 750 mm being most common. The design chart, shown in Figure 5.37, indicates that there is a small risk of failure for hip trusses, and a minimal risk for standard trusses, in roofs with eaves of these widths.

5.4.2 Loads on Bottom Chord Panels

The design chart in Figure 5.38 presents the probability of a finger jointed truss chord breaking at a finger joint when a builder stands at the mid-point of an end panel in the bottom chord of a truss. Probabilities are displayed for a simple "A-type" truss with a range of panel spans.

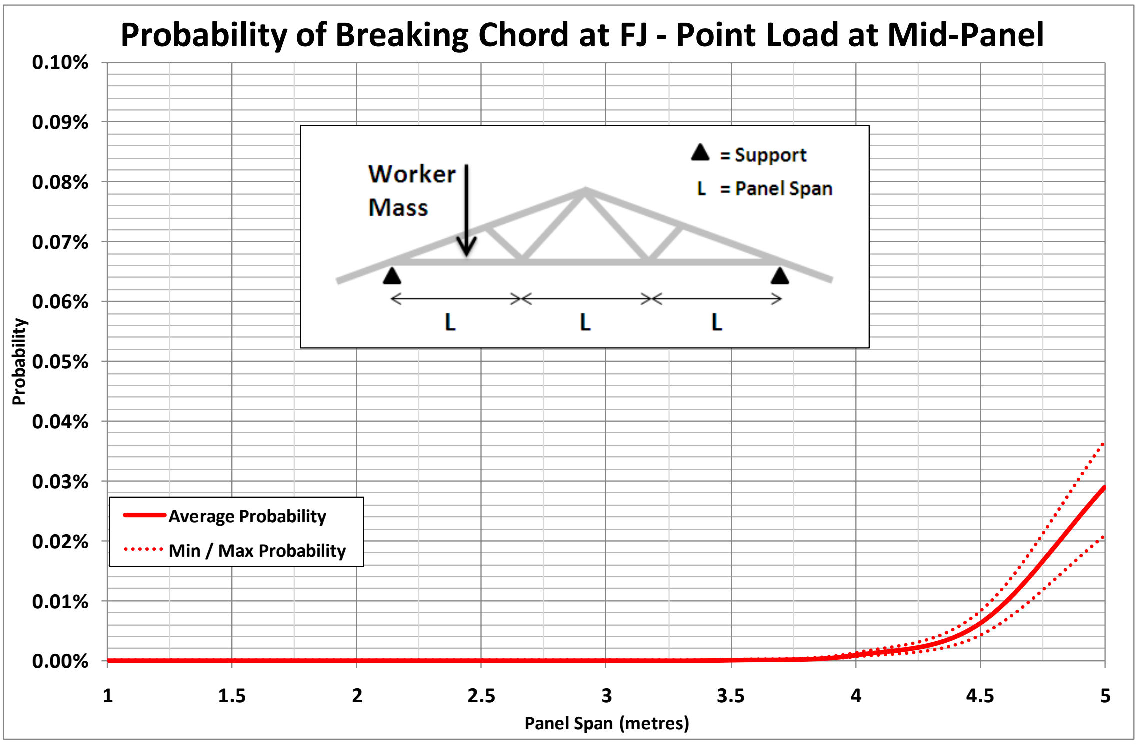


Figure 5.38 – Design Chart - Load at Mid-Panel

The same overall assessment process, as described in Section 4.4.1, was used to determine the probabilities shown. The finger joint capacity data in Appendix K.1, was used in the assessment, as it was for the truss overhang assessment.

The required modelling of applied stresses was conducted in accordance with Section 4.4.2.2, for each panel span. An example of the stress modelling, and probability calculation, for a given panel span, is provided in Appendix K.4.

The design chart, shown in Figure 5.38, indicates that the probability of failure, at a finger joint, of truss chords subjected to point loading at the mid-point of an end panel, is less than 1 in 10000 for panel spans up to 4.5 metres. Advice from Sid's Place indicates that the maximum panel span achievable by 90 x 35 mm truss chords is approximately 3 metres. Hence, it is considered that there is a minimal chance of failure at finger joints, in 90 x 35 mm truss chords loaded in this manner.

Chapter 6

Conclusions and Further Work

6.0 Summary

This research project has investigated the suitability of finger jointed structural timber for use in nail plated roof trusses. The research was based primarily on the experimental testing of sample truss components fabricated from finger jointed timber produced exclusively for this project. The results of this testing were assessed by comparing them against the performance of standard MGP10 framing, derived from Australian Standards requirements and similar testing. Modelling of loading situations, using static engineering principles, was also conducted to further investigate the performance of finger jointed timber.

This chapter presents the conclusions that were drawn from this research, and highlights some opportunities for further work related to this project.

6.1 Conclusions

The overall results of this research project were positive with regards to using finger jointed structural timber for the fabrication of nail plated roof trusses. The following major findings have been established, based on the core objectives identified in the Project Specification. Time was not permitting to undertake the additional objectives proposed in Section 1.3.

- Finger jointed timber can be produced to meet the mechanical property requirements of MGP10. It should be noted that the assessment of shear strength was based on 18 test samples only, and not the recommended 30, due to difficulties with the test method.

- No significant difference was observed in the capacity of joints and connections, manufactured from finger jointed timber and standard MGP10. This was in spite of the fact that the presence of a finger joint seemed to promote failure in some connections.

- No meaningful results were obtained from the joint deformation testing of finger jointed timber and standard MGP10. This was due to inadequacies in the test method used. Testing conducted, for comparison purposes, indicated that there was no significant difference in the tensile stiffness of standard MGP10 clear wood, and finger jointed timber assessed across a finger joint.

- It was determined that, while there is a possibility of a finger jointed board breaking, at a finger joint, during the fabrication process, the likelihood of it occurring can be minimised with the adoption of appropriate handling techniques. It should be noted that this assessment was based on static loading scenarios only.

- It was determined that there is a small likelihood of a finger jointed truss chord breaking, at a finger joint, under a temporary point load, during the truss erection process, in trusses with large spans and overhangs. The risk appears to be minimal however, for the panel spans and eave widths typically used in domestic residential construction.

6.3 Further Work

Along with the completion of the additional objectives proposed in the Project Specification, the following opportunities for further work were identified through the completion of this research project.

- An investigation of alternative methods used for the testing of shear strength in wood products, with the aim of identifying an improved method, for assessing beam shear strength.

- An investigation of the effect of finger joints on the deformation characteristics of nail plated truss joints using an improved test method.

- An investigation of the dynamic loading effects applied to long length timber during handling, and an assessment of the implications for handling finger jointed timber.

- A continuation of the investigation of truss erection issues, unique to finger jointed timber, to expand the range of design charts to include other commonly used truss types.

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Appendix A

Project Specification

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

FOR: ANTHONY DAKIN

TOPIC: INVESTIGATION OF THE SUITABILITY OF FINGER JOINTED STRUCTURAL TIMBER FOR USE IN NAIL PLATED ROOF TRUSSES

SUPERVISORS: A/ Prof Karu Karunasena

Geoff Stringer, Hyne & Son Pty Limited

Stephen Bolden, Hyne & Son Pty Limited

SPONSORSHIP: Hyne & Son Pty Limited

Sid's Place

PROJECT AIM: To determine the suitability of finger jointed timber for use in nail plated roof trusses from a fabrication, erection and in-service perspective. This will involve performance comparisons of trusses fabricated from conventional fixed length timber and trusses fabricated from proposed continuous length timber.

PROGRAMME: **Issue A, 22nd March 2011**

1. Research in-service performance/requirements of finger jointed timber and nail plated roof trusses and associated assessment methods.
2. Research fabrication and erection techniques relating to nail plated roof trusses to determine material requirements and associated assessment methods.
3. Design and complete testing regime to assess structural properties of finger jointed timber.
4. Design and complete testing regime to assess structural capacity, and deformation, of typical roof truss joints containing finger jointed timber.
5. Design and complete testing regime to replicate and assess issues related to fabrication and erection techniques.
6. Analyse and interpret the results of above testing to compare the performance of trusses fabricated from finger jointed and conventional fixed length timber.

As time permits,

7. Monitor the fabrication of full scale trusses from finger jointed timber and assess fabrication issues not previously identified.
8. Test full scale trusses fabricated from both finger jointed and fixed length timber to compare failure modes.
9. Fabricate truss from finger jointed timber and place into real structure for longer term performance monitoring.

AGREED: ____________________(student) ____________________(supervisor)

Date: / / Date: / /

Course Examiner:________________________

Appendix B

Purbond HB S109 Adhesive - Technical Data Sheet

Purbond
Adhesive systems for engineered wood

Finger joint

Face gluing

PURBOND® HB S109

Adhesive systems for engineered wood

One-component polyurethane adhesive for the production of engineered wood products

PURBOND HB S109_E
Holzleimbau Technik / 10.12.2007

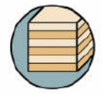
Properties

PURBOND HB S109 is a liquid one-component polyurethane adhesive. The adhesive requires moisture or humidity to cure into a strong, non-brittle adhesive film. A slight foaming effect during curing is a normal side effect of the chemical reaction. PURBOND HB S109 is manufactured solvent- and formaldehyde-free.

Product data

Chemical composition	Isocyanate pre-polymer
Consistence	free flowing
Assembly time[1]	**10 minutes**
Press time/Curing time[1]	**25 minutes**
Viscosity Brookfield	approx. 20'000 mPa.s (Sp. 6 / 20 UpM / 20 °C, Measuring > 8 hours after production)
Color	beige
Density	approx. 1'100 kg/m^3
Solids content	100 %
Flammability	low
Chemical resistance	against weak caustics, acids and solvents
Storage	6 months dry at 20 °C (note expiry date)
Packaging	Drum 200 kg net Container 1'100 kg net
Safety	See Material and Safety Data Sheet (MSDS) of PURBOND HB S109. Available from Purbond

[1] More information regarding the assembly time and press time/curing time can be found on pages 2 and 3.



Application	**Direction of use for face-joints (lamination)**
Preparation	PURBOND HB S109 is a one-component adhesive and can be fed directly into suitable application equipment. Surfaces must be clean and free from any adhesive-abrasive substances like oil, grease or separate agents. All machine parts that are in contact with the adhesive should be thoroughly treated with *PURBOND Trennmittel / Release Paste* before using.
Wood moisture conent	Wood moisture content at the joint surface should not be below 8 %. The difference in wood moisture between the lamellae should not exceed 4 % according EN 386.
Adhesive application	PURBOND HB S109 is automatically applied in a continuous process. The adhesive is applied on one side with a minimum application weight of approximately 180 g/m^2.
Assembly time	Coated surfaces should be pressed together immediately but under no circumstances later than 10 minutes after the application of the adhesive. Assembly time depends on the existing climatic conditions: Higher temperatures and humidity lead to shorter assembly times. It is absolutely necessary that the adhesive is still tacky when pressure is applied.
Press time	Press time depends on the existing climatic conditions of the surrounding and on the present temperature of the material. Minimum press time under conditions of 20 °C, 65 % relative humidity and 12 % wood moisture content is 25 minutes.
Pressure	The applied press force has to guarantee that the joint is pressed together properly. Normally pressure of 0,6 to 0,8 N/mm² is applied.
Processing	Bonded parts can be processed subsequently to pressing.
Final bond	Final bond strength is attained after approximately 12 hours. Until then, it is recommended to store the bonded at an ambient temperature of 20 °C.
Other recommendations	Please consider the following recommendations for the production of structural laminated beams: 1. The wood moisture content according EN 386 and DIN 1052 should not exceed 15 % (for untreated wood). 2. Keep bond-lines as thin as possible (maximum 0,3 mm). 3. The temperature of the production-facility, wood and adhesive should be at least 20 °C. 4. The gluing of larch wood is recommended for use in service class I and II. 5. It is recommended to conduct a suitable quality assurance procedure (for example according EN 386) while production is in progress.

Application	**Directions of use for end-joints (finger joints).**

Preparation

PURBOND HB S109 is a one-component adhesive and can be fed directly into suitable application equipment.

Surfaces must be clean and free from any adhesive-abrasive substances like oil, grease or separate agents.

Before using all machine parts that are in contact with the adhesive should be thoroughly treated with *PURBOND Trennmittel / Release Agent.*

Wood moisture content

Moisture content at the joint surface should not be inferior to 8 %.

According DIN 68140-1 the maximum difference of wood moisture between the bonded parts has to be:

- For solid finger-jointed timber: max. 5 %
- For finger-jointed lamellas for laminated beams: max. 4 %

Adhesive application

PURBOND HB S109 is automatically, in a continuous process applied to the finger-jointing line. The adhesive is applied by using a special comb system.

PURBOND HB S109 is applied either on one or on both sides with an application amount of approximately 140 to 180 g/m².

Parts must be pressed together immediately.

Press time

Pressure has to be exerted for at least 2 seconds.

Pressure

The used pressure (depending on the length of finger joint's keys) must guarantee a close contact joint.
In general exerted pressure of 2 to 12 N/mm² be applied.

Processing

Bonded parts can be processed after 25 minutes.

Final bond

Final bond strength is attained after approximately 12 hours.
It is recommended to store the parts until then at an ambient temperature of 20 °C.

Other recommendations

Please consider the following requirements for the production of structural finger joints:

1. Moisture content of wood parts should not exceed 15 % in case that the parts will be processed any further (e. g. finger jointing of glulam laminate). Otherwise moisture content of wood parts should not exceed 18 % (e.g. finger jointing of one-piece timber).
2. Fit of finger joint's keys should be in accordance with the local standard.
3. The gluing of larch wood is only permitted in service class I and II.
4. The temperature of the production-facility, wood and adhesive should be at least 20 °C.

Purbond
Adhesive systems for engineered wood

Safety and Clean up	**Direction of use for safety and clean up**
Safety	Purbond strongly recommends that protective gloves – *PURBOND Arbeitshandschuhe / Handling gloves* – and protective goggles must be worn when handling the liquid adhesive.
Clean up	For the removal of cured adhesive on equipment and machinery, Purbond recommends *PURBOND Löser / Solvent*. Before cleaning, please make sure that the parts are resistant to *PURBOND Löser / Solvent*. When handling the solvent, chemical resistant *PURBOND Reinigungshandschuhe / Cleaning Gloves* and protective goggles must be worn.
Certification and Registration	**International Certifications and Registrations**
Australia/New Zealand	Classified as Type I structural wood adhesive in accordance with AS/NZS 4364 (Int):2007.
JAIA F☆☆☆☆	Formaldehyde Standard: JAIA (Japan Adhesive Industry Association) Independent Control Standard against Indoor Air Pollution. Register Number: **JAIA-008439**
Guarantee	This information is based on the test results of the Otto-Graf-Institute (MPA, University Stuttgart), our Purbond application laboratory and our customers' experience. Purbond guarantee a consistent quality of this product which is manufactured in accordance with ISO 9001 / ISO 14001 guidelines. The product was found suitable for all applications and uses listed above; for other uses or applications Purbond strongly suggest you to contact our technical support staff. In general the sales and delivery conditions of Purbond AG apply.

Adhesive systems for engineered wood

Appendix C

Calculation of Tension Proof Loads

Tension Proof Testing of FJ Stock

Proof testing to be conducted in accordance with the test method for determining Tension Strength Parallel to Grain in AS/NZS 4063.1:2010.

$$f_{t,0} = \frac{F_{ult}}{bd}$$

Where,

$f_{t,0}$ is the Tension strength parallel to the grain (MPa)

F_{ult} is the Axial tension load at failure (N)

b is the breadth of the sample cross section (mm)

d is the depth of the sample cross section (mm)

This formula can be rearranged to determine the required load to be applied in order to develop a specified tension stress in the sample.

$$F = f_{t,0}bd$$

Where,

F is the required axial tension load (N)

$f_{t,0}$ is the specified tensions stress (MPa)

Table H3.1 from AS 1720.1:2010 indicates the Characteristic Tension strength parallel to grain (f_t') of 90x35 MGP10 as 7.7 MPa.

Substituting these values into the above equation the load required to achieve a tension stress of 7.7 MPa in the sample is:

$$F = 7.7 \times 35 \times 90$$

$$F = 24255\ N$$

$$F = 2472.5\ kg$$

Appendix D

Details of Tension Proof Testing

90 x 35 FJ Tension Proof Testing

Timber Details			
Depth (mm)	90	Length (mm)	5400
Breadth (mm)	35	Test Span (mm)	4200

Proof Test Details **(Target Proof Load 2473 kg)**

Board No.	Load Applied (kg)	% of Target Load	Failure	Failure Source	Board No.	Load Applied (kg)	% of Target Load	Failure	Failure Source
10	2510	101%	No	-	59	2702	109%	No	-
11	2518	102%	No	-	60	2612	106%	No	-
12	2580	104%	No	-	61	2674	108%	No	-
14	2510	101%	No	-	62	2474	100%	No	-
15	2568	104%	No	-	63	2504	101%	No	-
16	2592	105%	No	-	64	2556	103%	No	-
17	2602	105%	No	-	65	2574	104%	No	-
18	2600	105%	No	-	66	2600	105%	No	-
19	2614	106%	No	-	67	2604	105%	No	-
20	2470	100%	No	-	68	2468	100%	No	-
21	2550	103%	No	-	69	2774	112%	No	-
22	2562	104%	No	-	70	2528	102%	No	-
23	2522	102%	No	-	71	2528	102%	No	-
24	2554	103%	No	-	72	2486	101%	No	-
25	2646	107%	No	-	73	2644	107%	No	-
26	2470	100%	No	-	74	2472	100%	No	-
27	2546	103%	No	-	75	2622	106%	No	-
28	2472	100%	No	-	76	2486	101%	No	-
29	2642	107%	No	-	77	2580	104%	No	-
30	2690	109%	No	-	78	2648	107%	No	-
31	2498	101%	No	-	79	2504	101%	No	-
32	2548	103%	No	-	80	2550	103%	No	-
33	2470	100%	No	-	81	2596	105%	No	-
34	2594	105%	No	-	82	2554	103%	No	-
35	2610	106%	No	-	83	2760	112%	No	-
36	2484	100%	No	-	84	2478	100%	No	-
37	2708	110%	No	-	85	2564	104%	No	-
38	2596	105%	No	-	86	2596	105%	No	-
39	2476	100%	No	-	87	2566	104%	No	-
40	2586	105%	No	-	88	2544	103%	No	-
41	2468	100%	No	-	89	2510	101%	No	-
42	2512	102%	No	-	90	2606	105%	No	-
43	2546	103%	No	-	91	2564	104%	No	-
44	2510	101%	No	-	92	2592	105%	No	-
45	2496	101%	No	-	93	2644	107%	No	-
46	2562	104%	No	-	94	2492	101%	No	-
47	2630	106%	No	-	95	2592	105%	No	-
48	2590	105%	No	-	96	2520	102%	No	-
49	2538	103%	No	-	97	2510	101%	No	-
50	2486	101%	No	-	98	2576	104%	No	-
51	2498	101%	No	-	99	2524	102%	No	-
52	2644	107%	No	-	100	2630	106%	No	-
53	2468	100%	No	-	101	2504	101%	No	-
54	2560	104%	No	-	102	2640	107%	No	-
55	1064	**43%**	Yes	Low Density Wood	103	2560	104%	No	-
56	2632	106%	No	-	104	2470	100%	No	-
57	2526	102%	No	-	105	2592	105%	No	-
58	2476	100%	No	-	106	2578	104%	No	-

Appendix E

Method for Characterizing Bending Stiffness – AS/NZS 4063.2 (2010)

Characteristic values

The characteristic value for modulus of elasticity ($E_{k,mean}$) shall be taken as the lesser of $E_{k,mean,1}$ and $E_{k,mean,2}$ calculated from the following equations:

$$E_{k,mean,1} = k_s \, \overline{E}$$

$$E_{k,mean,2} = \frac{k_s \, E_{05}}{0.7}$$

where

k_s = sampling factor

$\overline{E}$ = mean modulus of elasticity of test data, in megapascals

E_{05} = 5th percentile value for modulus of elasticity of the test data, in megapascals

Sampling factor (k_s) mean modulus of elasticity ($\overline{E}$) and 5th percentile modulus of elasticity (E_{05})

The values of k_s, $\overline{E}$ and E_{05} shall be calculated from the following equations:

$$k_s = 1 - \frac{0.7\, V_E}{\sqrt{n}}$$

$$\overline{E} = \exp\left(\overline{y} + \frac{S_y^2}{2}\right)$$

$$E_{05} = \exp(\overline{y} - 1.645\, S_y)$$

$$V_E = \sqrt{\exp(S_y^2) - 1}$$

$$\overline{y} = \frac{1}{n}\sum_{i=1}^{n} \ln(E_i)$$

$$S_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\ln(E_i) - \overline{y}\right)^2}$$

where

V_E = coefficient of variation for modulus of elasticity of the test data

n = sample size

$\overline{y}$ = mean of the natural logarithms of the sample test values

S_y = standard deviation of the natural logarithms of the sample test values

E_i = test value for sample rank i, in megapascals

ln = natural logarithm

Appendix F

Method for Characterizing Strength Properties - AS/NZS 4063.2 (2010) Method 1

Statistical evaluation

General

The characteristic values for strength properties calculated by this method are based on the assumption that the distribution of data is lognormal.

Test data

The tests data for calculating the characteristic value for a strength property shall be based on the complete test data of a sample.

Characteristic value of a strength property

The characteristic value (f_k) of a strength property shall be calculated from

$$f_k = k_s f_{05}$$

Sampling factor (k_s) and 5th percentile strength (f_{05})

The values of k_s and f_{05} shall be calculated from the following equations:

$$k_s = 1 - 1.15\, V_R / \sqrt{n}$$

$$f_{05} = \exp(\bar{y} - 1.645\, S_y)$$

and

$$V_R = \sqrt{\exp(S_y^2) - 1}$$

$$S_y = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\ln(f_i) - \bar{y}\right)^2}$$

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n}\ln(f_i)$$

where

V_R = coefficient of variation of the complete test data

n = sample size

S_y = standard deviation of the natural logarithms of the complete test data

f_i = i-th ranked strength value in the test data, in megapascals

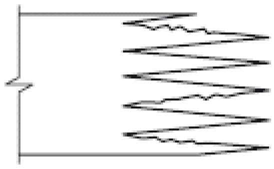
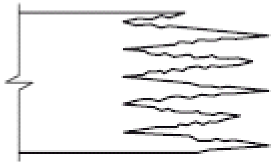
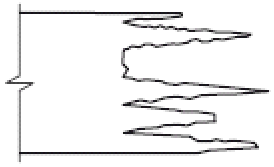
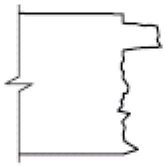
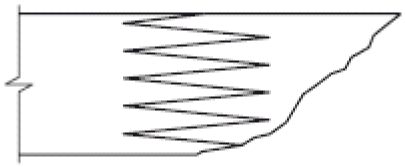
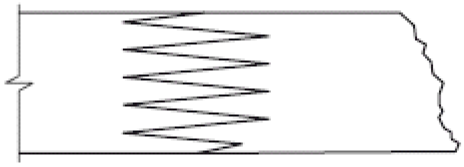
exp = exponential

ln = natural logarithm

Appendix G

Method for Classifying Finger Joint Failures – AS5068 (2006)

FAILURE MODES OF TEST SPECIMENS

Mode	Description	Example
1	Failure mostly along the bondline surfaces of the joint profile with poor wood failure of any kind (wood failure <70%)	
2	Failure mostly along the bondline surfaces of the joint profile with good wood failure of any kind (wood failure >70%)	
3	Failure mostly along the joint profile but with some failure at the finger roots or scarf tips. Good overall wood shear failure along the joint profile surfaces	
4	Mostly tensile wood failure at the finger joint roots or scarf tips and with high overall wood failure. Little failure of any kind along the joint profile	
5	Failure beginning at the joint (possibly due to a stress riser) and progressing away from the joint. Essentially 100% wood failure	
6	Failure away from the joint (not influenced by the joint)—all wood failure	

Appendix H

Test Data and Analysis – Mechanical Properties

Appendix H.1 – Bending Testing

90 x 35 Finger Jointed Timber - Bending Testing

Test Equipment - Hyne and Son Tuan Test Rig
Test Operator - Tony Dakin

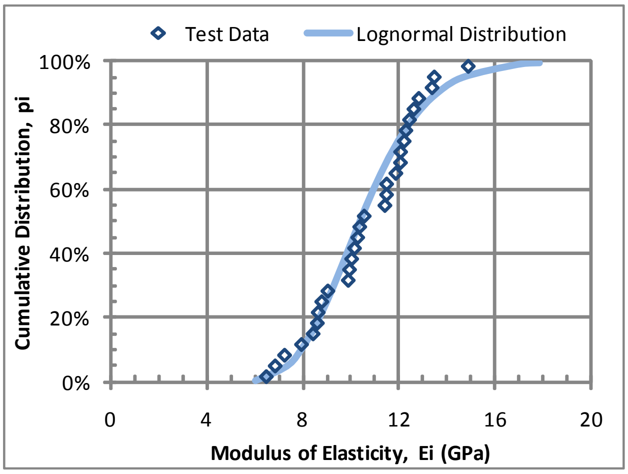
Sample Details			
Depth (mm)	Breadth (mm)	Length (mm)	Test Span (mm)
90	35	1800	1620

Test Data										
Sample No.	Density	Load 1	Defl. 1	Load 2	Defl. 2	Failure Load	Fail. Loc'n.	Failure Source	Mod. Of Elast.	Bending Strength
	(kg/m^3)	(kg)	(mm)	(kg)	(mm)	(kg)	(mm)		(MPa)	(MPa)
10B	578	44	1.43	204	6.05	896	240	Finger Joint	12056	50.23
11B	630	35	1.17	214	7.24	647	260	Finger Joint	10266	36.27
19B	628	35	0.97	206	4.97	691	420	Finger Joint	14882	27.98
20B	573	34	0.98	205	5.92	655	400	Knot	12050	27.88
27B	578	34	1.64	207	7.46	450	95	Finger Joint	10348	25.23
32B	556	35	1.34	212	8.37	582	0	Finger Joint	8765	32.63
33B	565	34	1.13	206	7.04	723	200	Finger Joint	10131	40.53
34B	536	35	1.38	207	8.36	351	100	Finger Joint	8578	19.68
35B	577	35	1.53	204	6.35	693	170	Finger Joint	12206	38.85
38B	556	34	1.02	205	6.04	747	150	Finger Joint	11858	41.87
39B	534	36	1.70	204	9.81	555	370	Finger Joint	7211	25.35
44B	605	35	1.56	204	5.93	579	100	Finger Joint	13463	32.46
45B	606	35	1.07	206	6.72	721	255	Finger Joint	10536	40.42
47B	592	37	1.36	204	5.97	559	80	Finger Joint	12611	31.34
49B	543	35	1.34	205	7.25	635	190	Finger Joint	10013	35.60
57B	575	36	2.11	205	9.54	599	130	Finger Joint	7918	33.58
59B	606	36	1.04	204	6.17	621	100	Finger Joint	11400	34.81
60B	609	34	1.20	211	7.41	763	240	Finger Joint	9922	42.77
62B	536	34	1.38	206	8.33	574	30	Finger Joint	8615	32.18
66B	544	34	1.91	205	7.10	611	190	Finger Joint	11470	34.25
70B	528	35	2.15	206	11.38	634	115	Clear Wood	6449	35.54
71B	569	35	1.02	205	5.84	615	70	Finger Joint	12278	34.48
77B	585	34	0.95	205	5.74	497	150	Finger Joint	12427	27.86
81B	613	35	1.14	204	7.10	489	30	Finger Joint	9871	27.41
84B	485	35	1.80	206	10.53	589	75	Clear Wood	6819	33.02
86B	640	35	1.05	212	6.42	573	215	Finger Joint	11474	32.12
89B	606	35	0.99	204	5.58	946	335	Finger Joint	12817	46.65
90B	571	35	0.89	204	5.29	521	85	Finger Joint	13371	29.21
95B	652	37	1.59	205	8.55	341	260	Finger Joint	8403	19.12
105B	573	37	1.45	208	8.05	665	395	Knot	9019	28.65

90 x 35 Finger Jointed Timber - Bending Stiffness Testing

Analysis Method - AS/NZS 4063.2 (2010)

Test Data		Calculated Parameters		
Rank	E_i	p_i	$\ln(E_i)$	$(\ln(E_i)-\hat{y})^2$
1	6449	0.017	8.772	0.224
2	6819	0.050	8.827	0.175
3	7211	0.083	8.883	0.131
4	7918	0.117	8.977	0.072
5	8403	0.150	9.036	0.044
6	8578	0.183	9.057	0.035
7	8615	0.217	9.061	0.034
8	8765	0.250	9.078	0.028
9	9019	0.283	9.107	0.019
10	9871	0.317	9.197	0.002
11	9922	0.350	9.203	0.002
12	10013	0.383	9.212	0.001
13	10131	0.417	9.223	0.000
14	10266	0.450	9.237	0.000
15	10348	0.483	9.245	0.000
16	10536	0.517	9.263	0.000
17	11400	0.550	9.341	0.009
18	11470	0.583	9.347	0.010
19	11474	0.617	9.348	0.011
20	11858	0.650	9.381	0.018
21	12050	0.683	9.397	0.023
22	12056	0.717	9.397	0.023
23	12206	0.750	9.410	0.027
24	12278	0.783	9.416	0.029
25	12427	0.817	9.428	0.033
26	12611	0.850	9.442	0.039
27	12817	0.883	9.459	0.045
28	13371	0.917	9.501	0.065
29	13463	0.950	9.508	0.069
30	14882	0.983	9.608	0.131
		∑	277.360	1.302



$\hat{y}$	=	9.245
S_y	=	0.212
V_E	=	0.214
k_s	=	0.973
$\hat{E}$	=	10591
E_{05}	=	7309
$E_{k,mean,1}$	=	10301
$E_{k,mean,2}$	=	10155

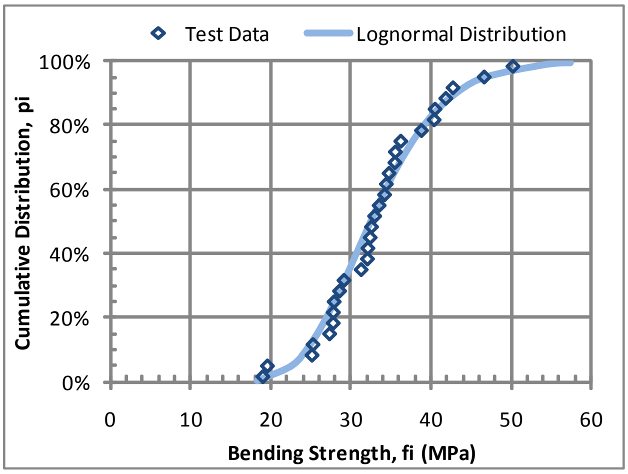
Characteristic Modulus of Elasticity, (MPa)

$E_{k,mean}$ = 10155

90 x 35 Finger Jointed Timber - Bending Strength Testing

Analysis Method - AS/NZS 4063.2 (2010) Method 1

Test Data		Calculated Parameters		
Rank	f_i	p_i	$\ln(f_i)$	$(\ln(f_i)-\hat{y})^2$
1	19.12	0.017	2.950	0.282
2	19.68	0.050	2.979	0.252
3	25.23	0.083	3.228	0.064
4	25.35	0.117	3.233	0.062
5	27.41	0.150	3.311	0.029
6	27.86	0.183	3.327	0.024
7	27.88	0.217	3.328	0.024
8	27.98	0.250	3.331	0.023
9	28.65	0.283	3.355	0.016
10	29.21	0.317	3.374	0.011
11	31.34	0.350	3.445	0.001
12	32.12	0.383	3.470	0.000
13	32.18	0.417	3.471	0.000
14	32.46	0.450	3.480	0.000
15	32.63	0.483	3.485	0.000
16	33.02	0.517	3.497	0.000
17	33.58	0.550	3.514	0.001
18	34.25	0.583	3.534	0.003
19	34.48	0.617	3.540	0.003
20	34.81	0.650	3.550	0.005
21	35.54	0.683	3.571	0.008
22	35.60	0.717	3.572	0.008
23	36.27	0.750	3.591	0.012
24	38.85	0.783	3.660	0.032
25	40.42	0.817	3.699	0.047
26	40.53	0.850	3.702	0.049
27	41.87	0.883	3.735	0.064
28	42.77	0.917	3.756	0.075
29	46.65	0.950	3.843	0.130
30	50.23	0.983	3.917	0.189
		∑	104.447	1.416



$\hat{y}$ = 3.482

S_y = 0.221

V_R = 0.224

k_s = 0.953

f_{05} = 22.60

Characteristic Bending Strength, (MPa)

f_b = 21.54

Appendix H.2 – Tension Testing

90 x 35 Finger Jointed Timber - Tension Strength Testing

Test Equipment - Hyne and Son Tension Test Rig
Test Operator - Tony Dakin

Sample Details			
Depth (mm)	Breadth (mm)	Length (mm)	Test Span (mm)
90	35	4000	2800

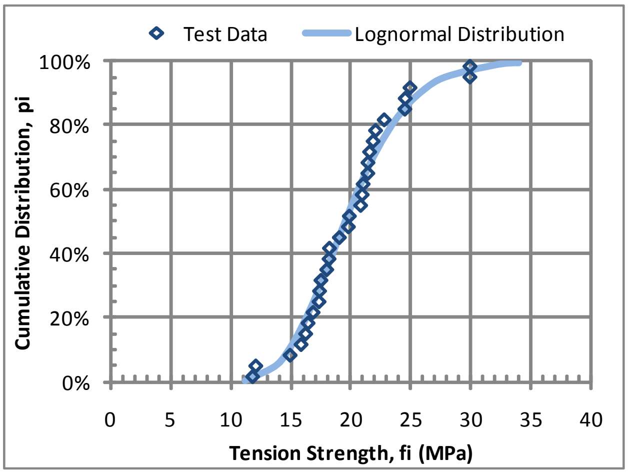
Test Data				
Sample No.	Density (kg/m³)	Failure Load (kg)	Failure Source	Tension Strength (MPa)
12T	594	6122	Knot	19.07
14T	579	7876	Finger Joint & Sloping Grain	24.53
18T	596	7022	Knot	21.87
23T	560	5422	Finger Joint	16.89
24T	629	6688	Finger Joint	20.83
25T	582	6388	Knot & Finger Joint	19.89
26T	565	3812	Knot & Finger Joint	11.87
29T	562	9600	Slipped in Jaws	29.90
30T	589	5848	Knot & Finger Joint	18.21
37T	598	3896	Knot	12.13
40T	582	6928	Finger Joint	21.58
41T	570	4810	Knot	14.98
42T	566	7316	Finger Joint	22.78
43T	592	7866	Knot in Finger Joint	24.50
46T	582	5288	Sloping Grain around Knot	16.47
48T	540	6884	Knot x2	21.44
52T	551	5224	Finger Joint	16.27
54T	588	6756	Finger Joint	21.04
64T	560	5632	Knot x2	17.54
74T	590	5580	Knot	17.38
76T	610	7086	Finger Joint	22.07
79T	546	5594	Knot	17.42
80T	617	5786	Knot	18.02
82T	587	8004	Finger Joint	24.93
85T	647	6730	Knot & Finger Joint	20.96
92T	573	6880	Finger Joint	21.43
96T	619	9598	Slipped in Jaws	29.89
101T	586	6362	Knot	19.81
102T	577	5102	Knot & Finger Joint	15.89
103T	618	5858	Knot	18.24

90 x 35 Finger Jointed Timber - Tension Strength Testing

Analysis Method - AS/NZS 4063.2 (2010) Method 1

Test Data		Calculated Parameters		
Rank	f_i	p_i	$\ln(f_i)$	$(\ln(f_i)-\hat{y})^2$
1	11.87	0.017	2.474	0.246
2	12.13	0.050	2.496	0.225
3	14.98	0.083	2.707	0.069
4	15.89	0.117	2.766	0.042
5	16.27	0.150	2.789	0.033
6	16.47	0.183	2.801	0.028
7	16.89	0.217	2.826	0.021
8	17.38	0.250	2.855	0.013
9	17.42	0.283	2.858	0.013
10	17.54	0.317	2.864	0.011
11	18.02	0.350	2.891	0.006
12	18.21	0.383	2.902	0.005
13	18.24	0.417	2.904	0.004
14	19.07	0.450	2.948	0.000
15	19.81	0.483	2.986	0.000
16	19.89	0.517	2.990	0.000
17	20.83	0.550	3.036	0.004
18	20.96	0.583	3.043	0.005
19	21.04	0.617	3.046	0.006
20	21.43	0.650	3.065	0.009
21	21.44	0.683	3.065	0.009
22	21.58	0.717	3.072	0.010
23	21.87	0.750	3.085	0.013
24	22.07	0.783	3.094	0.015
25	22.78	0.817	3.126	0.024
26	24.50	0.850	3.199	0.052
27	24.53	0.883	3.200	0.053
28	24.93	0.917	3.216	0.060
29	29.89	0.950	3.398	0.183
30	29.90	0.983	3.398	0.183

∑	89.101	1.345



$\hat{y}$ = 2.970

S_y = 0.215

V_R = 0.218

k_s = 0.954

f_{05} = 13.68

Characteristic Tension Strength, (MPa)

$\mathbf{f_t}$ **= 13.05**

Appendix H.3 – Compression Testing

90 x 35 Finger Jointed Timber - Compression Strength Testing

Test Equipment - Hyne and Son Compression Test Rig
Test Operator - Tony Dakin

Sample Details			
Depth (mm)	Breadth (mm)	Length (mm)	Test Span (mm)
90	35	2400	2400

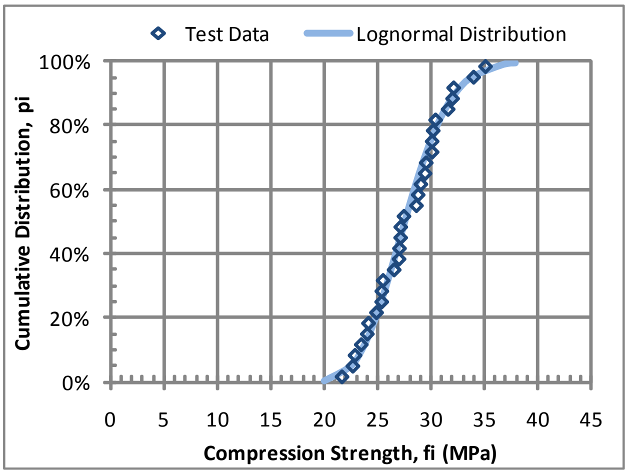
Test Data				
Sample No.	Density (kg/m³)	Failure Load (kN)	Failure Source	Compression Strength (MPa)
10C	597	79.84	Knot	25.35
11C	617	84.96	Knot	26.97
19C	619	91.44	Clear Wood	29.03
20C	541	95.82	Finger Joint	30.42
27C	549	85.46	Finger Joint	27.13
32C	538	85.08	Finger Joint	27.01
33C	545	78.26	Knot	24.84
34C	613	68.02	Knot	21.59
35C	643	71.24	Knot	22.62
38C	565	93.02	Knot	29.53
39C	557	79.80	Knot	25.33
44C	548	86.42	Knot	27.43
45C	557	94.80	Finger Joint	30.10
47C	593	85.44	Knot	27.12
49C	554	83.50	Knot	26.51
57C	594	75.54	Knot	23.98
59C	583	90.64	Clear Wood	28.77
60C	568	107.12	Finger Joint	34.01
62C	611	99.54	Knot	31.60
66C	563	90.12	Knot	28.61
70C	639	110.64	Knot	35.12
71C	545	73.74	Knot	23.41
77C	571	95.10	Finger Joint	30.19
81C	583	92.72	Clear Wood	29.43
84C	592	94.78	Clear Wood	30.09
86C	562	75.90	Knot	24.10
89C	572	71.88	Knot	22.82
90C	609	101.20	Knot	32.13
95C	635	100.86	Knot	32.02
105C	546	80.22	Knot	25.47

90 x 35 Finger Jointed Timber - Compression Strength Testing

Analysis Method - AS/NZS 4063.2 (2010) Method 1

Test Data		Calculated Parameters		
Rank	fi	p_i	$\ln(f_i)$	$(\ln(f_i)-\hat{y})^2$
1	21.59	0.017	3.072	0.059
2	22.62	0.050	3.119	0.039
3	22.82	0.083	3.128	0.036
4	23.41	0.117	3.153	0.027
5	23.98	0.150	3.177	0.019
6	24.10	0.183	3.182	0.018
7	24.84	0.217	3.213	0.011
8	25.33	0.250	3.232	0.007
9	25.35	0.283	3.233	0.007
10	25.47	0.317	3.237	0.006
11	26.51	0.350	3.277	0.001
12	26.97	0.383	3.295	0.000
13	27.01	0.417	3.296	0.000
14	27.12	0.450	3.300	0.000
15	27.13	0.483	3.301	0.000
16	27.43	0.517	3.312	0.000
17	28.61	0.550	3.354	0.001
18	28.77	0.583	3.359	0.002
19	29.03	0.617	3.368	0.003
20	29.43	0.650	3.382	0.004
21	29.53	0.683	3.385	0.005
22	30.09	0.717	3.404	0.008
23	30.10	0.750	3.404	0.008
24	30.19	0.783	3.408	0.008
25	30.42	0.817	3.415	0.010
26	31.60	0.850	3.453	0.019
27	32.02	0.883	3.466	0.023
28	32.13	0.917	3.470	0.024
29	34.01	0.950	3.527	0.044
30	35.12	0.983	3.559	0.059

∑	99.482	0.449



$\hat{y}$ = 3.316

S_y = 0.124

V_R = 0.125

k_s = 0.974

f_{05} = 22.45

Characteristic Compression Strength, (MPa)

f_c = 21.87

Appendix H.4 – Shear Testing

90 x 35 Finger Jointed Timber - Shear Strength Testing

Test Equipment - Hyne and Son Tuan Test Rig
Test Operator - Tony Dakin

Sample Details			
Depth (mm)	Breadth (mm)	Length (mm)	Test Span (mm)
90	35	720	540

Test Data					
Sample No.	Density (kg/m³)	Failure Load (kg)	Failure Mode	Failure Source	Shear Strength (MPa)
10S	578	2448	Bearing	Load Point	-
11S	576	2635	Bending	Finger Joint	-
19S	820	2392	Shear	Knot	5.59
20S	582	1265	Bending	Finger Joint	-
27S	573	2671	Bending	Clear Wood	-
32S	550	2371	Bending	Clear Wood	-
33S	537	1172	Bending	Knot	-
34S	604	1447	Shear	Finger Joint	3.38
35S	542	2079	Bending	Finger Joint	-
38S	563	1384	Shear	Finger Joint	3.23
39S	618	998	Bending	Finger Joint	-
44S	512	1424	Bending	Clear Wood	-
45S	515	2266	Bending	Clear Wood	-
47S	586	2627	Shear	Finger Joint	6.14
49S	511	1119	Bending	Finger Joint	-
57S	619	1822	Bending	Finger Joint	-
60S	675	3351	Shear	Finger Joint	7.83
62S	554	1400	Shear	Finger Joint	3.27
66S	565	2026	Bending	Finger Joint	-
70S	550	1603	Shear	Finger Joint	3.74
71S	799	3011	Shear	Finger Joint	7.03
77S	649	1422	Bending	Finger Joint	-
81S	569	1751	Bending	Finger Joint	-
84S	558	2303	Bending	Knot	-
86S	599	2640	Bending	Finger Joint	-
89S	579	2135	Bending	Finger Joint	-
89S	631	2796	Bearing	Load Point	-
90S	619	1082	Bending	Finger Joint	-
95S	695	2440	Bending	Finger Joint	-
105S	519	1905	Bending	Clear Wood	-
1	609	2416	Bending	Knot	-

90 x 35 Finger Jointed Timber - Shear Strength Testing (cont'd)

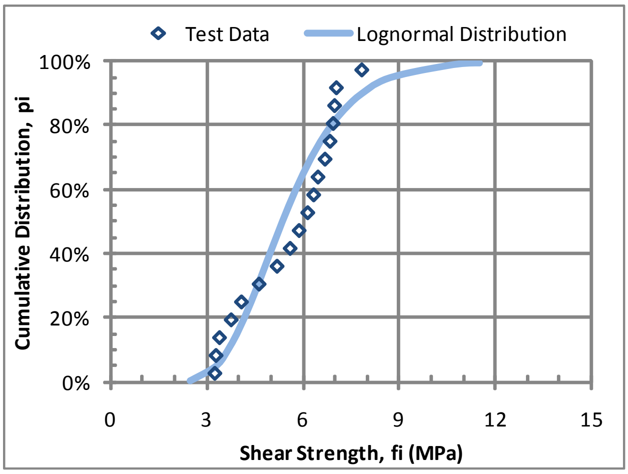
Test Data					
Sample No.	Density (kg/m³)	Failure Load (kg)	Failure Mode	Failure Source	Shear Strength (MPa)
2	599	2604	Bending	Knot	-
3	602	2512	Shear	Finger Joint	5.87
4	602	2069	Bending	Knot	-
5	519	2387	Bending	Knot	-
6	646	2976	Bending	Knot	-
7	535	2630	Bending	Clear Wood	-
8	587	1915	Bending	Knot	-
9	544	2297	Bending	Clear Wood	-
10	648	2410	Bearing	Load Point	-
11	601	2859	Shear	Knot	6.68
12	520	1447	Bending	Knot	-
13	629	1740	Shear	Knot	4.06
14	630	2987	Shear	Finger Joint	6.98
15	575	2809	Bending	Clear Wood	-
16	548	1711	Bending	Knot	-
17	559	2217	Shear	Clear Wood	5.18
18	616	2707	Shear	Load Point	6.32
19	560	2807	Bending	Clear Wood	-
20	588	3239	Bending	Clear Wood	-
21	667	2926	Shear	Clear Wood	6.83
22	598	2454	Bearing	Load Point	-
23	665	3545	Bending	Knot	-
24	623	2645	Bending	Clear Wood	-
25	620	3504	Bending	Clear Wood	-
26	643	3306	Bending	Clear Wood	-
27	529	546	Bending	Internal Fracture	-
28	561	2595	Bearing	Load Point	-
29	608	1976	Shear	Finger Joint	4.62
30	700	2968	Shear	Finger Joint	6.93
31	683	2765	Shear	Clear Wood	6.46
32	520	1954	Bending	Clear Wood	-

90 x 35 Finger Jointed Timber - Shear Strength Testing

Analysis Method - AS/NZS 4063.2 (2010) Method 1

Test Data		Calculated Parameters		
Rank	f_i	p_i	$\ln(f_i)$	$(\ln(f_i)-\hat{y})^2$
1	3.23	0.028	1.173	0.254
2	3.27	0.083	1.185	0.243
3	3.38	0.139	1.218	0.211
4	3.74	0.194	1.320	0.128
5	4.06	0.250	1.402	0.076
6	4.62	0.306	1.529	0.022
7	5.18	0.361	1.644	0.001
8	5.59	0.417	1.720	0.002
9	5.87	0.472	1.769	0.008
10	6.14	0.528	1.814	0.019
11	6.32	0.583	1.844	0.028
12	6.46	0.639	1.865	0.035
13	6.68	0.694	1.899	0.049
14	6.83	0.750	1.922	0.060
15	6.93	0.806	1.936	0.067
16	6.98	0.861	1.943	0.070
17	7.03	0.917	1.951	0.075
18	7.83	0.972	2.058	0.145

$\sum$	30.193	1.492



$\hat{y}$ = 1.677

S_y = 0.296

V_R = 0.303

k_s = 0.918

f_{05} = 3.29

<u>Characteristic Shear Strength, (MPa)</u>

f_s = 3.02

Appendix I

Test Data and Analysis – Truss Joints and Connections

Appendix I.1 – Nail Plate Parallel to the Grain

Truss Joint Testing - Nail Plate Parallel to Grain

Test Equipment - Hyne and Son Tension Test Rig
Test Operator - Tony Dakin

Sample Type - Finger Jointed Timber

Test Data				
Sample No.	Avg Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
FJ-1	459	3758	Tooth Pull out & Wood Break in FJ Piece	36.87
FJ-2	503	4080	Tooth Pull out & Plate Tear	40.02
FJ-3	509	4296	Plate Tear x2	42.14
FJ-4	521	4128	Plate Tear x2	40.50
FJ-5	524	3858	Tooth Pull out & Plate Tear	37.85
FJ-6	531	4064	Plate Tear x2	39.87
FJ-7	544	4108	Plate Tear & Wood Break	40.30
FJ-8	548	3116	Failed at Knot Away from Joint	30.57
FJ-9	556	4146	Plate Tear x2	40.67
FJ-10	559	4210	Plate Tear x2	41.30
FJ-11	564	4242	Plate Tear x2	41.61
FJ-12	586	3850	Broke in Low Dens Wood at back of plate	37.77
FJ-13	588	3748	Tooth Pull out & Plate Tear	36.77
FJ-14	599	3834	Tooth Pull out & Plate Tear	37.61
FJ-15	591	3984	Tooth Pull out & Plate Tear	39.08
FJ-16	604	3926	Tooth Pull out & Wood Break in FJ Piece	38.51
FJ-17	607	3862	Tooth Pull out & Plate Tear	37.89
FJ-18	653	2674	Teeth Pull out of non-FJ piece. Teeth not embedded.	26.23
FJ-19	664	3874	Plate Tear x2	38.00
FJ-20	675	3992	Plate Tear x2	39.16

Sample Type - Standard MGP10

Test Data				
Sample No.	Avg Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
S-2	460	3758	Teeth Pull out & Low Dens Wood Break	36.87
S-4	461	4010	Teeth Pull out & Plate Tear	39.34
S-6	466	4286	Plate Tear x2	42.05
S-8	468	3688	Teeth Pull out & Wood Break	36.18
S-10	476	4462	Teeth Pull out & Low Dens Wood Break	43.77
S-13	484	3826	Teeth Pull out & Low Dens Wood Break	37.53
S-15	489	3780	Teeth Pull out & Low Dens Wood Break	37.08
S-16	495	4142	Plate Tear & Wood Break	40.63
S-20	511	4244	Plate Tear x2	41.63
S-24	524	3218	Failed at Knot Away from Joint	31.57
S-26	526	4196	Teeth Pull out & Plate Tear	41.16
S-28	528	4304	Plate Tear x2	42.22
S-31	535	4122	Teeth Pull out & Plate Tear	40.44
S-34	537	4256	Plate Tear x2	41.75
S-35	544	4042	Teeth Pull out & Plate Tear	39.65
S-42	557	4150	Plate Tear x2	40.71
S-43	570	4370	Plate Tear x2	42.87
S-54	596	3952	Teeth Pull out & Low Dens Wood Break	38.77
S-55	615	3350	Teeth Pull Out	32.86
S-60	662	3798	Teeth Pull out & Low Dens Wood Break	37.26

Highlighted samples not included in analysis and comparison.

Truss Joint Testing - Nail Plate Parallel to Grain

Analysis Method - AS 1649 (2001)

Finger Jointed Timber			
Test Data		Calculations	
Rank	F_i	y_i	$(y_i)^2$
1	36.77	3.605	12.993
2	36.87	3.607	13.013
3	37.61	3.627	13.157
4	37.77	3.631	13.188
5	37.85	3.634	13.203
6	37.89	3.635	13.210
7	38.00	3.638	13.233
8	38.51	3.651	13.330
9	39.08	3.666	13.437
10	39.16	3.668	13.452
11	39.87	3.686	13.583
12	40.02	3.689	13.612
13	40.30	3.696	13.663
14	40.50	3.701	13.699
15	40.67	3.706	13.731
16	41.30	3.721	13.845
17	41.61	3.728	13.901
18	42.14	3.741	13.996
∑		66.029	242.246

Standard MGP10 Timber			
Test Data		Calculations	
Rank	x_i	y_i	$(y_i)^2$
1	32.86	3.492	12.197
2	36.18	3.588	12.877
3	36.87	3.607	13.013
4	37.08	3.613	13.055
5	37.26	3.618	13.089
6	37.53	3.625	13.142
7	38.77	3.658	13.378
8	39.34	3.672	13.485
9	39.65	3.680	13.543
10	40.44	3.700	13.688
11	40.63	3.705	13.724
12	40.71	3.707	13.738
13	41.16	3.718	13.820
14	41.63	3.729	13.905
15	41.75	3.732	13.926
16	42.05	3.739	13.978
17	42.22	3.743	14.010
18	42.87	3.758	14.124
19	43.77	3.779	14.281
∑		69.862	256.972

Finger Jointed Timber:

$\hat{y}$ = 3.668
s = 0.042

Avg = 39.19
Std Dev = 1.04

Standard MGP10 Timber:

$\hat{y}$ = 3.677
s = 0.072

Avg = 39.53
Std Dev = 1.07

Comparison Method - Spiegel (1982)

$n_1 =$ 18 $X_1 =$ 39.19 $S_1 =$ 1.04
$n_2 =$ 19 $X_2 =$ 39.53 $S_2 =$ 1.07

σ = 1.089

T = -0.951

$t_{.995}$ = 2.725
$t_{.975}$ = 2.03

$\mathbf{-t_{.995} < T < t_{.995}}$ **&** $\mathbf{-t_{.975} < T < t_{.975}}$

therefore,

<u>No significant difference between FJ Timber & MGP10</u>

Appendix I.2 – Nail Plate Perpendicular to the Grain

Truss Joint Testing - Nail Plate Perpindicular to Grain

Test Equipment - Hyne and Son Vertical Test Rig
Test Operator - Tony Dakin

Sample Type - Finger Jointed Timber

Test Data				
Sample No.	Chord Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
FJ-1	595	289	Teeth pull out of chord	7.09
FJ-2	527	282	Tens. Perp. in Chord at Top Teeth	6.92
FJ-3	600	253	Teeth pull out of chord	6.20
FJ-4	548	278	Teeth pull out of chord	6.82
FJ-5	564	246	Teeth pull out of chord	6.03
FJ-6	722	342	Teeth pull out of chord	8.39
FJ-7	572	308	Teeth pull out of chord	7.55
FJ-8	656	370	Teeth pull out of chord	9.07
FJ-9	642	324	Teeth pull out of chord	7.95
FJ-10	644	306	Teeth pull out of chord	7.50
FJ-11	550	227	Teeth pull out of chord	5.57
FJ-12	593	322	Teeth pull out of chord	7.90
FJ-13	487	364	Tens. Perp. in Chord at Top Teeth	8.93
FJ-14	591	304	Teeth pull out of chord	7.46
FJ-15	584	358	Teeth pull out of chord	8.78
FJ-16	558	354	Teeth pull out of chord	8.68
FJ-17	537	290	Teeth pull out of chord	7.11
FJ-18	565	294	Tens. Perp. in Chord at Top Teeth	7.21
FJ-19	554	308	Tens. Perp. in Chord at Top Teeth	7.55
FJ-20	531	357	Teeth pull out of chord	8.76

Sample Type - Standard MGP10

Test Data				
Sample No.	Chord Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
S-1	461	257	Tens. Perp. in Chord at Top Teeth	6.30
S-2	506	188	Teeth pull out of chord	4.61
S-3	638	454	Teeth pull out of chord	11.13
S-4	493	282	Teeth pull out of chord	6.92
S-5	523	311	Teeth pull out of chord	7.63
S-6	478	251	Teeth pull out of chord	6.16
S-7	515	324	Tens. Perp. in Chord at Top Teeth	7.95
S-8	662	393	Teeth pull out of chord	9.64
S-9	660	363	Teeth pull out of chord	8.90
S-10	582	273	Tens. Perp. in Chord at Top Teeth	6.70
S-11	572	326	Teeth pull out of chord	8.00
S-12	444	230	Teeth pull out of chord	5.64
S-13	562	363	Teeth pull out of chord	8.90
S-14	599	233	Teeth pull out of chord	5.71
S-15	669	287	Teeth pull out of chord	7.04
S-16	624	357	Teeth pull out of chord	8.76
S-17	589	299	Tens. Perp. in Chord at Top Teeth	7.33
S-18	576	269	Teeth pull out of chord	6.60
S-19	529	152	Tens. Perp. in Chord at Top Teeth	3.73
S-20	545	284	Teeth pull out of chord	6.97

Truss Joint Testing - Nail Plate Perpindicular to Grain

Analysis Method - AS 1649 (2001)

Finger Jointed Timber			
Test Data		Calculations	
Rank	F_i	y_i	$(y_i)^2$
1	5.57	1.717	2.948
2	6.03	1.797	3.230
3	6.20	1.825	3.332
4	6.82	1.920	3.685
5	6.92	1.934	3.740
6	7.09	1.958	3.835
7	7.11	1.962	3.849
8	7.21	1.976	3.903
9	7.46	2.009	4.036
10	7.50	2.016	4.062
11	7.55	2.022	4.089
12	7.55	2.022	4.089
13	7.90	2.066	4.270
14	7.95	2.073	4.296
15	8.39	2.127	4.523
16	8.68	2.161	4.671
17	8.76	2.170	4.707
18	8.78	2.172	4.720
19	8.93	2.189	4.792
20	9.07	2.205	4.864
∑		40.321	81.640

Standard MGP10 Timber			
Test Data		Calculations	
Rank	x_i	y_i	$(y_i)^2$
1	3.73	1.316	1.731
2	4.61	1.528	2.336
3	5.64	1.730	2.993
4	5.71	1.743	3.038
5	6.16	1.817	3.303
6	6.30	1.841	3.389
7	6.60	1.887	3.559
8	6.70	1.901	3.615
9	6.92	1.934	3.740
10	6.97	1.941	3.767
11	7.04	1.951	3.808
12	7.33	1.992	3.970
13	7.63	2.032	4.128
14	7.95	2.073	4.296
15	8.00	2.079	4.322
16	8.76	2.170	4.707
17	8.90	2.186	4.780
18	8.90	2.186	4.780
19	9.64	2.266	5.134
20	11.13	2.410	5.808
∑		38.984	77.205

Finger Jointed Timber:

$\hat{y}$ = 2.016
s = 0.136

Avg = 7.51
Std Dev = 1.15

Standard MGP10 Timber:

$\hat{y}$ = 1.949
s = 0.253

Avg = 7.02
Std Dev = 1.29

Comparison Method - Spiegel (1982)

$n_1 =$ 20 $X_1 =$ 7.51 $S_1 =$ 1.15

$n_2 =$ 20 $X_2 =$ 7.02 $S_2 =$ 1.29

σ = 1.251

T = 1.228

$t_{.995}$ = 2.71
$t_{.975}$ = 2.024

$-t_{.995} < T < t_{.995}$ & $-t_{.975} < T < t_{.975}$

therefore,

No significant difference between FJ Timber & MGP10

Appendix I.3 – Batten Screw Connection

Truss Connection Testing - Batten Screw

Test Equipment - Hyne and Son Vertical Test Rig
Test Operator - Tony Dakin

Sample Type - Finger Jointed Timber

Test Data				
Sample No.	Chord Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
FJ-1	573	212	Tens. Perp. in Chord at Screw Tip	5.20
FJ-2	585	256	Thread pull out of Chord	6.28
FJ-3	535	236	Thread pull out of Chord	5.79
FJ-4	578	223	Tens. Perp. in chord at Screw Tip & Thread pull out	5.47
FJ-5	551	236	Thread pull out of Chord	5.79
FJ-6	605	225	Thread pull out of Chord	5.52
FJ-7	569	234	Thread pull out of Chord	5.74
FJ-8	582	254	Tens. Perp. in Chord at Screw Tip	6.23
FJ-9	605	283	Thread pull out of Chord	6.94
FJ-10	566	253	Thread pull out of Chord	6.20

Sample Type - Standard MGP10

Test Data				
Sample No.	Chord Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
S-1	604	241	Thread pull out of Chord	5.91
S-2	546	196	Thread pull out of Chord	4.81
S-3	579	226	Thread pull out of Chord	5.54
S-4	534	211	Thread pull out of Chord	5.17
S-5	579	195	Thread pull out of Chord	4.78
S-6	549	228	Thread pull out of Chord	5.59
S-7	554	228	Thread pull out of Chord	5.59
S-8	594	211	Thread pull out of Chord	5.17
S-9	603	220	Thread pull out of Chord	5.40
S-10	603	223	Thread pull out of Chord	5.47

Truss Connection Testing - Batten Screw

Analysis Method - AS 1649 (2001)

Finger Jointed Timber			
Test Data		Calculations	
Rank	F_i	y_i	$(y_i)^2$
1	5.20	1.649	2.718
2	5.47	1.699	2.887
3	5.52	1.708	2.917
4	5.74	1.747	3.053
5	5.79	1.756	3.083
6	5.79	1.756	3.083
7	6.20	1.825	3.332
8	6.23	1.829	3.346
9	6.28	1.837	3.375
10	6.94	1.937	3.753
∑		17.744	31.547

Standard MGP10 Timber			
Test Data		Calculations	
Rank	x_i	y_i	$(y_i)^2$
1	4.78	1.565	2.449
2	4.81	1.570	2.465
3	5.17	1.644	2.702
4	5.17	1.644	2.702
5	5.40	1.686	2.841
6	5.47	1.699	2.887
7	5.54	1.712	2.933
8	5.59	1.721	2.963
9	5.59	1.721	2.963
10	5.91	1.777	3.157
∑		16.739	28.061

Finger Jointed Timber:

$\hat{y}$ = 1.774
s = 0.084

Avg = 5.90
Std Dev = 1.09

Standard MGP10 Timber:

$\hat{y}$ = 1.674
s = 0.068

Avg = 5.33
Std Dev = 1.07

Comparison Method - Spiegel (1982)

$n_1 =$ 10 $X_1 =$ 5.90 $S_1 =$ 1.09
$n_2 =$ 10 $X_2 =$ 5.33 $S_2 =$ 1.07

σ = 1.137

T = 1.108

$t_{.995}$ = 2.88
$t_{.975}$ = 2.10

$-t_{.995} < T < t_{.995}$ **&** $-t_{.975} < T < t_{.975}$

therefore,

<u>No significant difference between FJ Timber & MGP10</u>

Appendix I.4 – MultiGrip with Nails Connection

Truss Connection Testing - MultiGrip with Nails

Test Equipment - Hyne and Son Vertical Test Rig
Test Operator - Tony Dakin

Sample Type - Finger Jointed Timber

Test Data				
Sample No.	Chord Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
FJ-1	570	172	Horiz. nail pull out of Chord	4.22
FJ-2	532	209	Horiz. nail pull out of Chord	5.13
FJ-3	614	145	Horiz. nail pull out of Top Plate	3.56
FJ-4	601	186	Horiz. nail pull out of Chord	4.56
FJ-5	547	187	Horiz. nail pull out of Chord	4.59
FJ-6	466	163	Horiz. nail pull out of Chord	4.00
FJ-7	640	199	Horiz. nail pull out of Chord	4.88
FJ-8	507	169	Horiz. nail pull out of Chord	4.14
FJ-9	681	192	Horiz. nail pull out of Top Plate	4.71
FJ-10	536	218	Horiz. nail pull out of Chord	5.35

Sample Type - Standard MGP10

Test Data				
Sample No.	Chord Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
S-1	471	170	Horiz. nail pull out of Chord	4.17
S-2	600	178	Horiz. nail pull out of Chord	4.37
S-3	537	180	Horiz. nail pull out of Chord	4.41
S-4	651	175	Horiz. nail pull out of Chord	4.29
S-5	551	201	Horiz. nail pull out of Chord	4.93
S-6	468	121	Horiz. nail pull out of Chord	2.97
S-7	666	222	Horiz. nail pull out of Chord	5.44
S-8	488	130	Horiz. nail pull out of Chord	3.19
S-9	646	220	Horiz. nail pull out of Chord	5.40
S-10	555	171	Horiz. nail pull out of Top Plate	4.19

Truss Connection Testing - MultiGrip with Nails

Analysis Method - AS 1649 (2001)

Finger Jointed Timber			
Test Data		Calculations	
Rank	F_i	y_i	$(y_i)^2$
1	3.56	1.269	1.610
2	4.00	1.386	1.920
3	4.14	1.422	2.022
4	4.22	1.439	2.072
5	4.56	1.518	2.303
6	4.59	1.523	2.320
7	4.71	1.549	2.401
8	4.88	1.585	2.513
9	5.13	1.634	2.671
10	5.35	1.676	2.810

∑		15.002	22.641

$\hat{y}$ = 1.500
s = 0.123

Avg = 4.48
Std Dev = 1.13

Standard MGP10 Timber			
Test Data		Calculations	
Rank	x_i	y_i	$(y_i)^2$
1	2.97	1.088	1.183
2	3.19	1.159	1.344
3	4.17	1.428	2.038
4	4.19	1.434	2.055
5	4.29	1.457	2.122
6	4.37	1.474	2.172
7	4.41	1.485	2.205
8	4.93	1.595	2.545
9	5.40	1.686	2.841
10	5.44	1.695	2.872

∑		14.499	21.378

$\hat{y}$ = 1.450
s = 0.199

Avg = 4.26
Std Dev = 1.22

Comparison Method - Spiegel (1982)

$n_1 =$ 10 $X_1 =$ 4.48 $S_1 =$ 1.13
$n_2 =$ 10 $X_2 =$ 4.26 $S_2 =$ 1.22

σ = 1.240

T = 0.396

$t_{.995}$ = 2.88
$t_{.975}$ = 2.10

$-t_{.995} < T < t_{.995}$ & $-t_{.975} < T < t_{.975}$

therefore,

No significant difference between FJ Timber & MGP10

Appendix I.5 – Girder Bracket Screw Connection

Truss Connection Testing - Girder Bracket Screws

Test Equipment - Hyne and Son Vertical Test Rig
Test Operator - Tony Dakin

Sample Type - Finger Jointed Timber

Test Data				
Sample No.	Chord Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
FJ-1	436	297	Bending Failure at Finger Joint	7.28
FJ-2	506	367	Bear. at screws & tens. perp. in chord & bend at FJ	9.00
FJ-3	509	482	Bear. at screws & tens. perp. in chord & bend at FJ	11.82
FJ-4	532	443	Bear. at screws & tens. perp. in chord & bend at FJ	10.86
FJ-5	568	479	Bear. at screws & tens. perp. in chord & bend at FJ	11.75
FJ-6	569	489	Bear. at screws & tens. perp. in chord & bend at FJ	11.99
FJ-7	586	324	Bear. at screws & tens. perp. in chord & bend at FJ	7.95
FJ-8	614	440	Bear. at screws & tens. perp. in chord & bend at FJ	10.79
FJ-9	627	551	Bear. at screws & tens. perp. in chord & bend at FJ	13.51
FJ-10	659	504	Bear. at screws & tens. perp. in chord & bend at FJ	12.36

Sample Type - Standard MGP10

Test Data				
Sample No.	Chord Density	Measured Failure Load	Failure Description	Joint Capacity
	(kg/m³)	(kg)		(kN)
S-1	493	356	Bear. under screws & Tens. Perp. in chord	8.73
S-2	500	414	Bear. under screws & Screw Yield	10.15
S-3	516	431	Bear. under screws & Tens. Perp. in chord	10.57
S-4	534	463	Bear. under screws & Tens. Perp. in chord	11.36
S-5	534	370	Bear. under screws & Tens. Perp. in chord	9.07
S-6	562	442	Bear. under screws & Tens. Perp. in chord	10.84
S-7	569	510	Bear. under screws & Tens. Perp. in chord	12.51
S-8	580	500	Bear. under screws & Tens. Perp. in chord	12.26
S-9	588	432	Bear. under screws & Tens. Perp. in chord	10.59
S-10	646	413	Bear. under screws & Tens. Perp. in chord	10.13

Truss Connection Testing - Girder Bracket Screws

Analysis Method - AS 1649 (2001)

Finger Jointed Timber			
Test Data		Calculations	
Rank	F_i	y_i	$(y_i)^2$
1	7.28	1.986	3.943
2	7.95	2.073	4.296
3	9.00	2.197	4.828
4	10.79	2.379	5.658
5	10.86	2.386	5.691
6	11.75	2.464	6.070
7	11.82	2.470	6.100
8	11.99	2.484	6.172
9	12.36	2.515	6.323
10	13.51	2.604	6.779
∑		23.556	55.859

$\hat{y}$ = 2.356
s = 0.203

Avg = 10.54
Std Dev = 1.23

Standard MGP10 Timber			
Test Data		Calculations	
Rank	x_i	y_i	$(y_i)^2$
1	8.73	2.167	4.695
2	9.07	2.205	4.864
3	10.13	2.315	5.361
4	10.15	2.318	5.372
5	10.57	2.358	5.560
6	10.59	2.360	5.571
7	10.84	2.383	5.680
8	11.36	2.430	5.903
9	12.26	2.507	6.283
10	12.51	2.526	6.382
∑		23.570	55.673

$\hat{y}$ = 2.357
s = 0.115

Avg = 10.56
Std Dev = 1.12

Comparison Method - Spiegel (1982)

$n_1 =$ 10 $X_1 =$ 10.54 $S_1 =$ 1.23
$n_2 =$ 10 $X_2 =$ 10.56 $S_2 =$ 1.12

σ = 1.238

T = -0.026

$t_{.995}$ = 2.88
$t_{.975}$ = 2.10

$-t_{.995} < T < t_{.995}$ **&** $-t_{.975} < T < t_{.975}$

therefore,

<u>No significant difference between FJ Timber & MGP10</u>

Appendix I.6 – Joint Deformation Testing

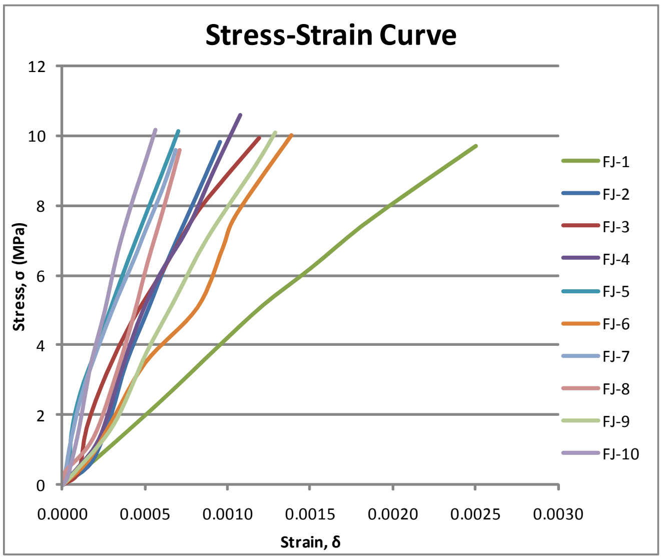
Truss Joint Testing - Joint Deformation

Test Equipment - Hyne and Son Tension Test Rig
Test Operator - Tony Dakin

Sample Type - 90 x35 Finger Jointed Timber with No Plate Joint

Test Data																					
Sample No.	Density	Recorded Loads (kg)										Recorded Deformations (mm)									
	(kg/m³)	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
FJ-1	539	226	772	1250	1646	1996	2376	2740	3112			0.04	0.12	0.19	0.25	0.31	0.37	0.44	0.51		
FJ-2	555	64	234	662	1118	1628	2072	2718	3158			0.01	0.04	0.06	0.08	0.11	0.13	0.17	0.20		
FJ-3	559	122	528	1028	1498	1936	2464	2784	3188			0.02	0.03	0.06	0.09	0.12	0.16	0.20	0.25		
FJ-4	569	118	420	982	1476	1922	2362	2872	3398			0.01	0.05	0.07	0.09	0.12	0.16	0.19	0.22		
FJ-5	571	88	478	846	1260	1960	2404	2912	3258			0.01	0.01	0.02	0.04	0.08	0.10	0.13	0.14		
FJ-6	596	226	582	1124	1630	2166	2480	3210				0.03	0.06	0.10	0.17	0.20	0.22	0.29			
FJ-7	602	54	432	930	1606	2074	2334	2752	3082			0.00	0.01	0.03	0.06	0.09	0.10	0.13	0.14		
FJ-8	647	120	432	1054	1610	2038	2570	3080				0.00	0.04	0.07	0.09	0.11	0.13	0.15			
FJ-9	671	118	552	1216	1700	2264	2934	3242				0.02	0.06	0.10	0.14	0.18	0.24	0.26			
FJ-10	679	74	468	1108	1596	2134	2576	2896	3268			0.01	0.02	0.04	0.05	0.07	0.09	0.10	0.12		

Calculated Values																					
Sample No.	Stress (MPa)										Strain (x10^-6)										Joint Stiffness
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	(MPa)
FJ-1	0.70	2.40	3.89	5.13	6.22	7.40	8.53	9.69			190	595	927	1210	1507	1810	2146	2502			3808
FJ-2	0.20	0.73	2.06	3.48	5.07	6.45	8.46	9.83			63	185	298	385	522	639	829	956			11811
FJ-3	0.38	1.64	3.20	4.67	6.03	7.67	8.67	9.93			98	146	268	420	595	800	966	1195			7804
FJ-4	0.37	1.31	3.06	4.60	5.99	7.36	8.94	10.6			68	220	341	454	585	761	912	1078			10454
FJ-5	0.27	1.49	2.63	3.92	6.10	7.49	9.07	10.1			39	54	107	205	371	483	615	702			13039
FJ-6	0.70	1.81	3.50	5.08	6.75	7.72	10.0				156	298	502	820	971	1054	1390				7490
FJ-7	0.17	1.35	2.90	5.00	6.46	7.27	8.57	9.60			10	54	137	302	434	502	615	688			12551
FJ-8	0.37	1.35	3.28	5.01	6.35	8.00	9.59				15	185	332	439	512	615	707				15981
FJ-9	0.37	1.72	3.79	5.29	7.05	9.14	10.1				73	307	507	678	873	1166	1288				8416
FJ-10	0.23	1.46	3.45	4.97	6.65	8.02	9.02	10.2			29	93	171	254	332	415	483	561			18447



Average Joint Stiffness of

FJ Timber with No Plate Joint

10980 MPa

Std Dev Joint Stiffness of

FJ Timber with No Plate Joint

4330 MPa

Truss Joint Testing - Joint Deformation

Test Equipment - Hyne and Son Tension Test Rig
Test Operator - Tony Dakin

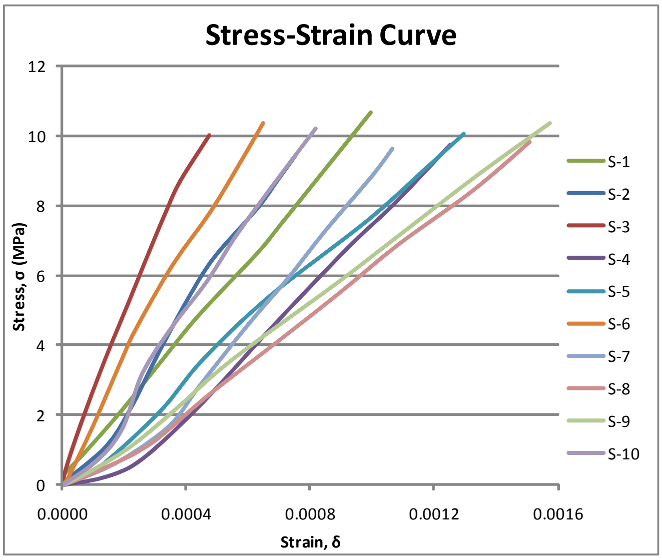
Sample Type - 90 x35 Standard MGP10 with No Plate Joint

Test Data

Sample No.	Density	Recorded Loads (kg)										Recorded Deformations (mm)									
	(kg/m³)	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
S-1	486	80	302	682	1130	1556	2130	2386	2868	3420		0.00	0.02	0.04	0.07	0.09	0.13	0.14	0.17	0.20	
S-2	548	64	360	704	1230	1762	2104	2544	2796	3026		0.00	0.03	0.05	0.06	0.09	0.10	0.13	0.14	0.15	
S-3	568	142	560	1152	1726	2136	2534	2800	3214			0.00	0.01	0.03	0.05	0.06	0.07	0.08	0.10		
S-4	579	82	254	760	1440	2178	2586	3126				0.03	0.05	0.09	0.14	0.19	0.22	0.26			
S-5	593	58	208	684	1156	1736	2434	2918	3232			0.01	0.03	0.07	0.09	0.14	0.20	0.24	0.27		
S-6	613	78	540	1150	1448	2028	2516	2952	3332			0.00	0.02	0.04	0.05	0.07	0.10	0.12	0.13		
S-7	659	26	202	538	922	1482	1902	2344	2850	3092		0.01	0.04	0.07	0.09	0.12	0.15	0.17	0.21	0.22	
S-8	663	112	368	822	1316	1752	2208	2700	3150			0.02	0.06	0.10	0.14	0.18	0.22	0.27	0.31		
S-9	679	118	344	674	1150	1840	2330	2852	3330			0.02	0.04	0.07	0.11	0.18	0.23	0.28	0.32		
S-10	697	240	530	1030	1462	1876	2310	2876	3278			0.02	0.04	0.05	0.07	0.10	0.12	0.15	0.17		

Calculated Values

Sample No.	Stress (MPa)										Strain (x10^-6)										Joint Stiffness
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	(MPa)
S-1	0.25	0.94	2.12	3.52	4.85	6.63	7.43	8.93	10.7		0	73	190	317	439	629	702	839	995		10456
S-2	0.20	1.12	2.19	3.83	5.49	6.55	7.92	8.71	9.42		20	141	220	312	415	493	629	693	751		13574
S-3	0.44	1.74	3.59	5.38	6.65	7.89	8.72	10.0			10	59	137	220	278	337	380	473			20332
S-4	0.26	0.79	2.37	4.48	6.78	8.05	9.74				146	263	454	673	922	1073	1254				9085
S-5	0.18	0.65	2.13	3.60	5.41	7.58	9.09	10.1			49	137	317	454	668	985	1176	1298			8016
S-6	0.24	1.68	3.58	4.51	6.32	7.84	9.19	10.4			20	98	190	239	356	478	571	649			15238
S-7	0.08	0.63	1.68	2.87	4.62	5.92	7.30	8.88	9.63		24	171	341	444	600	727	849	1000	1063		10411
S-8	0.35	1.15	2.56	4.10	5.46	6.88	8.41	9.81			98	278	468	693	888	1083	1322	1507			6992
S-9	0.37	1.07	2.10	3.58	5.73	7.26	8.88	10.4			83	215	356	546	878	1102	1341	1576			6819
S-10	0.75	1.65	3.21	4.55	5.84	7.19	8.96	10.2			117	195	259	356	468	566	712	820			13213



Average Joint Stiffness of

Std MGP10 with No Plate Joint

11414 MPa

Std Dev Joint Stiffness of

Std MGP10 with No Plate Joint

4238 MPa

Truss Joint Testing - Joint Deformation

Test Equipment - Hyne and Son Tension Test Rig
Test Operator - Tony Dakin

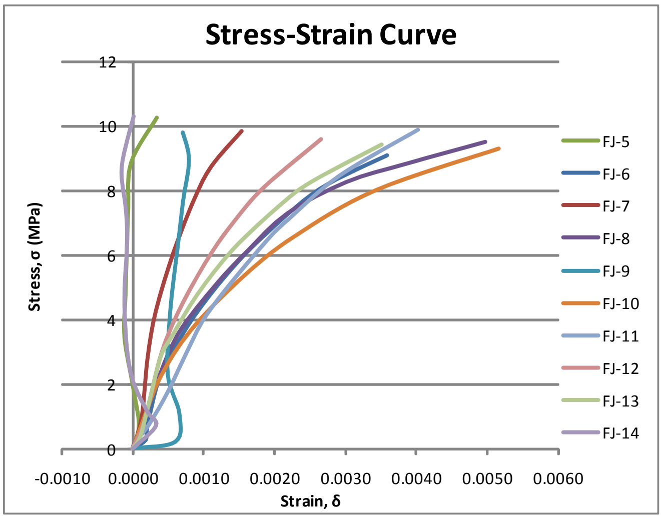
Sample Type - 90 x35 Finger Jointed Timber with Plate Joint

Test Data

Sample No.	Avg Density	Recorded Loads (kg)										Recorded Deformations (mm)									
	(kg/m³)	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
FJ-5	524	60	244	594	1104	1512	1988	2390	2842	3290		0.01	0.02	0.00	-0.02	-0.02	-0.02	-0.01	-0.01	0.07	
FJ-6	531	86	226	694	932	1300	1734	2100	2576	2916		0.04	0.04	0.08	0.11	0.18	0.27	0.38	0.54	0.74	
FJ-7	543	132	380	898	1372	1968	2498	2816	3166			0.01	0.03	0.04	0.07	0.12	0.18	0.23	0.31		
FJ-8	548	28	170	592	1132	1628	1974	2344	2654	2840	3054	0.00	0.02	0.06	0.13	0.24	0.33	0.45	0.62	0.80	1.02
FJ-9	556	68	350	738	1366	2022	2462	2870	3142			0.12	0.13	0.10	0.11	0.13	0.15	0.16	0.14		
FJ-10	559	36	292	716	1176	1688	2106	2574	2986			0.01	0.03	0.08	0.17	0.31	0.47	0.70	1.06		
FJ-11	565	86	242	580	980	1384	2048	2312	2722	3174		0.01	0.05	0.10	0.16	0.22	0.38	0.46	0.60	0.82	
FJ-12	590	284	970	1468	1950	2276	2608	3086				0.04	0.09	0.15	0.23	0.30	0.38	0.54			
FJ-13	591	116	468	914	1116	1530	1986	2436	2668	3028		0.02	0.05	0.08	0.11	0.19	0.29	0.43	0.52	0.72	
FJ-14	592	230	380	768	1432	2066	2384	2800	3304			0.07	0.04	-0.01	-0.03	-0.02	-0.02	-0.03	0.00		

Calculated Values

Sample No.	Stress (MPa)										Strain (x10^-6)										Joint Stiffness
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	(MPa)
FJ-5	0.19	0.76	1.85	3.44	4.71	6.19	7.44	8.85	10.2		29	88	10	-117	-102	-83	-63	-24	341		
FJ-6	0.27	0.70	2.16	2.90	4.05	5.40	6.54	8.02	9.08		185	210	371	541	854	1332	1829	2629	3590		
FJ-7	0.41	1.18	2.80	4.27	6.13	7.78	8.77	9.86			68	141	210	327	580	873	1107	1532			
FJ-8	0.09	0.53	1.84	3.53	5.07	6.15	7.30	8.27	8.84	9.51	10	102	307	634	1171	1629	2185	3015	3878	4976	
FJ-9	0.21	1.09	2.30	4.25	6.30	7.67	8.94	9.79			600	654	493	527	634	707	790	702			
FJ-10	0.11	0.91	2.23	3.66	5.26	6.56	8.02	9.30			24	156	395	820	1522	2268	3434	5161			
FJ-11	0.27	0.75	1.81	3.05	4.31	6.38	7.20	8.48	9.88		63	234	507	776	1093	1859	2239	2922	4015		
FJ-12	0.88	3.02	4.57	6.07	7.09	8.12	9.61				171	415	717	1107	1439	1849	2649				
FJ-13	0.36	1.46	2.85	3.48	4.76	6.18	7.59	8.31	9.43		107	234	395	551	907	1415	2093	2541	3502		
FJ-14	0.72	1.18	2.39	4.46	6.43	7.42	8.72	10.3			332	195	-39	-122	-83	-102	-161	10			



Average Joint Stiffness of

FJ Timber with Plate Joint

- MPa

Std Dev Joint Stiffness of

FJ Timber with Plate Joint

- MPa

Test Method Inadequate - Refer Section 5.2.7.2

Truss Joint Testing - Joint Deformation

Test Equipment - Hyne and Son Tension Test Rig
Test Operator - Tony Dakin

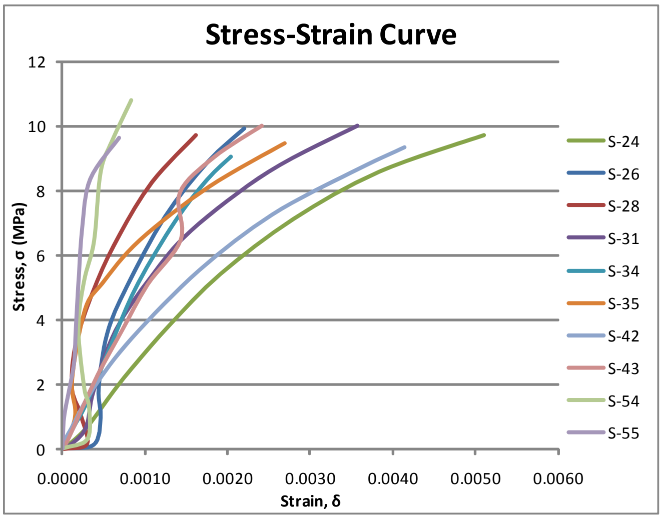
Sample Type - 90 x35 Standard MGP10 with Plate Joint

Test Data

Sample No.	Avg Density	Recorded Loads (kg)										Recorded Deformations (mm)									
	(kg/m³)	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
S-24	524	72	228	574	838	1232	1740	2288	2758	3124		0.03	0.06	0.13	0.18	0.27	0.39	0.57	0.79	1.05	
S-26	526	40	310	598	1142	1610	2304	2848	3184			0.08	0.10	0.09	0.11	0.16	0.26	0.36	0.45		
S-28	528	52	354	622	1086	1668	2138	2654	3120			0.06	0.04	0.02	0.04	0.09	0.14	0.22	0.33		
S-31	535	36	206	576	1178	1712	2174	2762	3218			0.02	0.06	0.08	0.13	0.22	0.32	0.51	0.73		
S-34	537	208	422	760	1174	1652	2266	2676	2904			0.03	0.06	0.09	0.14	0.19	0.28	0.36	0.42		
S-35	544	146	350	696	1384	1642	2070	2600	3034			0.02	0.03	0.02	0.06	0.10	0.19	0.36	0.55		
S-42	557	86	204	604	1100	1780	2334	2754	3006			0.01	0.02	0.08	0.17	0.34	0.52	0.72	0.85		
S-43	570	60	350	734	1164	1634	2084	2548	2904	3218		0.01	0.04	0.09	0.15	0.21	0.29	0.29	0.38	0.50	
S-54	596	96	436	592	1204	1666	2070	2752	3062	3472		0.06	0.07	0.05	0.04	0.05	0.08	0.09	0.12	0.17	
S-55	615	114	344	836	1182	1740	2196	2678	3088			0.00	0.01	0.03	0.03	0.04	0.05	0.07	0.14		

Calculated Values

Sample No.	Stress (MPa)										Strain (x10^-6)										Joint Stiffness
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	(MPa)
S-24	0.22	0.71	1.79	2.61	3.84	5.42	7.13	8.59	9.73		122	312	620	878	1298	1912	2795	3829	5102		
S-26	0.12	0.97	1.86	3.56	5.01	7.18	8.87	9.92			380	463	439	541	780	1244	1761	2210			
S-28	0.16	1.10	1.94	3.38	5.19	6.66	8.27	9.72			298	215	112	171	420	698	1088	1620			
S-31	0.11	0.64	1.79	3.67	5.33	6.77	8.60	10.0			93	283	376	644	1073	1561	2502	3576			
S-34	0.65	1.31	2.37	3.66	5.14	7.06	8.33	9.04			132	273	454	659	922	1371	1756	2044			
S-35	0.45	1.09	2.17	4.31	5.11	6.45	8.10	9.45			88	156	117	273	483	937	1776	2698			
S-42	0.27	0.64	1.88	3.43	5.54	7.27	8.58	9.36			29	107	376	839	1659	2541	3498	4146			
S-43	0.19	1.09	2.29	3.63	5.09	6.49	7.94	9.04	10.0		49	210	424	712	1029	1434	1420	1834	2415		
S-54	0.30	1.36	1.84	3.75	5.19	6.45	8.57	9.54	10.8		302	317	263	190	259	380	459	595	829		
S-55	0.36	1.07	2.60	3.68	5.42	6.84	8.34	9.62			5	24	137	161	200	239	337	688			



Average Joint Stiffness of

Std MGP10 with Plate Joint

- MPa

Std Dev Joint Stiffness of

Std MGP10 with Plate Joint

- MPa

Test Method Inadequate - Refer Section 5.2.7.2

Truss Joint Testing - Tensile Stiffness without Splice

Arithmetic Mean and Standard Deviation - Microsoft Excel

<u>Finger Jointed Timber</u>			**<u>Standard MGP10 Timber</u>**		
Avg	=	10980	Avg	=	11414
Std Dev	=	4330	Std Dev	=	4238

Comparison Method - Spiegel (1982)

$n_1 =$	10	$X_1 =$	10980	$S_1 =$	4330
$n_2 =$	10	$X_2 =$	11414	$S_2 =$	4238

σ = 4515.993

T = -0.215

$t_{.995}$ = 2.88

$t_{.975}$ = 2.10

$-t_{.995} < T < t_{.995}$ & $-t_{.975} < T < t_{.975}$

therefore,

<u>No significant difference between FJ Timber & MGP10</u>

Appendix J

Test Data and Analysis – Fabrication Issues

Appendix J.1 – Flatwise Finger Joint Capacity

90 x 35 Finger Jointed Timber - Flatwise Finger Joint Testing

Test Equipment - Hyne and Son Tuan Test Rig
Test Operator - Tony Dakin

Sample Details			
Depth (mm)	Breadth (mm)	Length (mm)	Test Span (mm)
35	90	650	540

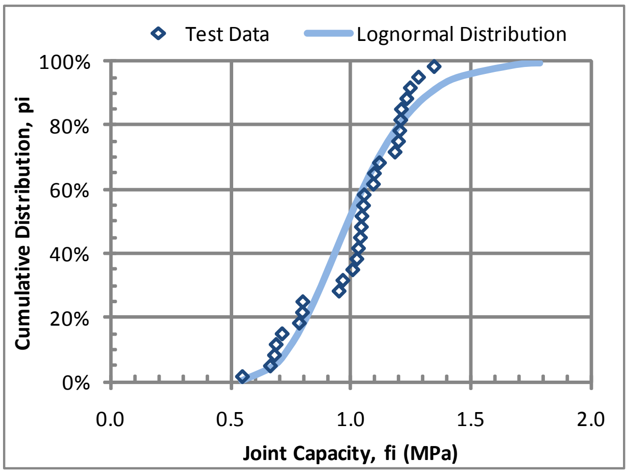
Test Data				
Sample No.	Density (kg/m³)	Failure Load (kg)	AS5068 Failure Mode	Joint Capacity (kN.m)
FWB2-1	605	915	3	1.21
FWB2-2	459	604	4	0.80
FWB2-3	732	540	4	0.72
FWB2-4	579	775	4	1.03
FWB2-5	622	827	4	1.10
FWB2-6	649	719	4	0.95
FWB2-7	694	910	2	1.21
FWB2-8	539	516	5	0.68
FWB2-9	588	906	3	1.20
FWB2-10	581	932	3	1.23
FWB2-11	586	762	3	1.01
FWB2-12	614	913	3	1.21
FWB2-13	513	415	4	0.55
FWB2-14	595	786	5	1.04
FWB2-15	706	943	2	1.25
FWB2-16	558	791	4	1.05
FWB2-17	586	521	4	0.69
FWB2-18	530	830	4	1.10
FWB2-19	551	1018	4	1.35
FWB2-20	560	780	5	1.03
FWB2-21	716	969	2	1.28
FWB2-22	564	789	4	1.04
FWB2-23	718	895	3	1.19
FWB2-24	564	594	5	0.79
FWB2-25	481	731	4	0.97
FWB2-26	664	846	3	1.12
FWB2-27	573	798	4	1.06
FWB2-28	461	605	4	0.80
FWB2-29	634	796	4	1.05
FWB2-30	554	503	4	0.67

90 x 35 Finger Jointed Timber - Flatwise Finger Joint Testing

Analysis Method - AS/NZS 4063.2 (2010) Method 1

Test Data		Calculated Parameters		
Rank	fi	p_i	$\ln(f_i)$	$(\ln(f_i)-\hat{y})^2$
1	0.55	0.017	-0.599	0.344
2	0.67	0.050	-0.406	0.156
3	0.68	0.083	-0.381	0.136
4	0.69	0.117	-0.371	0.129
5	0.72	0.150	-0.335	0.105
6	0.79	0.183	-0.240	0.052
7	0.80	0.217	-0.223	0.045
8	0.80	0.250	-0.222	0.044
9	0.95	0.283	-0.049	0.001
10	0.97	0.317	-0.032	0.000
11	1.01	0.350	0.009	0.000
12	1.03	0.383	0.026	0.001
13	1.03	0.417	0.032	0.002
14	1.04	0.450	0.040	0.003
15	1.04	0.483	0.044	0.003
16	1.05	0.517	0.046	0.003
17	1.05	0.550	0.053	0.004
18	1.06	0.583	0.055	0.004
19	1.10	0.617	0.091	0.011
20	1.10	0.650	0.095	0.011
21	1.12	0.683	0.114	0.016
22	1.19	0.717	0.170	0.033
23	1.20	0.750	0.182	0.038
24	1.21	0.783	0.187	0.039
25	1.21	0.817	0.190	0.041
26	1.21	0.850	0.192	0.042
27	1.23	0.883	0.210	0.049
28	1.25	0.917	0.222	0.055
29	1.28	0.950	0.249	0.068
30	1.35	0.983	0.299	0.096

∑	-0.351	1.533



$\hat{y}$ = **-0.012**

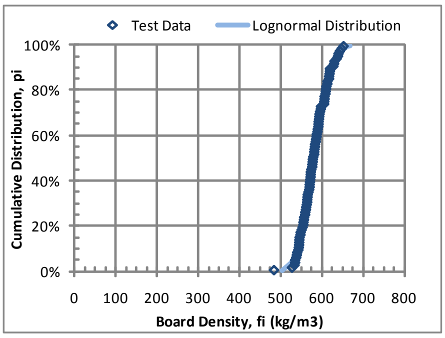
S_y = **0.230**

Appendix J.2 – Analysis of Board Densities

90 x 35 Finger Jointed Timber - Board Density

Analysis Method - AS/NZS 4063.2 (2010) Method 1

Test Data		Calculated Parameters			Test Data		Calculated Parameters		
Rank	fi	p_i	$\ln(f_i)$	$(\ln(f_i)-\hat{y})^2$	Rank	fi	p_i	$\ln(f_i)$	$(\ln(f_i)-\hat{y})^2$
1	485	0.006	6.184	0.032	46	579	0.506	6.362	0.000
2	528	0.017	6.269	0.009	47	582	0.517	6.366	0.000
3	534	0.028	6.281	0.007	48	582	0.528	6.366	0.000
4	536	0.039	6.283	0.006	49	582	0.539	6.367	0.000
5	536	0.050	6.283	0.006	50	583	0.550	6.368	0.000
6	538	0.061	6.288	0.006	51	583	0.561	6.369	0.000
7	540	0.072	6.291	0.005	52	585	0.572	6.372	0.000
8	541	0.083	6.293	0.005	53	586	0.583	6.373	0.000
9	543	0.094	6.298	0.004	54	587	0.594	6.375	0.000
10	544	0.106	6.300	0.004	55	588	0.606	6.376	0.000
11	545	0.117	6.301	0.004	56	589	0.617	6.379	0.000
12	545	0.128	6.302	0.004	57	590	0.628	6.380	0.000
13	546	0.139	6.302	0.004	58	592	0.639	6.383	0.000
14	546	0.150	6.303	0.004	59	592	0.650	6.383	0.000
15	548	0.161	6.307	0.003	60	592	0.661	6.384	0.000
16	549	0.172	6.308	0.003	61	593	0.672	6.385	0.000
17	551	0.183	6.312	0.003	62	594	0.683	6.386	0.001
18	554	0.194	6.316	0.002	63	594	0.694	6.387	0.001
19	556	0.206	6.320	0.002	64	596	0.706	6.389	0.001
20	556	0.217	6.320	0.002	65	597	0.717	6.393	0.001
21	557	0.228	6.322	0.002	66	598	0.728	6.393	0.001
22	557	0.239	6.323	0.002	67	605	0.739	6.406	0.002
23	560	0.250	6.327	0.001	68	606	0.750	6.406	0.002
24	560	0.261	6.328	0.001	69	606	0.761	6.407	0.002
25	562	0.272	6.331	0.001	70	606	0.772	6.407	0.002
26	562	0.283	6.332	0.001	71	609	0.783	6.411	0.002
27	563	0.294	6.334	0.001	72	609	0.794	6.412	0.002
28	565	0.306	6.336	0.001	73	610	0.806	6.413	0.002
29	565	0.317	6.336	0.001	74	611	0.817	6.415	0.003
30	565	0.328	6.338	0.001	75	613	0.828	6.418	0.003
31	566	0.339	6.338	0.001	76	613	0.839	6.419	0.003
32	568	0.350	6.342	0.000	77	617	0.850	6.425	0.004
33	569	0.361	6.345	0.000	78	617	0.861	6.425	0.004
34	570	0.372	6.346	0.000	79	618	0.872	6.427	0.004
35	571	0.383	6.347	0.000	80	619	0.883	6.428	0.004
36	571	0.394	6.348	0.000	81	619	0.894	6.428	0.004
37	572	0.406	6.349	0.000	82	628	0.906	6.442	0.006
38	573	0.417	6.350	0.000	83	629	0.917	6.444	0.007
39	573	0.428	6.351	0.000	84	630	0.928	6.446	0.007
40	573	0.439	6.352	0.000	85	635	0.939	6.454	0.008
41	575	0.450	6.354	0.000	86	639	0.950	6.459	0.009
42	577	0.461	6.357	0.000	87	640	0.961	6.461	0.010
43	577	0.472	6.358	0.000	88	643	0.972	6.466	0.010
44	578	0.483	6.359	0.000	89	647	0.983	6.473	0.012
45	578	0.494	6.360	0.000	90	652	0.994	6.480	0.014
							∑	572.738	0.261



$\hat{y}$ = **6.364**

s_y = **0.054**

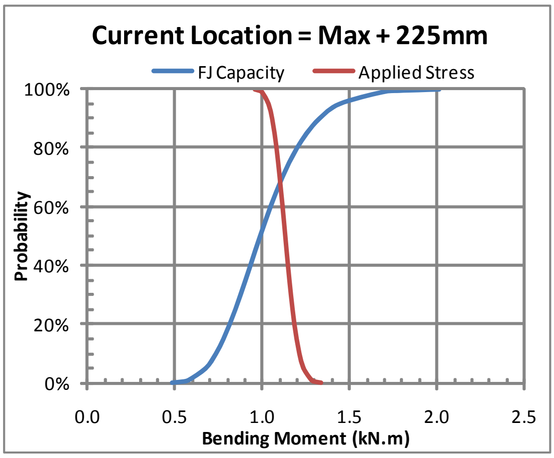
Appendix J.3 – Modelling and Assessment Example – Levering

90 x 35 Finger Jointed Timber - Assesment of Handling Loads

Technique -	Levering		FJ Capacity		Board Density	
Board Length, L =	10.8	m	$\hat{y}$ =	-0.012	$\hat{y}$ =	6.364
a/L =	0.25		S_y =	0.230	S_y =	0.054

Prob.	FJ Capacity (kN.m)	Board Density (kg/m3)	Applied Stress (kN.m) Location (mm from Max Moment Location) -225	-180	-135	-90	-45	0	45	90	135	180	225
0.1%	0.486	686	1.269	1.294	1.318	1.342	1.367	1.391	1.380	1.368	1.357	1.345	1.334
0.5%	0.547	667	1.235	1.258	1.282	1.306	1.329	1.353	1.342	1.331	1.319	1.308	1.297
1.0%	0.579	658	1.218	1.241	1.265	1.288	1.311	1.335	1.324	1.313	1.302	1.291	1.280
5.0%	0.677	635	1.174	1.196	1.219	1.241	1.264	1.286	1.276	1.265	1.254	1.244	1.233
10.0%	0.736	622	1.151	1.173	1.195	1.217	1.239	1.261	1.251	1.240	1.230	1.220	1.209
15.0%	0.779	614	1.136	1.157	1.179	1.201	1.223	1.245	1.234	1.224	1.214	1.204	1.193
20.0%	0.814	608	1.124	1.145	1.167	1.188	1.210	1.232	1.221	1.211	1.201	1.191	1.181
25.0%	0.846	602	1.114	1.135	1.156	1.178	1.199	1.221	1.210	1.200	1.190	1.180	1.170
30.0%	0.876	597	1.105	1.126	1.147	1.168	1.189	1.211	1.201	1.191	1.181	1.171	1.161
35.0%	0.905	593	1.096	1.117	1.138	1.159	1.180	1.202	1.192	1.182	1.172	1.162	1.152
40.0%	0.932	588	1.089	1.109	1.130	1.151	1.172	1.193	1.183	1.173	1.163	1.154	1.144
45.0%	0.960	584	1.081	1.102	1.122	1.143	1.164	1.185	1.175	1.165	1.155	1.146	1.136
50.0%	0.988	580	1.074	1.094	1.115	1.135	1.156	1.177	1.167	1.157	1.148	1.138	1.128
55.0%	1.017	576	1.066	1.087	1.107	1.128	1.148	1.169	1.159	1.149	1.140	1.130	1.121
60.0%	1.048	573	1.059	1.079	1.100	1.120	1.140	1.161	1.151	1.141	1.132	1.122	1.113
65.0%	1.080	568	1.052	1.072	1.092	1.112	1.132	1.152	1.143	1.133	1.124	1.114	1.105
70.0%	1.115	564	1.044	1.064	1.084	1.104	1.124	1.144	1.134	1.125	1.115	1.106	1.097
75.0%	1.154	560	1.035	1.055	1.075	1.095	1.115	1.135	1.125	1.116	1.106	1.097	1.088
80.0%	1.199	555	1.026	1.045	1.065	1.085	1.105	1.124	1.115	1.106	1.096	1.087	1.078
85.0%	1.254	549	1.015	1.035	1.054	1.073	1.093	1.113	1.103	1.094	1.085	1.076	1.067
90.0%	1.327	541	1.002	1.021	1.040	1.059	1.079	1.098	1.089	1.080	1.071	1.062	1.053
95.0%	1.443	531	0.982	1.001	1.020	1.039	1.058	1.076	1.067	1.059	1.050	1.041	1.032
99.0%	1.687	512	0.947	0.965	0.983	1.001	1.019	1.037	1.029	1.020	1.012	1.003	0.995
99.5%	1.787	505	0.934	0.952	0.970	0.988	1.005	1.023	1.015	1.006	0.998	0.990	0.981
99.9%	2.011	491	0.908	0.926	0.943	0.960	0.978	0.995	0.987	0.979	0.971	0.962	0.954

$Prob_{STR}$	61.47%	63.99%	66.42%	68.73%	70.94%	73.05%	72.07%	71.06%	70.04%	69.00%	67.93%
$Prob_{CAP}$	61.47%	63.99%	66.42%	68.73%	70.94%	73.05%	72.07%	71.06%	70.04%	69.00%	67.93%
$Prob_{BREAK}$	37.78%	40.95%	44.11%	47.24%	50.33%	53.36%	51.93%	50.50%	49.06%	47.60%	46.15%



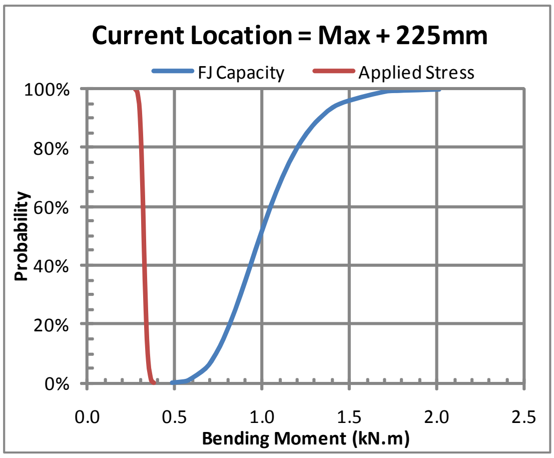
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
$Prob_{BREAK-MIN}$	50.33%	47.24%	44.11%	40.95%	37.78%
$Prob_{BREAK-MAX}$	53.36%	51.93%	50.50%	49.06%	47.60%
$Prob_{OA-MIN}$	**44.08%**				
$Prob_{OA-MAX}$	**50.49%**				
$Prob_{OA-AVG}$	**47.29%**				

90 x 35 Finger Jointed Timber - Assesment of Handling Loads

Technique -	2-Man Lift	**FJ Capacity**		**Board Density**	
Board Length, L =	12.0 m	**ŷ =**	-0.012	**ŷ =**	6.364
		S_y =	0.230	**S_y =**	0.054

Prob.	**FJ Capacity**	**Board Density**	**Applied Stress (kN.m)**										
			Location (mm from Max Moment Location)										
	(kN.m)	**(kg/m3)**	**-225**	**-180**	**-135**	**-90**	**-45**	**0**	**45**	**90**	**135**	**180**	**225**
0.1%	0.486	686	0.381	0.381	0.382	0.382	0.382	0.382	0.382	0.382	0.382	0.381	0.381
0.5%	0.547	667	0.371	0.371	0.371	0.371	0.371	0.371	0.371	0.371	0.371	0.371	0.371
1.0%	0.579	658	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366	0.366
5.0%	0.677	635	0.352	0.353	0.353	0.353	0.353	0.353	0.353	0.353	0.353	0.353	0.352
10.0%	0.736	622	0.346	0.346	0.346	0.346	0.346	0.346	0.346	0.346	0.346	0.346	0.346
15.0%	0.779	614	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341	0.341
20.0%	0.814	608	0.337	0.338	0.338	0.338	0.338	0.338	0.338	0.338	0.338	0.338	0.337
25.0%	0.846	602	0.334	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.334
30.0%	0.876	597	0.332	0.332	0.332	0.332	0.332	0.332	0.332	0.332	0.332	0.332	0.332
35.0%	0.905	593	0.329	0.329	0.329	0.330	0.330	0.330	0.330	0.330	0.329	0.329	0.329
40.0%	0.932	588	0.327	0.327	0.327	0.327	0.327	0.327	0.327	0.327	0.327	0.327	0.327
45.0%	0.960	584	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325
50.0%	0.988	580	0.322	0.323	0.323	0.323	0.323	0.323	0.323	0.323	0.323	0.323	0.322
55.0%	1.017	576	0.320	0.320	0.320	0.321	0.321	0.321	0.321	0.321	0.320	0.320	0.320
60.0%	1.048	573	0.318	0.318	0.318	0.318	0.318	0.318	0.318	0.318	0.318	0.318	0.318
65.0%	1.080	568	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316	0.316
70.0%	1.115	564	0.313	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.313
75.0%	1.154	560	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311
80.0%	1.199	555	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308	0.308
85.0%	1.254	549	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305	0.305
90.0%	1.327	541	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301	0.301
95.0%	1.443	531	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295
99.0%	1.687	512	0.284	0.284	0.284	0.285	0.285	0.285	0.285	0.285	0.284	0.284	0.284
99.5%	1.787	505	0.280	0.281	0.281	0.281	0.281	0.281	0.281	0.281	0.281	0.281	0.280
99.9%	2.011	491	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273

$Prob_{STR}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$Prob_{CAP}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$Prob_{BREAK}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%



	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**
$Prob_{BREAK-MIN}$	0.00%	0.00%	0.00%	0.00%	0.00%
$Prob_{BREAK-MAX}$	0.00%	0.00%	0.00%	0.00%	0.00%
$Prob_{OA-MIN}$	**0.0000001650%**				
$Prob_{OA-MAX}$	**0.0000001664%**				
$Prob_{OA-AVG}$	**0.0000001657%**				

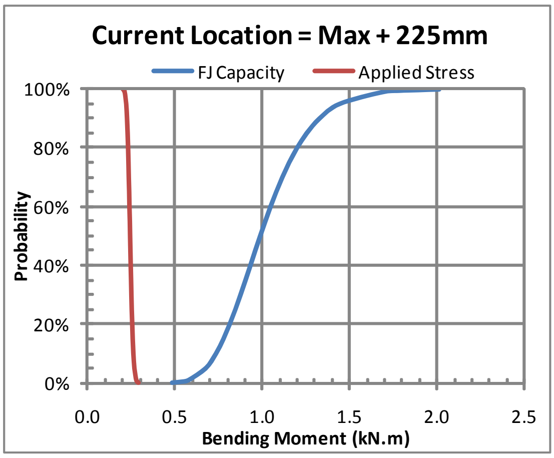
Appendix J.5 – Modelling and Assessment Example – Fork Lift

90 x 35 Finger Jointed Timber - Assesment of Handling Loads

Technique -	Fork Lift	**FJ Capacity**		**Board Density**	
Board Length, L =	12.0 m	**ŷ =** -0.012		**ŷ =** 6.364	
		Sy = 0.230		**Sy =** 0.054	

Prob.	FJ Capacity (kN.m)	Board Density (kg/m3)	Applied Stress (kN.m) – Location (mm from Max Moment Location) -225	-180	-135	-90	-45	0	45	90	135	180	225
0.1%	0.486	686	0.268	0.273	0.277	0.282	0.287	0.292	0.292	0.291	0.290	0.290	0.289
0.5%	0.547	667	0.260	0.265	0.270	0.275	0.279	0.284	0.284	0.283	0.282	0.282	0.281
1.0%	0.579	658	0.257	0.261	0.266	0.271	0.276	0.280	0.280	0.279	0.279	0.278	0.277
5.0%	0.677	635	0.248	0.252	0.257	0.261	0.266	0.270	0.270	0.269	0.268	0.268	0.267
10.0%	0.736	622	0.243	0.247	0.252	0.256	0.260	0.265	0.264	0.264	0.263	0.263	0.262
15.0%	0.779	614	0.240	0.244	0.248	0.253	0.257	0.261	0.261	0.260	0.260	0.259	0.259
20.0%	0.814	608	0.237	0.241	0.246	0.250	0.254	0.259	0.258	0.258	0.257	0.256	0.256
25.0%	0.846	602	0.235	0.239	0.243	0.248	0.252	0.256	0.256	0.255	0.255	0.254	0.254
30.0%	0.876	597	0.233	0.237	0.241	0.246	0.250	0.254	0.254	0.253	0.253	0.252	0.252
35.0%	0.905	593	0.231	0.235	0.240	0.244	0.248	0.252	0.252	0.251	0.251	0.250	0.250
40.0%	0.932	588	0.230	0.234	0.238	0.242	0.246	0.251	0.250	0.249	0.249	0.248	0.248
45.0%	0.960	584	0.228	0.232	0.236	0.240	0.245	0.249	0.248	0.248	0.247	0.247	0.246
50.0%	0.988	580	0.226	0.231	0.235	0.239	0.243	0.247	0.247	0.246	0.246	0.245	0.245
55.0%	1.017	576	0.225	0.229	0.233	0.237	0.241	0.246	0.245	0.244	0.244	0.243	0.243
60.0%	1.048	573	0.223	0.227	0.231	0.236	0.240	0.244	0.243	0.243	0.242	0.242	0.241
65.0%	1.080	568	0.222	0.226	0.230	0.234	0.238	0.242	0.241	0.241	0.240	0.240	0.240
70.0%	1.115	564	0.220	0.224	0.228	0.232	0.236	0.240	0.240	0.239	0.239	0.238	0.238
75.0%	1.154	560	0.218	0.222	0.226	0.230	0.234	0.238	0.238	0.237	0.237	0.236	0.236
80.0%	1.199	555	0.216	0.220	0.224	0.228	0.232	0.236	0.236	0.235	0.235	0.234	0.234
85.0%	1.254	549	0.214	0.218	0.222	0.226	0.230	0.234	0.233	0.233	0.232	0.232	0.231
90.0%	1.327	541	0.211	0.215	0.219	0.223	0.227	0.231	0.230	0.230	0.229	0.229	0.228
95.0%	1.443	531	0.207	0.211	0.215	0.218	0.222	0.226	0.226	0.225	0.225	0.224	0.224
99.0%	1.687	512	0.200	0.203	0.207	0.210	0.214	0.218	0.217	0.217	0.216	0.216	0.216
99.5%	1.787	505	0.197	0.200	0.204	0.208	0.211	0.215	0.214	0.214	0.214	0.213	0.213
99.9%	2.011	491	0.192	0.195	0.198	0.202	0.206	0.209	0.209	0.208	0.208	0.207	0.207

Prob$_{STR}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Prob$_{CAP}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Prob$_{BREAK}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%



	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Prob$_{BREAK-MIN}$	0.00%	0.00%	0.00%	0.00%	0.00%
Prob$_{BREAK-MAX}$	0.00%	0.00%	0.00%	0.00%	0.00%
Prob$_{OA-MIN}$	**0.0000000000063%**				
Prob$_{OA-MAX}$	**0.0000000000245%**				
Prob$_{OA-AVG}$	**0.0000000000154%**				

Appendix K

Test Data and Analysis – Truss Erection Issues

Appendix K.1 – Edgewise Finger Joint Capacity

90 x 35 Finger Jointed Timber - Edgewise Finger Joint Testing

Test Equipment - Hyne and Son Tuan Test Rig
Test Operator - Tony Dakin

Sample Details			
Depth (mm)	Breadth (mm)	Length (mm)	Test Span (mm)
90	35	2600	2320

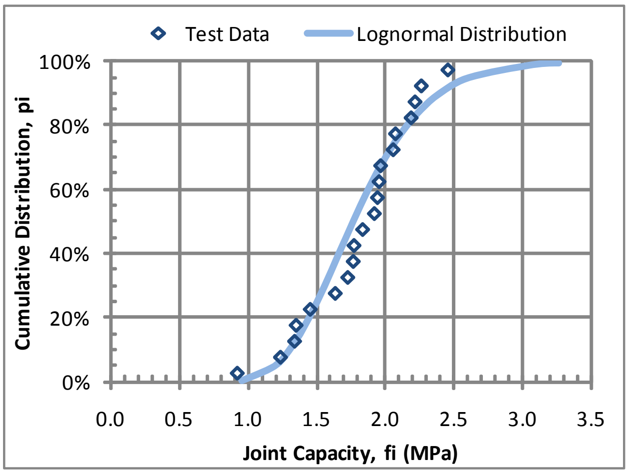
Test Data					
Sample No.	Density (kg/m³)	Failure Load (kg)	Failure Source	Failure Location (mm)	Joint Capacity (kN.m)
1	526	385	Finger Joint	0	2.19
2	593	311	Finger Joint	0	1.77
3	611	390	Finger Joint	0	2.22
4	587	312	Finger Joint	0	1.78
5	627	320	Finger Joint	570	0.93
6	556	288	Finger Joint	0	1.64
7	559	365	Finger Joint	0	2.08
8	593	432	Finger Joint	0	2.46
9	574	338	Finger Joint	0	1.92
10	619	346	Finger Joint	0	1.97
11	569	256	Finger Joint	0	1.46
12	582	238	Finger Joint	0	1.35
13	546	218	Finger Joint	0	1.24
14	575	236	Finger Joint	0	1.34
15	553	323	Finger Joint	0	1.84
16	599	344	Finger Joint	0	1.96
17	637	342	Finger Joint	0	1.95
18	605	304	Finger Joint	0	1.73
19	546	398	Finger Joint	0	2.26
20	582	362	Finger Joint	0	2.06

90 x 35 Finger Jointed Timber - Edgewise Finger Joint Testing

Analysis Method - AS/NZS 4063.2 (2010) Method 1

Test Data		Calculated Parameters		
Rank	f_i	p_i	$\ln(f_i)$	$(\ln(f_i)-\hat{y})^2$
1	0.93	0.025	-0.077	0.414
2	1.24	0.075	0.215	0.123
3	1.34	0.125	0.295	0.074
4	1.35	0.175	0.303	0.069
5	1.46	0.225	0.376	0.036
6	1.64	0.275	0.494	0.005
7	1.73	0.325	0.548	0.000
8	1.77	0.375	0.571	0.000
9	1.78	0.425	0.574	0.000
10	1.84	0.475	0.609	0.002
11	1.92	0.525	0.654	0.008
12	1.95	0.575	0.666	0.010
13	1.96	0.625	0.672	0.011
14	1.97	0.675	0.677	0.012
15	2.06	0.725	0.723	0.024
16	2.08	0.775	0.731	0.027
17	2.19	0.825	0.784	0.047
18	2.22	0.875	0.797	0.053
19	2.26	0.925	0.817	0.063
20	2.46	0.975	0.899	0.111

∑	11.328	1.090



$\hat{y}$ = **0.566**

S_y = **0.240**

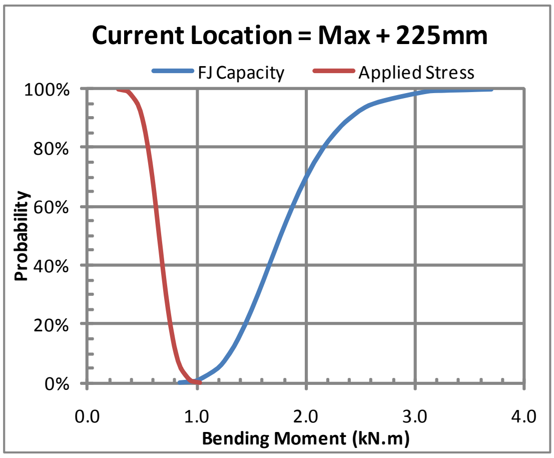
Appendix K.2 – Modelling and Assessment Example – Standard Truss Overhang

90 x 35 Finger Jointed Timber - Assesment of Erection Loads

Technique -	O/hang - Std		**FJ Capacity**		**Builders Weight**		
Eave Width, W_E =	0.9	m	**$\hat{y}$ =**	0.566	**$\hat{y}$ =**	81.9	
O/hang Length, L	0.9	m	**S_y =**	0.240	**S_y =**	15.02	

Prob.	**FJ Capacity**	**Applied Stress (kN.m)**											
		Point Load	**Location (mm from Max Moment Location)**										
	(kN.m)	**kg**	**-225**	**-180**	**-135**	**-90**	**-45**	**0**	**45**	**90**	**135**	**180**	**225**
0.1%	0.840	128	0.850	0.906	0.963	1.020	1.076	1.133	1.112	1.090	1.069	1.048	1.027
0.5%	0.951	121	0.799	0.852	0.905	0.958	1.011	1.065	1.045	1.025	1.005	0.985	0.965
1.0%	1.009	117	0.774	0.825	0.877	0.928	0.980	1.032	1.012	0.993	0.974	0.954	0.935
5.0%	1.188	107	0.706	0.753	0.800	0.847	0.894	0.941	0.924	0.906	0.888	0.871	0.853
10.0%	1.296	101	0.670	0.714	0.759	0.804	0.848	0.893	0.876	0.860	0.843	0.826	0.809
15.0%	1.374	97	0.645	0.688	0.731	0.774	0.818	0.861	0.844	0.828	0.812	0.796	0.780
20.0%	1.440	95	0.626	0.668	0.709	0.751	0.793	0.835	0.819	0.803	0.788	0.772	0.756
25.0%	1.499	92	0.609	0.650	0.691	0.731	0.772	0.813	0.797	0.782	0.767	0.752	0.736
30.0%	1.554	90	0.594	0.634	0.674	0.713	0.753	0.793	0.778	0.763	0.748	0.733	0.718
35.0%	1.607	88	0.581	0.619	0.658	0.697	0.735	0.774	0.760	0.745	0.731	0.716	0.702
40.0%	1.658	86	0.568	0.605	0.643	0.681	0.719	0.757	0.743	0.728	0.714	0.700	0.686
45.0%	1.710	84	0.555	0.592	0.629	0.666	0.703	0.740	0.726	0.712	0.698	0.684	0.670
50.0%	1.762	82	0.542	0.578	0.615	0.651	0.687	0.723	0.710	0.696	0.682	0.669	0.655
55.0%	1.816	80	0.530	0.565	0.600	0.636	0.671	0.706	0.693	0.680	0.667	0.653	0.640
60.0%	1.872	78	0.517	0.552	0.586	0.621	0.655	0.689	0.677	0.664	0.651	0.638	0.625
65.0%	1.932	76	0.504	0.538	0.571	0.605	0.638	0.672	0.659	0.647	0.634	0.622	0.609
70.0%	1.998	74	0.490	0.523	0.556	0.588	0.621	0.654	0.641	0.629	0.617	0.605	0.592
75.0%	2.071	72	0.475	0.507	0.539	0.570	0.602	0.634	0.622	0.610	0.598	0.586	0.574
80.0%	2.155	69	0.459	0.489	0.520	0.550	0.581	0.611	0.600	0.589	0.577	0.566	0.554
85.0%	2.258	66	0.439	0.469	0.498	0.527	0.556	0.586	0.575	0.564	0.553	0.542	0.531
90.0%	2.395	63	0.415	0.443	0.470	0.498	0.525	0.553	0.543	0.532	0.522	0.512	0.501
95.0%	2.613	57	0.379	0.404	0.429	0.454	0.480	0.505	0.496	0.486	0.477	0.467	0.458
99.0%	3.076	47	0.311	0.332	0.352	0.373	0.394	0.415	0.407	0.399	0.391	0.383	0.376
99.5%	3.266	43	0.286	0.305	0.324	0.343	0.362	0.382	0.374	0.367	0.360	0.353	0.346
99.9%	3.694	35	0.235	0.251	0.266	0.282	0.298	0.313	0.307	0.302	0.296	0.290	0.284

$Prob_{STR}$	0.11%	0.20%	0.34%	0.53%	0.81%	1.17%	1.02%	0.89%	0.77%	0.66%	0.56%
$Prob_{CAP}$	0.11%	0.20%	0.34%	0.53%	0.81%	1.17%	1.02%	0.89%	0.77%	0.66%	0.56%
$Prob_{BREAK}$	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%



	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**
$Prob_{BREAK-MIN}$	0.01%	0.00%	0.00%	0.00%	0.00%
$Prob_{BREAK-MAX}$	0.01%	0.01%	0.01%	0.01%	0.00%
$Prob_{OA-MIN}$	**0.0022%**				
$Prob_{OA-MAX}$	**0.0085%**				
$Prob_{OA-AVG}$	**0.0053%**				

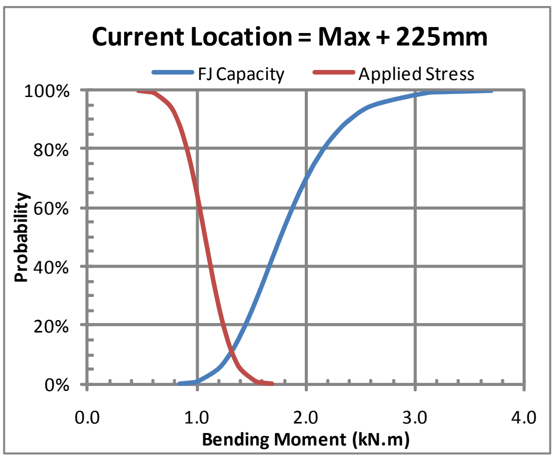
Appendix K.3 – Modelling and Assessment Example – Hip Truss Overhang

90 x 35 Finger Jointed Timber - Assesment of Erection Loads

Technique -	O/hang - Hip		**FJ Capacity**		**Builders Weight**		
Eave Width, W_E =	1.05	m	**ŷ =**	0.566	**ŷ =**	81.9	
O/hang Length, L	1.485	m	**S_y =**	0.240	**S_y =**	15.02	

Prob.	**FJ Capacity (kN.m)**	**Applied Stress (kN.m)** Point Load kg	Location (mm from Max Moment Location) -225	-180	-135	-90	-45	0	45	90	135	180	225
0.1%	0.840	128	1.586	1.643	1.699	1.756	1.813	1.869	1.834	1.799	1.764	1.729	1.694
0.5%	0.951	121	1.490	1.544	1.597	1.650	1.703	1.757	1.724	1.691	1.658	1.625	1.592
1.0%	1.009	117	1.444	1.496	1.547	1.599	1.650	1.702	1.670	1.638	1.606	1.574	1.542
5.0%	1.188	107	1.318	1.365	1.412	1.459	1.506	1.553	1.524	1.495	1.466	1.436	1.407
10.0%	1.296	101	1.250	1.295	1.339	1.384	1.429	1.473	1.446	1.418	1.391	1.363	1.335
15.0%	1.374	97	1.205	1.248	1.291	1.334	1.377	1.420	1.393	1.367	1.340	1.313	1.287
20.0%	1.440	95	1.169	1.210	1.252	1.294	1.335	1.377	1.351	1.326	1.300	1.274	1.248
25.0%	1.499	92	1.137	1.178	1.219	1.259	1.300	1.341	1.315	1.290	1.265	1.240	1.215
30.0%	1.554	90	1.110	1.149	1.189	1.229	1.268	1.308	1.283	1.259	1.234	1.210	1.185
35.0%	1.607	88	1.084	1.123	1.161	1.200	1.239	1.277	1.253	1.229	1.206	1.182	1.158
40.0%	1.658	86	1.059	1.097	1.135	1.173	1.211	1.248	1.225	1.202	1.178	1.155	1.131
45.0%	1.710	84	1.036	1.073	1.110	1.147	1.184	1.221	1.198	1.175	1.152	1.129	1.106
50.0%	1.762	82	1.012	1.048	1.085	1.121	1.157	1.193	1.171	1.148	1.126	1.104	1.081
55.0%	1.816	80	0.989	1.024	1.060	1.095	1.130	1.166	1.144	1.122	1.100	1.078	1.056
60.0%	1.872	78	0.965	1.000	1.034	1.069	1.103	1.138	1.116	1.095	1.074	1.052	1.031
65.0%	1.932	76	0.941	0.974	1.008	1.042	1.075	1.109	1.088	1.067	1.046	1.026	1.005
70.0%	1.998	74	0.915	0.948	0.980	1.013	1.046	1.078	1.058	1.038	1.018	0.997	0.977
75.0%	2.071	72	0.887	0.919	0.950	0.982	1.014	1.045	1.026	1.006	0.987	0.967	0.947
80.0%	2.155	69	0.856	0.887	0.917	0.948	0.978	1.009	0.990	0.971	0.952	0.933	0.914
85.0%	2.258	66	0.820	0.849	0.878	0.908	0.937	0.966	0.948	0.930	0.912	0.894	0.876
90.0%	2.395	63	0.774	0.802	0.830	0.857	0.885	0.913	0.896	0.878	0.861	0.844	0.827
95.0%	2.613	57	0.707	0.732	0.757	0.783	0.808	0.833	0.818	0.802	0.786	0.771	0.755
99.0%	3.076	47	0.580	0.601	0.622	0.643	0.663	0.684	0.671	0.658	0.646	0.633	0.620
99.5%	3.266	43	0.534	0.553	0.572	0.591	0.610	0.629	0.618	0.606	0.594	0.582	0.570
99.9%	3.694	35	0.439	0.454	0.470	0.486	0.501	0.517	0.507	0.498	0.488	0.478	0.468

	-225	-180	-135	-90	-45	0	45	90	135	180	225
$Prob_{STR}$	8.46%	9.96%	11.57%	13.28%	15.10%	17.00%	15.81%	14.66%	13.54%	12.46%	11.41%
$Prob_{CAP}$	8.46%	9.96%	11.57%	13.28%	15.10%	17.00%	15.81%	14.66%	13.54%	12.46%	11.41%
$Prob_{BREAK}$	0.72%	0.99%	1.34%	1.76%	2.28%	2.89%	2.50%	2.15%	1.83%	1.55%	1.30%



	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
$Prob_{BREAK\text{-}MIN}$	2.28%	1.76%	1.34%	0.99%	0.72%
$Prob_{BREAK\text{-}MAX}$	2.89%	2.50%	2.15%	1.83%	1.55%
$Prob_{OA\text{-}MIN}$	**1.42%**				
$Prob_{OA\text{-}MAX}$	**2.18%**				
$Prob_{OA\text{-}AVG}$	**1.80%**				

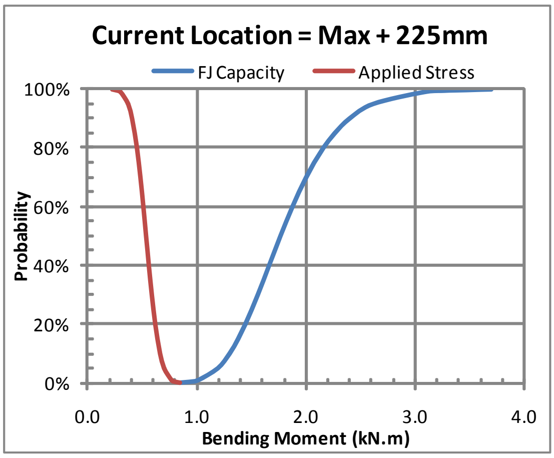
Appendix K.4 – Modelling and Assessment Example – Panel Mid-Span

90 x 35 Finger Jointed Timber - Assesment of Erection Loads

Technique -	Mid Panel	**FJ Capacity**		**Builders Weight**	
Panel Span, L	4.0 m	**ŷ =**	0.566	**ŷ =**	81.9
		S_y =	0.240	**S_y =**	15.02

Prob.	**FJ Capacity**	**Applied Stress (kN.m)**											
		Point Load	**Location (mm from Max Moment Location)**										
	(kN.m)	**kg**	**-225**	**-180**	**-135**	**-90**	**-45**	**0**	**45**	**90**	**135**	**180**	**225**
0.1%	0.840	128	0.894	0.916	0.939	0.962	0.984	1.007	0.973	0.939	0.905	0.871	0.837
0.5%	0.951	121	0.840	0.861	0.883	0.904	0.925	0.946	0.914	0.883	0.851	0.819	0.787
1.0%	1.009	117	0.814	0.834	0.855	0.876	0.896	0.917	0.886	0.855	0.824	0.793	0.762
5.0%	1.188	107	0.743	0.761	0.780	0.799	0.818	0.837	0.808	0.780	0.752	0.724	0.695
10.0%	1.296	101	0.705	0.722	0.740	0.758	0.776	0.794	0.767	0.740	0.713	0.687	0.660
15.0%	1.374	97	0.679	0.696	0.713	0.731	0.748	0.765	0.739	0.713	0.687	0.662	0.636
20.0%	1.440	95	0.658	0.675	0.692	0.709	0.725	0.742	0.717	0.692	0.667	0.642	0.617
25.0%	1.499	92	0.641	0.657	0.674	0.690	0.706	0.722	0.698	0.674	0.649	0.625	0.600
30.0%	1.554	90	0.625	0.641	0.657	0.673	0.689	0.705	0.681	0.657	0.633	0.609	0.586
35.0%	1.607	88	0.611	0.626	0.642	0.657	0.673	0.688	0.665	0.642	0.618	0.595	0.572
40.0%	1.658	86	0.597	0.612	0.627	0.642	0.657	0.673	0.650	0.627	0.605	0.582	0.559
45.0%	1.710	84	0.584	0.598	0.613	0.628	0.643	0.658	0.635	0.613	0.591	0.569	0.547
50.0%	1.762	82	0.570	0.585	0.599	0.614	0.628	0.643	0.621	0.599	0.578	0.556	0.534
55.0%	1.816	80	0.557	0.571	0.586	0.600	0.614	0.628	0.607	0.586	0.564	0.543	0.522
60.0%	1.872	78	0.544	0.558	0.572	0.585	0.599	0.613	0.592	0.572	0.551	0.530	0.509
65.0%	1.932	76	0.530	0.544	0.557	0.570	0.584	0.597	0.577	0.557	0.537	0.517	0.497
70.0%	1.998	74	0.516	0.529	0.542	0.555	0.568	0.581	0.561	0.542	0.522	0.503	0.483
75.0%	2.071	72	0.500	0.513	0.525	0.538	0.551	0.563	0.544	0.525	0.506	0.487	0.468
80.0%	2.155	69	0.482	0.495	0.507	0.519	0.531	0.544	0.525	0.507	0.489	0.470	0.452
85.0%	2.258	66	0.462	0.474	0.485	0.497	0.509	0.521	0.503	0.485	0.468	0.450	0.433
90.0%	2.395	63	0.436	0.447	0.458	0.470	0.481	0.492	0.475	0.458	0.442	0.425	0.409
95.0%	2.613	57	0.398	0.408	0.419	0.429	0.439	0.449	0.434	0.419	0.403	0.388	0.373
99.0%	3.076	47	0.327	0.335	0.344	0.352	0.360	0.369	0.356	0.344	0.331	0.319	0.306
99.5%	3.266	43	0.301	0.309	0.316	0.324	0.331	0.339	0.328	0.316	0.305	0.293	0.282
99.9%	3.694	35	0.247	0.253	0.260	0.266	0.272	0.278	0.269	0.260	0.250	0.241	0.231

$Prob_{STR}$	0.18%	0.22%	0.27%	0.33%	0.40%	0.48%	0.37%	0.27%	0.20%	0.14%	0.10%
$Prob_{CAP}$	0.18%	0.22%	0.27%	0.33%	0.40%	0.48%	0.37%	0.27%	0.20%	0.14%	0.10%
$Prob_{BREAK}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%



	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
$Prob_{BREAK\text{-}MIN}$	0.00%	0.00%	0.00%	0.00%	0.00%
$Prob_{BREAK\text{-}MAX}$	0.00%	0.00%	0.00%	0.00%	0.00%
$Prob_{OA\text{-}MIN}$	**0.00055%**				
$Prob_{OA\text{-}MAX}$	**0.00125%**				
$Prob_{OA\text{-}AVG}$	**0.00090%**				