University of Southern Queensland
Faculty of Engineering and Surveying

Behaviour of Gang-Nail Plated Timber Joints in Tension Perpendicular to the Grain

A dissertation submitted by

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Abstract

According to the American Wood Association, a tension perpendicular to the grain failure is the evil of all wood connections. However there are very limited studies conducted to address this issue. This project aims to investigate the behaviour of timber joints using Gang-Nail Plates.

A failure of a joint in a prefabricated timber roof truss as a result of tension perpendicular to the grain has the potential to be a catastrophic accident. The current method of analysing timber joints subject to a tensile force perpendicular to the grain is based on a professional engineers' theoretical analysis without the physical test data. AS1720.1 Section 4 suggests a procedure to calculate the design capacity of timber joints using screws, bolts and nails but not for gang-nail plates.

Through physical testing, the strength of timber joints with gang-nail plates was determined and the results were analysed to propose a new method of design. By this, destructive testing in accordance with AS1649-2001 has been conducted to find the failure mechanism and ultimate failure force. This was then analysed to find the relationship between the force, timber properties and plate geometry.

It was found that the failure load of the timber joint increases with increasing bite depth. Similarly the joints with a 125mm plate exhibited a higher failure load compared to 75mm and plates at 45 degrees for a similar bite depth. Failure in tension perpendicular to the grain occurred just below the bottom row of teeth. All failures of the tested samples were observed to be along the grain in a similar location.

From the analysis, it was found that the relationship between the bite per mm depth and the bite (or plate) width produced the equation for the design force of:

$$F_D = (0.00187w + 0.149) \times t_p \times 0.76 \times k_1 \times \emptyset$$

This equation produced more consistent results when compared to the current MiTek method, however, as only one species and grade of timber was used during this investigation, the equation is only a fit for this material. Further investigation will now be required to confirm this equation's fit with other materials by conducting a similar testing regime with other species, grades and engineered wood products.

University of Southern Queensland

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ENG4111 Research Project Part 1 &
ENG4112 Research Project Part 2

Limitations of Use

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CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

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.

Craig Desmond Klinge
0050041591

Signature

Date

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The idea for this dissertation originated from discussions with MiTek Australia’s Technical Services Manager Mr Robert Tan. His support, encouragement and guidance in getting the project off the ground were essential and I would like to thank him for this.

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Craig Klinge
2012

Table of Contents

List of Figures

List of Tables

Nomenclature

F_D	Design Force (in tension perpendicular)
F_{tpw}	Force / mm bite depth for a given width
F_u	Ultimate Failure Force
f_{tp}	Tension Perpendicular to grain Characteristic Value
kN	Kilo-Newton
k_1	Duration of Load Factor
k_{11}	given by $\left(\frac{V_0}{V}\right)^{0.2}$ where V_0 is 10^7
N_{tp}	Force in Tension Perpendicular
thk	Thickness of the truss
t_p	Bite depth
UL	Ultimate Load
w	Plate width
ρ	Density
Ø	Capacity factor

Glossary

ABCB	Australian Building Codes Board
AS	Australian Standard
BCA	Building Code of Australia
EWP	Engineered Wood Products
MGP	Machine Graded Pine
MiTek	MiTek Australia Ltd
UFL	Ultimate Failure Load
USQ	University of Southern Queensland
TPI	Truss Plate Institute (America)
TPIC	Truss Plate Institute Canada

Chapter 1 Introduction

With the design and shape of most residential homes today, their open plan living areas and limited internal walls, buildings using a “pitched rafter” design with rafters, strutting and hanging beams are becoming part of our history. Most builders today will tell you that prefabricated trusses “are the only way to go” (Raftertales, 2008).

There are many benefits of using trusses over the conventionally pitched roof. These include:

- Ecological sound choice – timber used is a renewable resource
- Members are of smaller section size that span greater distances
- Light weight – enabling fast and efficient construction

(Wood solutions, 2012)

However, one result of the use of trusses also means that these lighter members are required to transfer the applied loads via joints. While many forces act on the joints, a tension perpendicular to the grain failure within a timber roof truss can cause a catastrophic collapse that could result in the death or injury of anyone inside the building at the time. Therefore truss design packages need to account for all the various forces that act within the joints of the truss and resist against failure. This means that design checks of the timber and plates need to be analysed.

1.1 What is a Roof Truss

A roof truss is a prefabricated structural framing component that supports the roof and ceiling material. It was the first major component of residential buildings to be fully prefabricated in the factory and delivered to site (MiTek 2012). The members of a truss act as strut and ties, which once all connected together can act as a beam to span relatively large distances. Figure 1.1 shows roof trusses installed on a small extension.

Figure 1.1 - Roof Trusses in use (during construction)

The strength of a roof truss is gained by the general configuration of a series (one or more) of triangles. Triangles are used as they are generally quite stable when a force is applied when compared to other shapes (Figure 1.2). Studies have been conducted where it has been shown that it is impossible to change the shape of a triangle under load – unless one or more sides is bent or broken (Multinail, 2012).

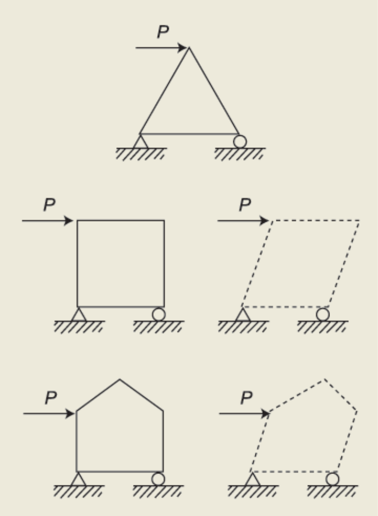


Figure 1.2 - Deformation of shapes with applies loads

The benefits of roof trusses are numerous. By using the triangulation, they are able to span further distances than conventional rafters, with small dimensional members. Being light weight and quick to install, trusses are a cost-effective way of construction. Almost any shape is achievable, as long as the basic principal of triangulation is maintained.

Today, they are generally constructed using timber that has been joined together at joints using metal gang-nail plates (Figure 1.3) however some steel trusses are also made.

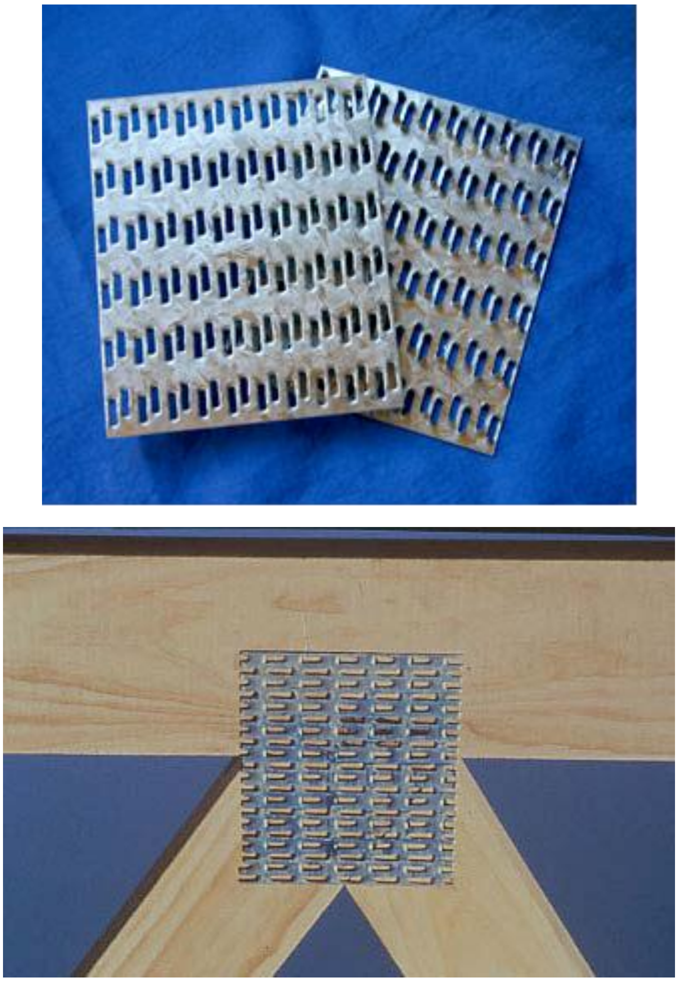


Figure 1.3 - Gang-Nail connector plates

1.2 History of Timber Roof Trusses

The evolution of trusses can date back to when man first used timber to form a shelter by use of a simple beam. The Romans have been accredited with the development of the arch in the middle ages where they found that by leaning rocks against each other, they were able to span greater distances (Figure 1.4). In a similar way, timber beams were leant against each other to form timber arches. For the final basic truss design used today was to add a tie between these two simple members to stop the supports being pushed apart (MiTek, 2012).

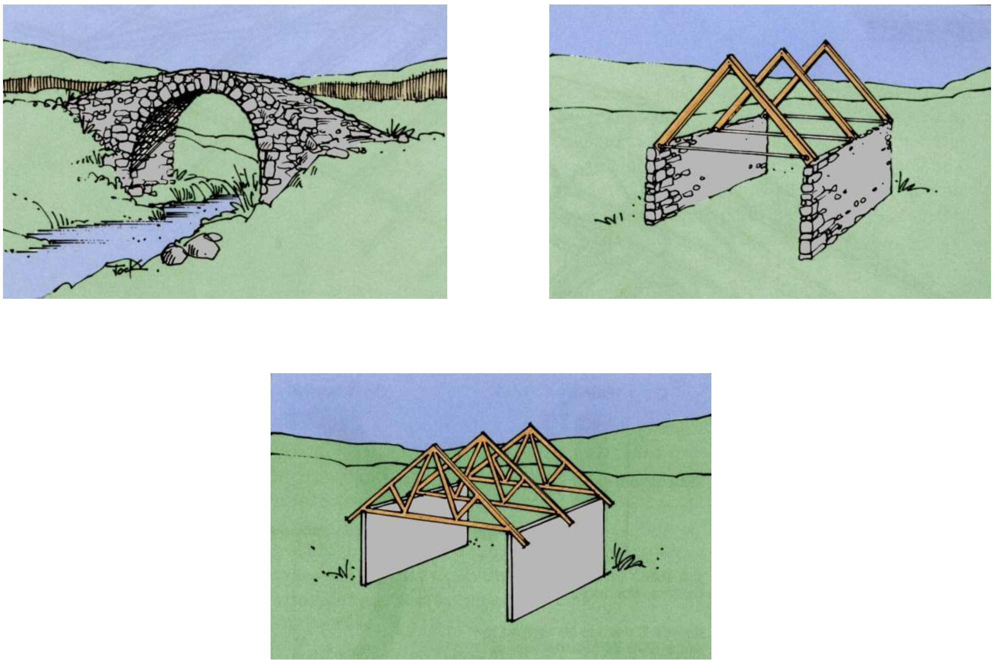


Figure 1.4 - Evolution of the truss

Before the introduction of roof trusses, all house carpentry was carried out on site by “crafting the material” (MiTek, 2012). In the early truss designs, the joints were either bolted using overlapping members or by use of large ply gussets. In 1952 A. Carrol Sandford is accredited with designing the first metal nail plate called the Gri-P-Late. This was then further developed in 1955 by J. Calvin Jureit, founder of Gang-Nail Systems Inc. (now MiTek Industries), where he developed the Gang-Nail Plate which was the first connector plate for trusses that did not require any supplemental nail fixings. This is the type of plate still in use today (Structural Building Components Association, 2012).

Further plate systems have been developed and there are now many different plate manufacturers and software providers around the world.

1.3 Project Aim and Objectives

The purpose of this study is to analyse the behaviour of gang-nail plated timber joints in perpendicular to the grain. The strength and failure mechanism of the timber will be analysed by investigating the effect of plate width, bite depth and plate orientation by destructive testing. If possible, a prediction equation will be generated for this design of gang-nail plated timber joints and this will be compared with the current MiTek Australia Ltd (MiTek) method.

The project is supported primarily by MiTek Australia Ltd, a major supplier of engineered design software and building products to the Timber Roof Truss Industry and by Hyne and Son Pty Ltd, operator of some of the largest saw mills in Australia.

1.4 Overview

Chapter 1 is a general introduction. It also discussed some background history of roof trusses and set out the aims and objectives of the project.

Chapter 2 discusses exactly what a tension perpendicular to the grain failure is and how it occurs. It also reviews existing literature and standards that are available for the calculation of how this is checked in the design of a nail plated joint. It also investigates the test methods that will be used for the testing procedure.

Chapter 3 outlines the materials used to manufacture the specimens and how the testing will be conducted.

Chapter 4 discusses the experimental results and observation obtained during the testing procedure.

Chapter 5 includes an analysis of the test data to find suitable parameters that can be investigated further for the proposal of a new calculation method

Chapter 6 presents the proposed new calculation method for both ultimate failure and design failure based on the test results and materials used

Chapter 7 presents the conclusions that can be drawn from this project and discuss any further recommendations for future work

References and Appendices provide all the supporting documentation referred to throughout this dissertation

Chapter 2 Literature Review

2.1 Introduction

The current MiTek method for determining the tension perpendicular to the grain failure has not yet been proven by any formal study. It has been determined as a conservative theoretical estimate by a professional engineer based on the values for various connection types in AS1720.1 along with their technical experience with gang-nail plates.

While AS1720.1 discusses the tension perpendicular calculation for various joints including nailed, screwed and bolted, it does not cover the use of gang-nail plates. Therefore this chapter aims to identify literature to support the project objectives and to identify methods for achieving these. It will also investigate the current methods used in the United States of America and in Canada by the Truss Institutes in these countries.

Through discussions with the Technical Services Manager of MiTek, Mr Robert Tan, it was indicated that there was a need to verify the current MiTek method for determining the tension values with some physical research and testing. He indicated that he was not aware of any previous work within Australia and research on this topic has concluded as such.

2.2 Truss Mechanics

Trusses are designed to support all the loads applied to them and to transfer the loads through its members into the supports. These include:

- Dead Loads – Permanent loads due to weight of materials and truss self-weight (e.g. Roof and Ceiling materials, Air-conditioner Units, Hot Water Units, etc.);
- Live Loads – Temporary load due to traffic, construction, maintenance (e.g. people and their tools)
- Wind Loads – Load applied to the roof by the wind

(Gang-Nail Truss Systems, 2009)

All the trusses in a structure are designed for their worst case of the above combined loads. These loads cause the members of the truss to be in (usually) either tension or compression, which then transfers these loads through the joints.

Tension forces	These have the effect of pulling on the member causing it to stretch.
Compression Force	These have the opposite effect of pushing on the end of the member, causing it to buckle.

In a standard “A” type truss as shown below in Figure 2.1, the type of force acting on each member is shown.

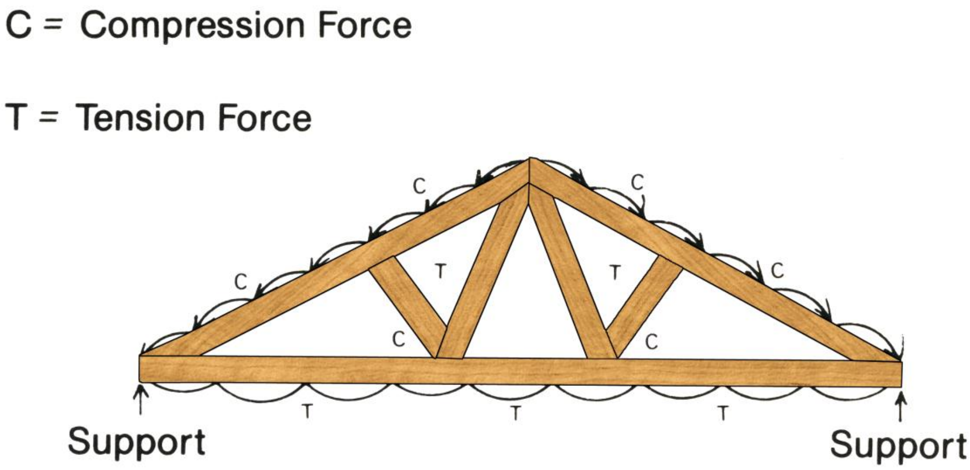


Figure 2.1 - Force direction on members

(MiTek, 2012)

These member forces in turn apply loads to the truss joints. The joints are covered with a gang-nail plate which transfers all the loads into the adjoining members. As the gang-nail plate produces an assumed pin joint, then all the forces in the joint need to be in equilibrium. The design of these joints in dependent on:

- Properties of the connector plate
- Properties of the teeth and the characteristics of the timber (MiTek, 2009)

The basis of these joints is to ensure that enough teeth exist in each member of the joint to adequately transfer the loads. During the analysis of the members, it can be found that a member force may exert a tension perpendicular to the grain force in the joining member. Therefore this force needs to be accounted for in the design software to ensure that no failures will occur.

2.3 Truss Joints

A joint in a timber roof truss is a node point at the intersection of two or more members. Today, the most common connector is a multi-tooth plate, but they have been constructed using many different methods since their conception. These could be:

- Overlapped and bolted/pinned (dowel type connectors)
- Ply gussets
- Metal gussets

The connection transfers the forces from each member back to the supporting structure. Therefore, the timber used in the roof truss and each connector must be able to withstand the applied forces to provide a satisfactory design.

Schoenmakers and Jorissen (2011) investigated the failure mechanisms of dowel-type fastener connections perpendicular to the grain and found that the failure could be either ductile or brittle. Under tensile stresses, cracking was the primary failure, and this is also what is predicted to occur with the gang-nail plate.

They also found that many studies have been done that deal with the splitting of timber in tension perpendicular; however, these have been limited to the dowel-type connections. Many empirical and theoretical models have been reported.

The use of gusset type connectors assisted in the reduction of tension perpendicular failure occurring, as generally the gusset covered the entire member with multiple fasteners used. However, Todd and Turnbull (1970) found in their analysis of the tensile strength of plywood gussets that the previous assumed theory of nailed ply gussets (that were commonly used in the 1970’s for truss manufacture) was that the nails simply parted the fibres of the timber, but didn’t reduce the strength. They found in fact that when subjected to tensile forces, the nails did reduce the tensile strength of the timber and the gusset.

When bolts or rivets are used, it was customary to account for the section area of the material removed when performing the design. Greater care was also taken in regards to the formulation of minimum edge distances to ensure that the forces could be transferred around these fixings.

Regardless of the connection type used, tension perpendicular stresses will exist and will need to be accounted for in the design.

2.4 Tension Perpendicular

The American Wood Council describes tension perpendicular to the grain as “the evil of wood connections” (AWC, 2001). A tension perpendicular failure will often lead to sudden catastrophic failures and should be avoided at all cost. However it is not possible to always avoid it from occurring.

The strength to weight ratio of timber is relatively high when the load is applied parallel to the grain, however it is considered weak when loaded perpendicular. Under compression it will cause significant deformations and under tensile forces it may result in a brittle failure (Jensen, 2012).

Many truss collapses around the world can be attributed to a tension perpendicular failure. Burdzik wrote in his 2004 paper to the South African Institute of Civil Engineering that, due to recent timber roof truss failures in South Africa of large span trusses, a rethink about the analysis was required.

A tension perpendicular to the grain force occurs at the intersection of two members where the butting member is acting under tension. A common place for this to occur is at the intersection of the bottom chord of the truss and a vertical web, at an internal support or in a half truss. These forces tear the fibres of the timber along the grain (see Figure 2.2). The results of testing by Vahik Enjily (2001) in the performance of trusses recommends that tension perpendicular to the grain failure in the vicinity of joints must be considered during the design process

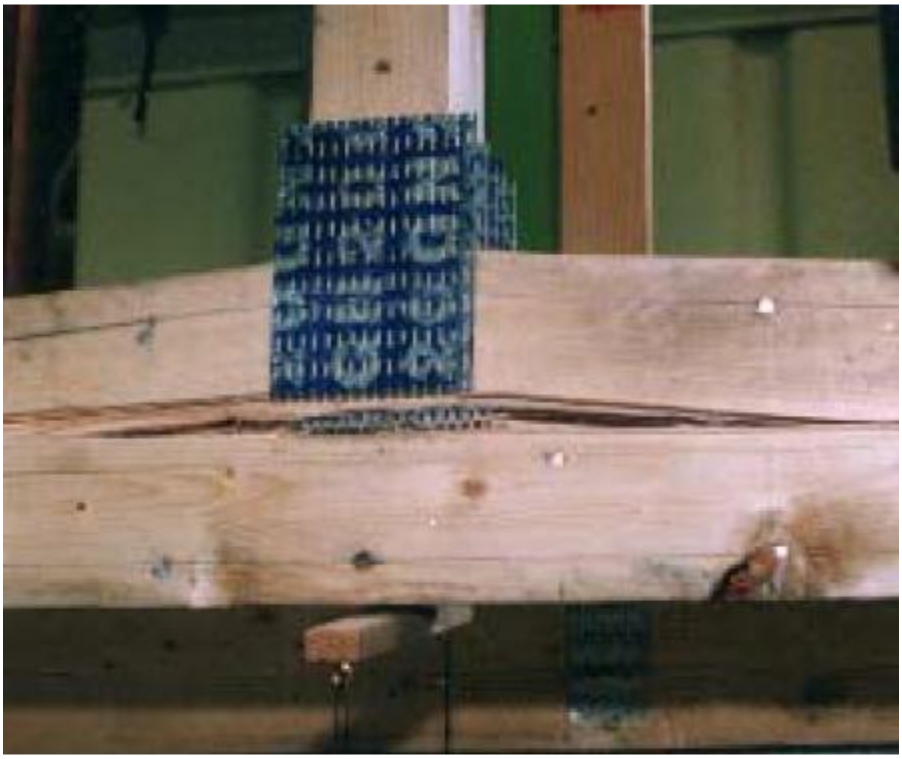


Figure 2.2 - Common Tension Perpendicular Failure (Enjily, 2001)

Soltis and Ritter (1996) in their paper wrote that "*Eccentric loading is produced at connections when the resultant member forces are offset at the connection. Eccentricity in connections induces tension perpendicular to grain which can severely reduce the capacity of the members. The strength of eccentric connections is difficult to evaluate and connections of this type must be avoided unless tests are employed in design to insure members can safely carry applied loads.*"

It is not always possible to avoid a tension perpendicular force, so ways must be found of adequately designing the truss joints to avoid a failure from occurring. Beebe (2012), in her presentation Wood Design for Architects discussed the importance of "Load Path Continuity" to help avoid a tension perpendicular failure. This is best done by the use of suitable fasteners and avoiding drilling and notching where possible.

Hansson (2011), in her paper to the Engineering Structures Journal regarding failures (collapses) under high snow loads during the 2005/2006 winter in Germany and

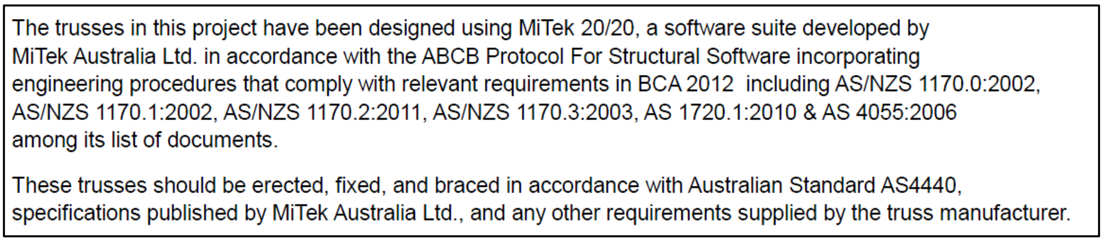
Austria, found that joints were involved in 23% of the failures. Of this, 11% was attributed to tension perpendicular to the grain and punched metal plates were involved in 10% of these cases. Her recommendations were that the majority of these could have been avoided if available knowledge had been utilised and that to "*include control of risk for perpendicular to the grain failure in design control procedures*" and that the "*design of joints should be of high priority in timber engineering research, education and Quality Assurance procedures*".

It must also be noted that the force may not be perpendicular to the grain but at an angle to the grain. The effect of this on the timber is outside the scope of this project.

2.5 Standards

2.5.1 Australian Standards

Currently there is no Australian Standard for the design of Timber Roof Trusses themselves; however, the design of trusses is based on AS1120, AS1170 and AS1684. The basis for the design of trusses can be clearly seen in outputs for certification from MiTek's design software.



The trusses in this project have been designed using MiTek 20/20, a software suite developed by MiTek Australia Ltd. in accordance with the ABCB Protocol For Structural Software incorporating engineering procedures that comply with relevant requirements in BCA 2012 including AS/NZS 1170.0:2002, AS/NZS 1170.1:2002, AS/NZS 1170.2:2011, AS/NZS 1170.3:2003, AS 1720.1:2010 & AS 4055:2006 among its list of documents.

These trusses should be erected, fixed, and braced in accordance with Australian Standard AS4440, specifications published by MiTek Australia Ltd., and any other requirements supplied by the truss manufacturer.

Figure 2.3 - Exert from Truss Certificate from MiTek's 20/20 program

There have been some initial discussions on the development of AS1684.5 – Design Criteria for Nail-plated Timber Trusses that is hoped to provide some uniformity in the industry (MiTek, 2012). However due to the use of design software and intellectual property of the design methods used, it has been hard for the industry to finalise this document.

The BCA 2012 has introduced a new reference document called ABCB “Protocol for Structural Software”. It refers to design software that is used by non-engineers like truss detailers. To comply, the software must be based on the provisions of the BCA and reference documents (Australian Standards) and its users must fully understand any limitations of the package. Users must also be kept up to date with training in the version of the software they wish to use (GN Guideline 177, MiTek, 2012).

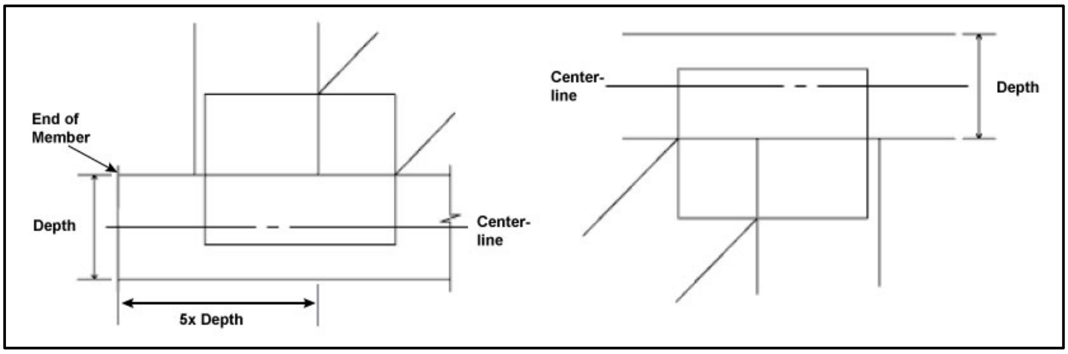
2.5.2 International Standards

The Truss Plant Institutes of America and Canada provide the provisions for designing joints allowing for Tension Perpendicular. Section 7.5.3 and 8.10 of ANSI/TPI 1-2007 (American National Standard) discuss the required modifications.

Section 7.5.3.2.1 discusses the testing of 8x2 (200 x 50 mm) lumber loaded in tension perpendicular to the grain using various bite depths and was found to have a safe recommended concentration load of 800 lbs. (approx. 360 kg or 3.6 kN). After this, the plate is required to extend past the centre line of the member. Through this testing, the failure was attributed to a combination of tension across the grain and horizontal shear.

Even our MiTek office in the United States allows for this in the designing of trusses, even though the same basic software structure is used globally. MiTek US state:

5. *Plating for Tension Perpendicular to the Grain –*
   MiTek Engineering contains new calculations to determine the minimum distance a connector plate must extend past the centreline of a member under the following conditions:
   - *The net tension force is perpendicular to the grain*
   - *The net tension force exceeds the allowable value of 400 set by TPI 2007 and the joint is less than 5x the depth from the end of the member OR*
   - *The net tension*



(MiTek US, 2012)

The Truss Plate Institute Canada Standard (TPIC - 2011) states in CL5.5.6 that:

Any joint which carries a factored concentrated load that is perpendicular to the chord or has a component that is perpendicular to the chord and/or has a shear component that is perpendicular to the chord and exceeds 2.5 kN (562 lbs.) must be reinforced for tension perpendicular-to-grain with a minimum chord bite as follows:

$$Min\ Bite\ (mm) = \frac{P - 2.500}{0.041}\ \ (for\ Spruce - Pine - Fir) \tag{2.1}$$

$$Min\ Bite\ (mm) = \frac{P - 2.500}{0.055}\ \ (for\ Douglas - Fir - Larch) \tag{2.2}$$

where

P = *Factored Concentrated Load, kN*

The calculated minimum bite requirement need not exceed 3/4 of the depth of the lumber.

Like the American TPI, the maximum tension perpendicular force occurs about the centreline, so once the plate extends past these points, the consideration of them will be reduced.

2.5.3 Current Plate and Software Suppliers

Within Australia, there are currently three different plate and design software suppliers. These are MiTek, Multi-Nail and Pryda. While each nail plate serves the same purpose in truss manufacture, each company manufactures their plates slightly differently. This means that the way a joint is designed and functions within their own design software packages will be different.

However, it is expected that if the metal strength and grip are satisfied for a joint regardless of the plate supplier used, it could be expected that the tension perpendicular failure for the same bite depth/width will be the same. The objective is ultimately a timber failure in tension perpendicular to the grain below or at the bottom edge of the plate. Therefore it could be reasonably expected that the results found through this project and from further testing could be utilised in standard design guidelines as an Australian Standard.

2.6 Current MiTek Method

The current MiTek method allows for an ultimate estimated failure loads as shown in Table 2.1. These values have been determined using:

$$N_{tp} = \emptyset \times k_1 \times k_{11} \times f_{tp} \times thk \times \left(2t_p + w\right) \tag{2.3}$$

Where:

k_1 is the Duration of Load Factor

Ø is a capacity factor

f_{tp} Tension Perpendicular to grain Characteristic Value

thk is the thickness of the truss

t_p is the bite depth

w is the plate width

k_{11} is given by $\left(\frac{V_0}{V}\right)^{0.2}$ where V_0 is 10^7

and:

$$V = 1.2 \times (2t_p + w) \times tp \times thk \tag{2.4}$$

When computing these values in Table 2.1, the following constants have been used:

k_1	0.57	(AS 1720.1-2010, Table 2.3)
Ø	0.9	(AS 1720.1-2010, Table 2.1)
f_{tp}	0.5 MPa	(AS 1720.1-2010, Table H3.1)
thk	35mm	
t_p	range of 20, 40, 60 mm and 30, 50, 70 mm	
w	75 and 125mm	
k_{11}	is given by $\left(\frac{V_0}{V}\right)$ where V_0 is 10^7	

The value for N_{tp} from equation 2.3 is multiplied by a 3.5 safety factor in order to find the ultimate failure load.

Table 2.1 - Estimated Ultimate Failure Load in Tension Perpendicular

Plate Size	Bite Width	Bite Depth	Ultimate Failure Load (kN)
125200	125	20	12.23
125200	125	40	12.82
125200	125	60	13.65
75200	75	20	9.34
75200	75	40	10.37
75200	75	60	11.47
125200 R	60	30	5.01
125200 R	100	50	6.80
125200 R	140	70	8.33

(R – Plate orientation rotated 45 degrees – initial width taken at timber edge)

These values will be used as a guide as to when the timber in the samples fail. Parts of the equations are based on AS1720-1 cl 2.4.6 (d) Size Factors.

While AS1649-2001 cl 1.7.4 calls for a minimum of ten samples of each setup, due to the time restrictions in conducting the test, a maximum of four will be used. The objective of the project is to compare test results against the current MiTek method and, if possible, to produce an alternative equation. It is believed that four of each setup will provide sufficient detail to achieve this objective.

Chapter 3 Materials and Methods

3.1 Introduction

In order to find when tension perpendicular occurs in a truss member, testing will be conducted on specimens plated in a T configuration. The objective is to achieve a tension perpendicular failure in the timber, so any other possible failures need to be eliminated. The other failures that can occur in this configuration include:

- Metal failure of the gang-nail plate
- Plate withdrawal (gang-nail plate teeth withdrawing from the members)
- Tension parallel in non-test member

.

3.2 Materials

3.2.1 Timber

The timber that is being used for the testing is Australian Radiata Pine sourced from Hyne and Son Pty Ltd from their saw mill at Tumbarumba in New South Wales. Radiata Pine would be the most common material used in the manufacture of trusses in varying stress grades from MGP 10, 12 and 15. The most common sizes used are 90x35 mm for the chords and 70x35 mm for webs, however heavily loaded trusses and special shapes may utilise larger end sections.

For the purpose of this study, 140x35 mm MGP10 has been used as it is a common member in trusses that support the heavier loads that will be exposed to the higher internal forces. The material supplied has been treated using a T2 treatment, however, this will have no effect on the performance of the material during the testing.

Generic timber properties are available in AS1170.1 and AS1649 (Table 3.1 and 3.2 below). The densities of the materials used in the specimens will need to be verified against these properties to ensure that they conform to the standard. The verification of the grade and characteristic values of the material is outside the scope of this project.

Table 3.1 - Characteristic Values from AS1170.1-2010

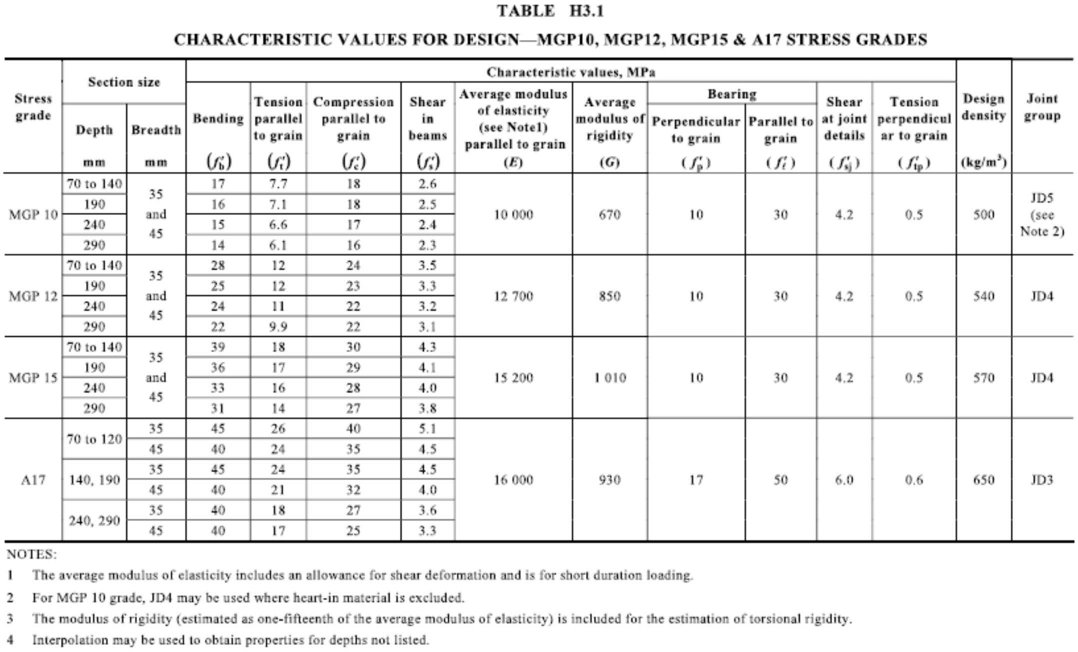


TABLE H3.1

CHARACTERISTIC VALUES FOR DESIGN—MGP10, MGP12, MGP15 & A17 STRESS GRADES

Stress grade	Section size		Characteristic values, MPa						Bearing				Design density	Joint group
	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 (see Note1) parallel to grain (*E*)	Average modulus of rigidity (*G*)	Perpendicular to grain (f'_p)	Parallel to grain (f'_l)	Shear at joint details (f'_{sj})	Tension perpendicular to grain (f'_{tp})	(kg/m^3)	
MGP 10	70 to 140	35 and 45	17	7.7	18	2.6	10 000	670	10	30	4.2	0.5	500	JD5 (see Note 2)
	190		16	7.1	18	2.5								
	240		15	6.6	17	2.4								
	290		14	6.1	16	2.3								
MGP 12	70 to 140	35 and 45	28	12	24	3.5	12 700	850	10	30	4.2	0.5	540	JD4
	190		25	12	23	3.3								
	240		24	11	22	3.2								
	290		22	9.9	22	3.1								
MGP 15	70 to 140	35 and 45	39	18	30	4.3	15 200	1 010	10	30	4.2	0.5	570	JD4
	190		36	17	29	4.1								
	240		33	16	28	4.0								
	290		31	14	27	3.8								
A17	70 to 120	35	45	26	40	5.1	16 000	930	17	50	6.0	0.6	650	JD3
		45	40	24	35	4.5								
	140, 190	35	45	24	35	4.5								
		45	40	21	32	4.0								
	240, 290	35	40	18	27	3.6								
		45	40	17	25	3.3								

NOTES:

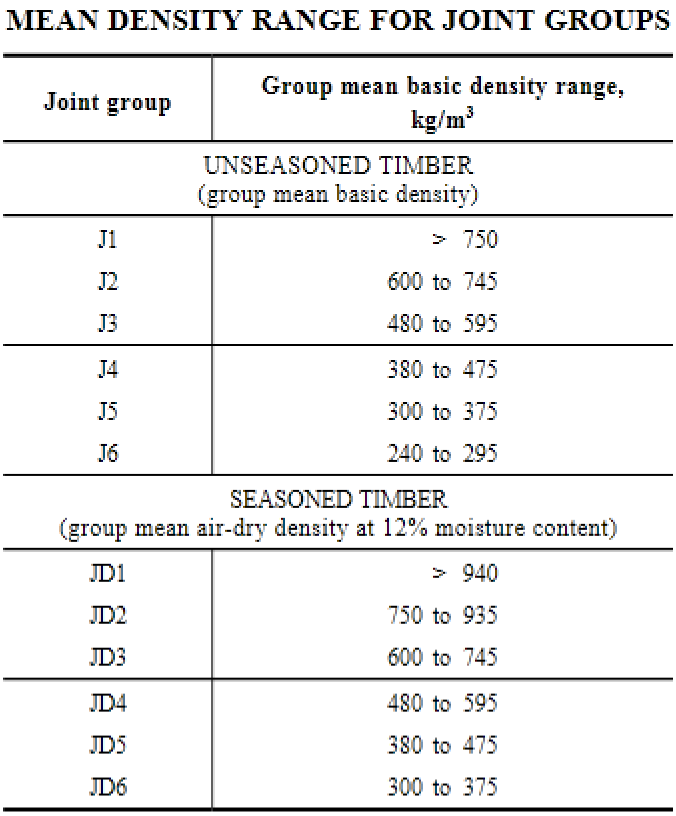
1 The average modulus of elasticity includes an allowance for shear deformation and is for short duration loading.

2 For MGP 10 grade, JD4 may be used where heart-in material is excluded.

3 The modulus of rigidity (estimated as one-fifteenth of the average modulus of elasticity) is included for the estimation of torsional rigidity.

4 Interpolation may be used to obtain properties for depths not listed.

Table 3.2- Mean Density ranges from AS1649-2001



MEAN DENSITY RANGE FOR JOINT GROUPS

Joint group	Group mean basic density range, kg/m^3
UNSEASONED TIMBER (group mean basic density)	
J1	> 750
J2	600 to 745
J3	480 to 595
J4	380 to 475
J5	300 to 375
J6	240 to 295
SEASONED TIMBER (group mean air-dry density at 12% moisture content)	
JD1	> 940
JD2	750 to 935
JD3	600 to 745
JD4	480 to 595
JD5	380 to 475
JD6	300 to 375

In accordance with AS1649 cl 1.6.1, it has been assumed that the timber supplied from a commercial supplier is compliant with the standard moisture contents for dry timber. The material was supplied in a standard pack as it would be to any truss manufacturer. This material was transported with the cover as installed by the supplier and kept inside buildings/sheds during every process to keep the moisture content constant.

Once all the samples had been cut to 1000 mm lengths, ensuring that they were clear of any defects in accordance with AS1649 cl 1.5.2 where "*No significant strength reducing characteristics shall be present except small pin knots, and the like, if typical of the species*", they were re-measured for length, breadth and width to calculate the volume. The specimens were then weighed on a digital scale (Figure 3.1).

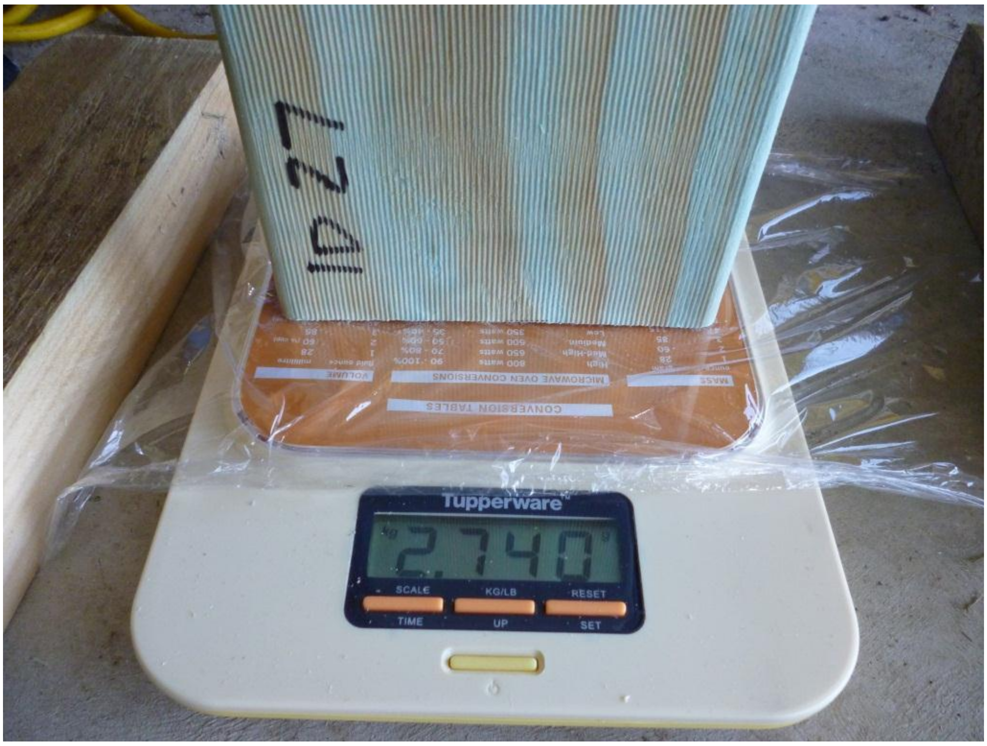


Figure 3.1 - Weighing of sample members

The densities were found to be in a range from 391 to 568 kg/m^3. Individual specimen densities have been included in Appendix B. These generally fit the density for JD4-JD5 where the higher densities appear to not include any heart material via visual inspection.

3.2.2 Gang-Nail Plates

Gang-nail connector plates are a punched steel plate where teeth (or spikes) are formed during the punching process. There is not one single plate that produces the optimum solution in all situations, so the plates are available in a wide range of sizes and MiTek supply three different steel grades. These are:

GQ – 20 Gauge (1.0 mm thick)
GE – 18 Gauge (1.2 mm thick)
GS – 16 Gauge (1.6 mm thick)

The steel used in the manufacture of the gang-nail plates is galvanised coil to AS1397, with a zinc coating to Z275 (MiTek, 2012)

Since the testing is to find the failure force perpendicular to the grain, no steel failure can occur. The shear force that the plate can resist is given by:

$$Design\ Shear\ Capacity = \emptyset \times Shear\ Length \times Q_s \qquad (4.2)$$

Where:

Q_s is the Connector Plate Strength in N/mm for steel (Table 3.3)
$\emptyset$ is a capacity factor (0.9)
Shear Length is the plate width of 75 and 125 mm respectively.

Table 3.3 - Characteristic Capacity for Steel Qs

Type of Stress	**GQ**	**GE**	**GS**
Longitudinal Tension	263	387	578
Lateral Tension	187	226	272
Longitudinal Shear	197	297	408
Lateral Shear	178	215	323
Note: Longitudinal axis is parallel with the slots			

MiTek, 2012

As the slots will be perpendicular to the sample piece, the lateral shear values will be used. The two plate widths selected to give a range of values are 75 mm and 125 mm. The design capacities are shown below in Table 3.4.

Table 3.4 - Design Shear Capacity – value in kN

Plate Size	GQ	GE	GS
75x200	12.015	14.512	21.802
125x200	20.025	24.197	36.337

NOTE: These are design capacities not Ultimate Failure Capacities

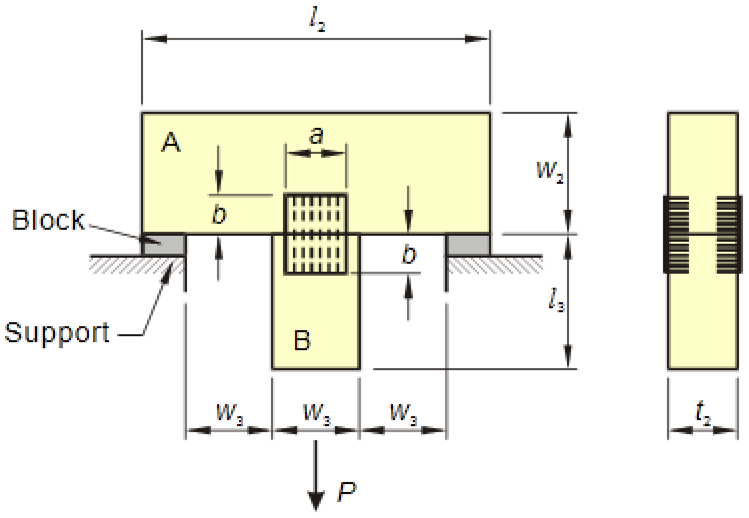
As the above values are design capacities and our testing will provide an ultimate failure load, we can apply a value of 1.5 times the design capacities to check that the ultimate capacity will be satisfied. Using GE plates in the selected sizes, the ultimate failure loads for 75 mm and 125 mm widths will be 21.8 kN and 36.3 kN respectively. These forces can be applied without a metal failure occurring, which is greater than the predicted tension perpendicular failure expected as discussed in Section 2.6.

By using a plate that is 200 mm long and only relatively short bite depths, the additional length in the plate will restrict a tension parallel failure in the non-test vertical member by providing sufficient bite.

There is a concern that plate withdrawal may occur as the bite reduces, which was discussed with Robert Tan prior to the testing. If this does occur during the testing of the first specimen of each setup, 12 mm ply will be clamped over the plate in order to restrict plate withdrawal, but without exerting sufficient pressure of the plate over the specimen that will interfere with the test procedure.

3.3 Manufacture of Samples

The test piece was calculated at needing to be a minimum of 700 mm to allow for a sufficient span for a tension perpendicular failure to occur. This was calculated based on the use of 140x35 mm timber for both the test piece and the vertical member. AS1649-2001 cl 2.2.6.1 (ii) states that for a perpendicular type test (Figure 3.2), the length of the specimen is to be not less than 450 mm or 5*a* where *a* is the plate width. Therefore the minimum length of the actual sample can be 625 mm and the distance between the supports is to be $3w_3$ where w_3 is the width of the vertical member (420 mm).



(b) Perpendicular Type

Figure 3.2 - Tension Perpendicular test as per AS1649

However, due to the over straps in the test accessories, it can be assumed that the straps will provide support to the timber and a tension perpendicular failure will not occur in the 45 degree triangle from this point (Figure 3.3). Therefore the length between the supports will be taken as 5w which will be 700 mm.

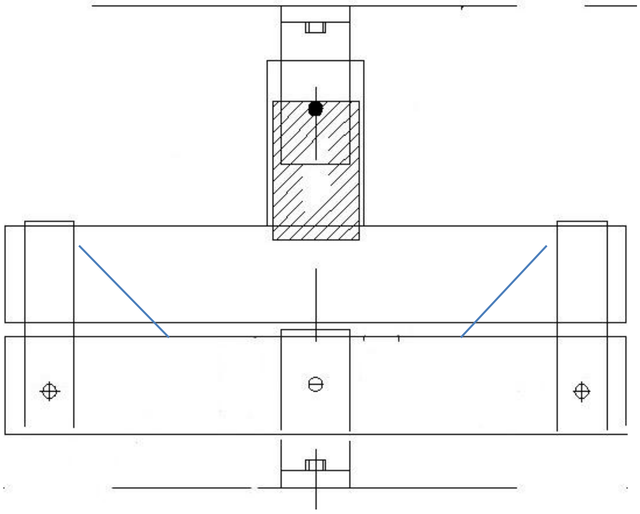


Figure 3.3 - Tension Perpendicular is assumed to not occur in the 45 degrees from straps

The height will also be governed at maximum 700 mm due to height restriction on the Avery Testing Machine.

The samples were made in a series of different plate combinations using two plate sizes and three bite lengths. The samples were pressed together on an Auto-10 table press at TrussTec Pty Ltd. as seen in Figure 3.4. The Auto-10 is a platen hydraulic press with a pressing force of 45 tonne. It is a common piece of machinery used by truss manufacturers. Other common presses used also have a capacity of 45 tonne, so the pressing force of the plate into the timber is common.

Figure 3.4 - Pressing of test samples

During the pressing of the first sample using the 125200 plate with 20 mm bite, it was observed that the pressing process caused cracking of the timber within the expected tension perpendicular area (Figure 3.5). This caused an immediate recalculation of the samples that would be used, as any failure during the pressing would give a false failure during the tests.

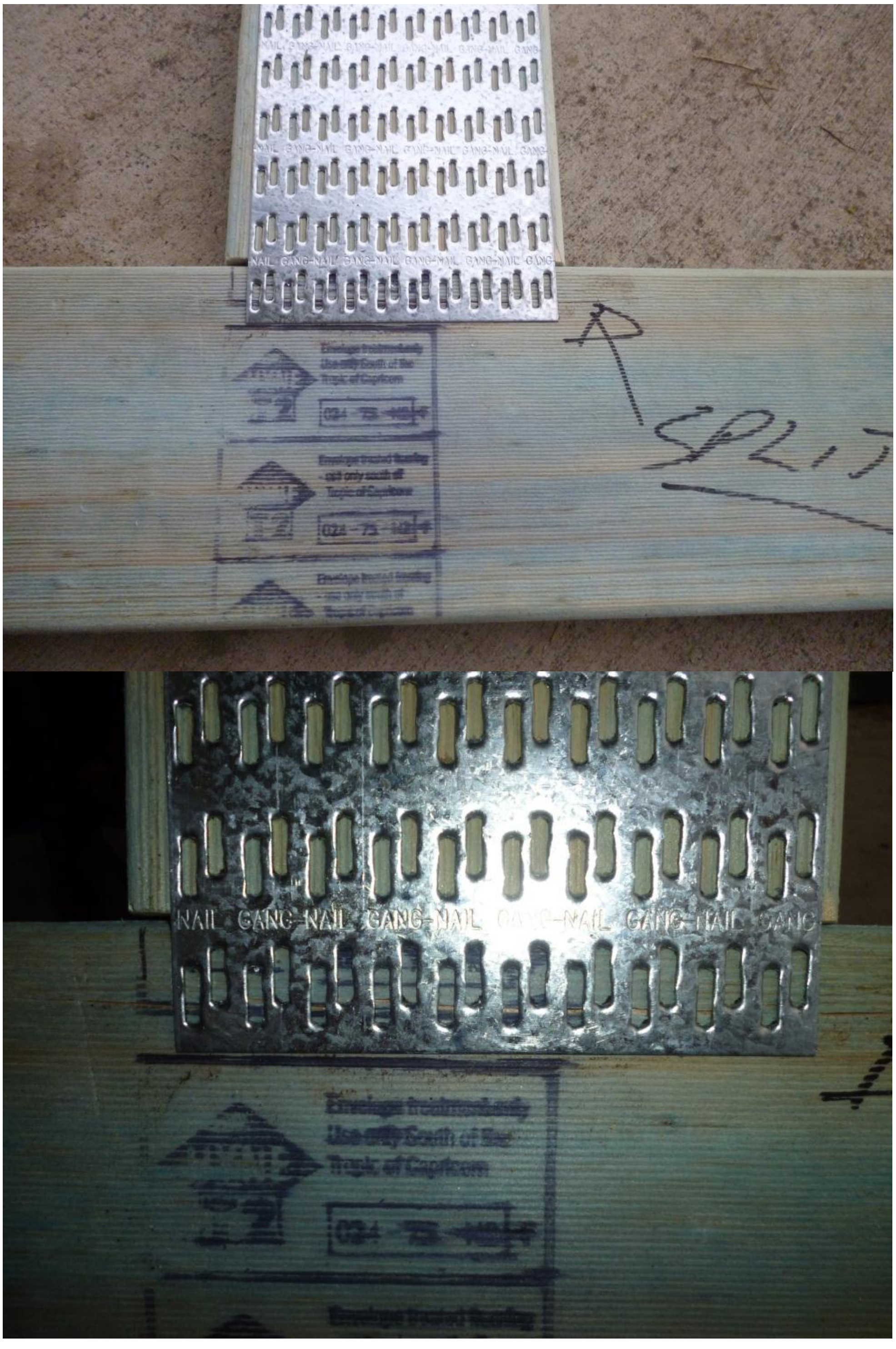


Figure 3.5 - Failure within plate area during pressing at 20 mm bite

A second sample was pressed using a 25 mm bite and no cracking was observed. The remaining samples with a 25 mm bite were pressed with no further pressing issues. Therefore, to ensure that the step in bite distances were consistent, the bites were finally pressed at 25, 45 and 65 mm for the 75200 and 125200 plates.

Similar issues were encountered during the manufacture of the 45 degree rotated plates. Both at 20 mm and 25 mm, failure occurred due to the small bite area. Trialling 5mm increases; it was found that no timber failure occurred at 30 mm, so 30, 50, 70 mm bite depths were adopted for this orientation.

The values from Table 2.1 were revised for the new bites into Table 3.5.

Table 3.5- Revised Estimated Ultimate Failure Load in Tension Perpendicular

Plate Size	Bite Width	Bite Depth	Ultimate Failure Load (kN)
125200	125	25	12.23
125200	125	45	12.82
125200	125	65	13.65
75200	75	25	9.34
75200	75	45	10.37
75200	75	65	11.47
125200 R	60	30	5.01
125200 R	100	50	6.80
125200 R	140	70	8.33

3.4 Testing Method

3.4.1 Introduction

The samples will have a tensile force applied to the vertical component. During the application, the force will pass via the vertical member, through the metal gang-nail connector plate into the test sample. It is predicted that the timber will fail along the grain below the plates. The project is to find the relationship between the bite-length combination and the applied force. It will also be investigated whether there is a difference if the plate is rotated 45 degrees to the grain. An Avery Universal Tension

Test machine will be used to conduct the test which is located in the University of Southern Queensland Engineering Laboratories.

Figure 3.6 - Avery Test Machine at USQ Toowoomba

3.4.2 Testing Setup

In order to conduct the tension test, a way of transferring the force (movement) from the Avery Machine into the samples would be required. MiTek Australia regularly undertakes a wide range of testing and has developed a series of accessories that fit the machines. The accessories consist of a top and bottom “grip” that fit into the cross arms of the testing machine and grip the bending beam at the bottom and the non-test member at the top. Over straps are then fitted to the bending beam to support the test member at the required spacing. The setup is displayed in Figure 3.7.

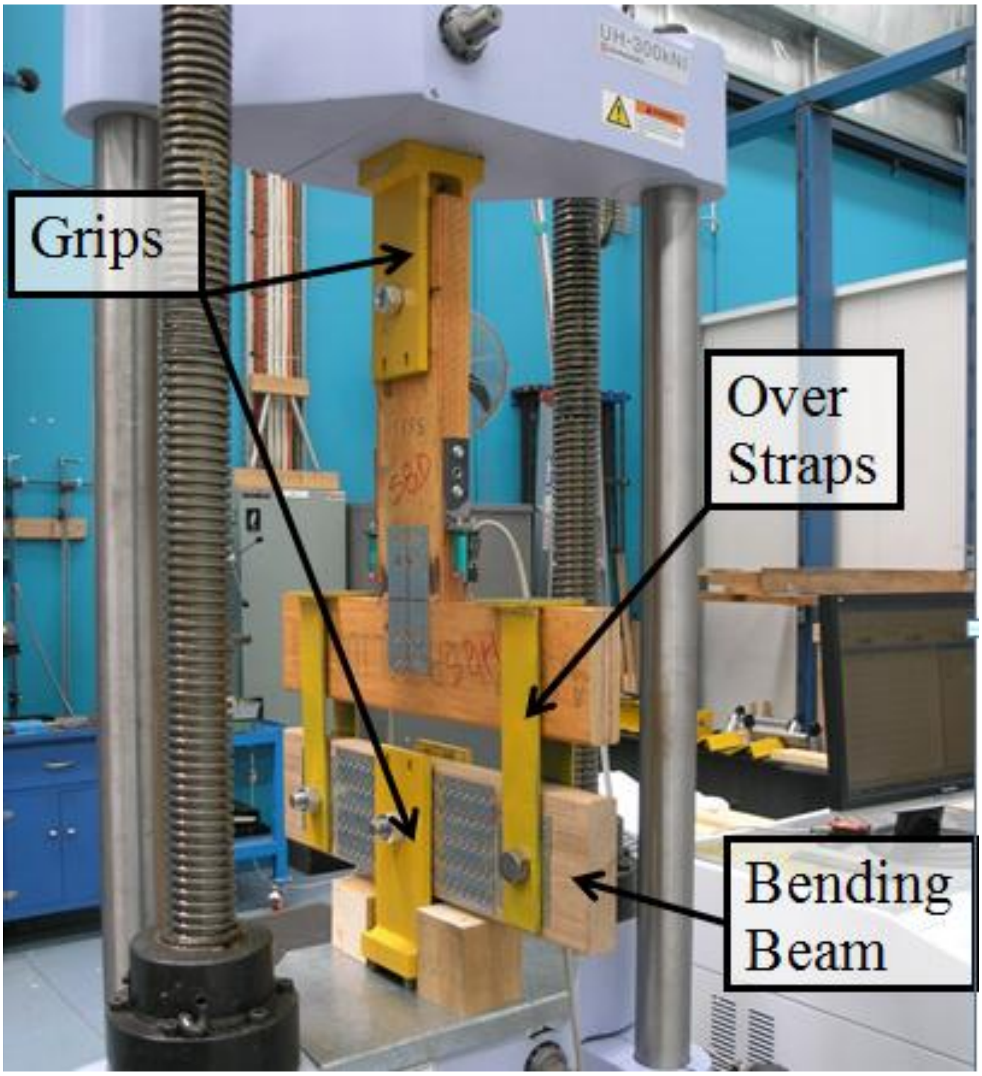


Figure 3.7 – Accessories for Testing Machine (MiTek Australia)

All bolts used are a M20 Grade 8.8 threaded bolt. In order to stop the bolts from shearing through either the bending beam or the non-test member, gang-nail plates were pressed into the members prior to drilling to transfer the load over a larger area. The hole drilled was 20 mm to ensure a tight fit for the bolts.

The bending beam was made from a section of 140x35 F27 Hardwood to ensure that it was stiff enough to not deflect excessively and have any adverse effect on the resultant forces. The bending beam was made the same length at the samples (1000 mm) to ensure sufficient edge distance for the bolts could be achieved.

3.4.3 Testing Procedure

Apart from the minimum number of samples required for testing, all tests were conducted in accordance with AS1649-2001 Timber—Methods of test for mechanical fasteners and connectors—Basic working loads and characteristic strengths.

As each new sample was loaded into the test rig, the bolt of the top bolt into the cross arms was tightened until the point where there was a slight force applied – just enough to hold the sample in place. The sample member was then checked that it was horizontal and the load was then applied at a rate of 1.3 mm per minute in accordance with AS 1649 cl 2.2.6.1.

Using the software attached to the testing machine (Figure 3.8), the applied force in kN was measured every 0.4 seconds and saved into a text file. The maximum force at failure point was recorded as the Ultimate Failure Load (UFL). The UFL and method of failure will be recorded and photographed

This is the Tensile Master

Test in progress

Axial Displacement	Extension	Axial Load	Strain	Stress	Time
7.46800	7.46800	12.29983	7.46800	3.05456	344.68000
mm	mm	kN	%	MPa	s

Figure 3.8 - Avery Test Machine Software during a test

3.5 Health and Safety

Taking proper precautions during the manufacture and testing of the samples was important for my safety and those assisting me and also to protect the property of the building and equipment. The equipment used ranged from general handyman tools like drops saws and drill presses through to commercial hydraulic presses that are used for the manufacture of timber roof trusses. For testing, an Avery Tensile Test machine was used. Therefore, risk assessments (refer Appendix G) were conducted for each step of the manufacture and testing procedures to minimise the impact on health and safety.

With previous training in all truss manufacturing equipment, a site induction with Mr Shane Moore was all that was required before I could operate the Auto-10 table press at TrussTec Pty Ltd. Training was provided by Mr Mohan Trada on the Avery machine at the University of Southern Queensland prior to the tensile tests being conducted.

During all stages of the manufacture and testing, Personal Protective Equipment (PPE) was worn in accordance with the risk assessment.

Chapter 4 Experimental Results and Observations

4.1 Introduction

During the conduction of the tests, records were kept in regards to the sample number (ID), what its plate orientation was, and the order that the test was conducted. As the sample failed, the Ultimate Failure Force was noted along with the visual appearance of the failure and anything that occurred during the test. The data collected via the Avery Test Machine is included in Appendix C.1 with a sample individual report in Appendix C.2. Full data is attached to the supplementary file.

4.2 Forces

The ultimate failure force of each sample as measured by the Avery Software was recorded. The UFL occurred at the point where the sample physically failed. The various forces of failure will be discussed in Section 4.3. Once the four UFL of each sample type were known, an average was calculated. These have been noted in Table 4.1 and the full list of failure forces in Appendix D.

Table 4.1- Average Actual UFL

Bite Width	Bite Depth	Average Actual Ultimate Failure Load (kN)	Standard Deviation
125	25	9.815	1.193
125	45	17.794	1.790
125	65	22.290	2.990
75	25	6.587	0.756
75	45	13.936	0.537
75	65	19.480	1.984
60	30	3.987	0.766
100	50	9.956	1.792
140	70	15.676	4.425

4.3 Failure Mechanisms

4.3.1 125 mm Width Range

When using the 125 mm wide plate, all bite depths experienced a major tension perpendicular failure where the sample member fully fractured. After the first few tests, it was noted that even though a major failure occurred, the samples only broke into two parts. No pieces from the samples left the testing area that could have resulted in damage or injury. Once this was observed, closer inspections during the test cycle were possible, however a small distance was still kept from the samples and appropriate protective equipment was worn at all times.

There were no visible signs of plate withdrawal occurring during the testing and this was monitored closely. It was noted that after the failure, some plate withdrawal had occurred, however this was put down to have occurred during the failure.

For the 65mm bite depth, all four samples fractured at the bottom row of connector teeth with the fracture following the grain of the timber from end to end. It was also notes that audible cracking noises were heard at approximately 10 kN for ID12 and 18 kN for ID10 however at the time there were not visible cracks appearing.

With the 45 mm bite depths, again major tension perpendicular failures occurred. Similar to the 65 mm bites, the failure occurred along the length of the grain and also followed the grain in cross section. This was observed in sample ID5 where on one side it failed at the bottom row of teeth, however on the other side it failed below the plate.

Figure 4.1 - ID5 Failure at bottom row of teeth

Figure 4.2 - ID5 failure below the plate

However the samples did not fully fracture along the full length. Either the ends of the grain fibres still remained or the failure followed the grain up to the top of the sample.

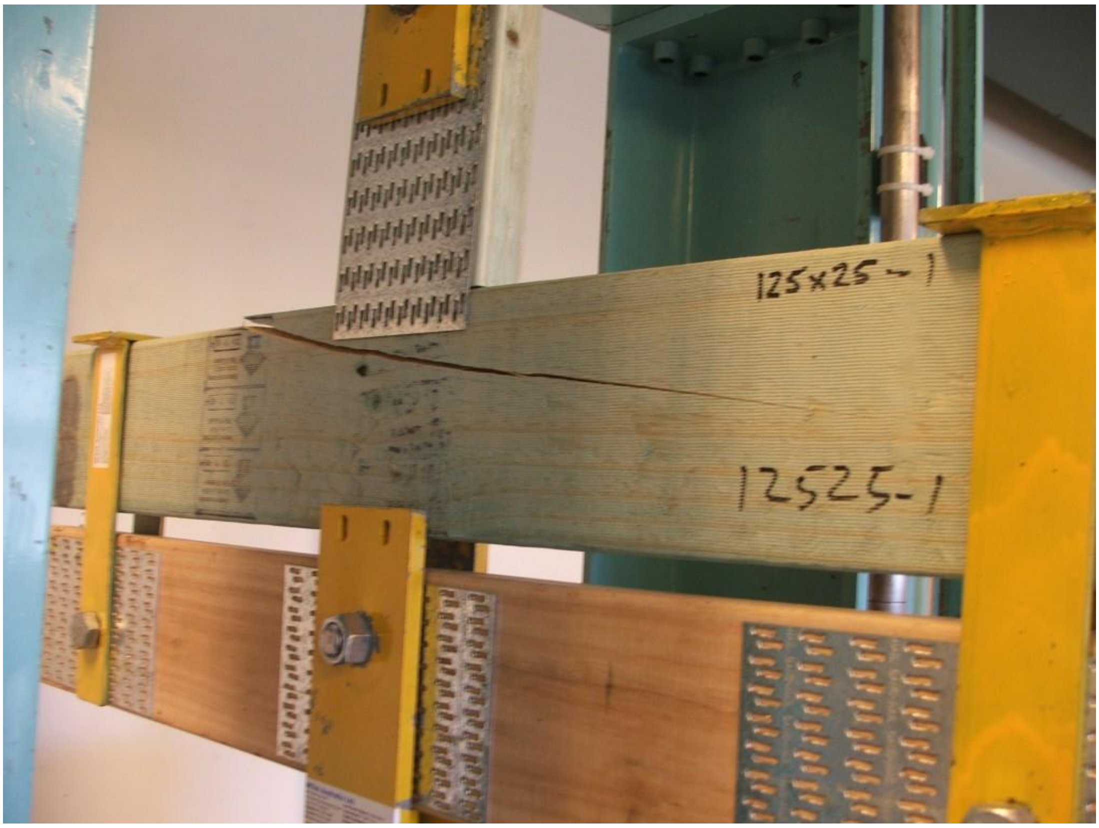


Figure 4.3 - Sloping failure along grain. End fibres remain intact

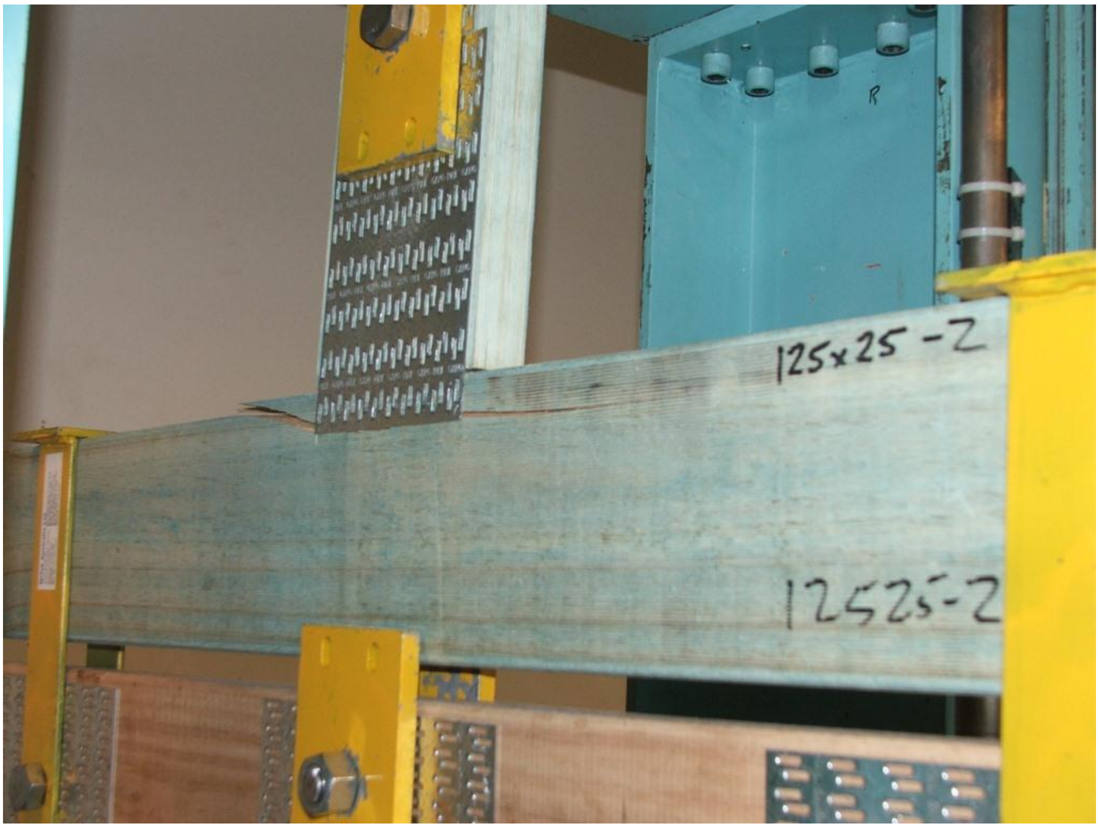


Figure 4.4 - Small fracture length along grain

When testing the 25 mm bite depths, the initial concern that plate withdrawal may occur was eliminated. No withdrawal occurred on any of the four samples. The failures were not as significant as the larger bites. Generally they only fractured a few hundred millimetres either side of the vertical non-test member. Depth of failure varied from test 1 which failed well below the plate along the timber grain, to failing at the bottom edge of the teeth similar to the larger bite depths.

Sample ID1 (Figure 4.5) only produced a minor failure with fibre separation for 100 mm either side of the vertical member. The timber also failed laterally which gave the effect of plate withdrawal, however closer observation saw that the teeth were still fully embedded into the timber and it was the timber itself pushing outwards (Figure 4.6).

Figure 4.5 - ID1 with failure 100 mm either side of plate

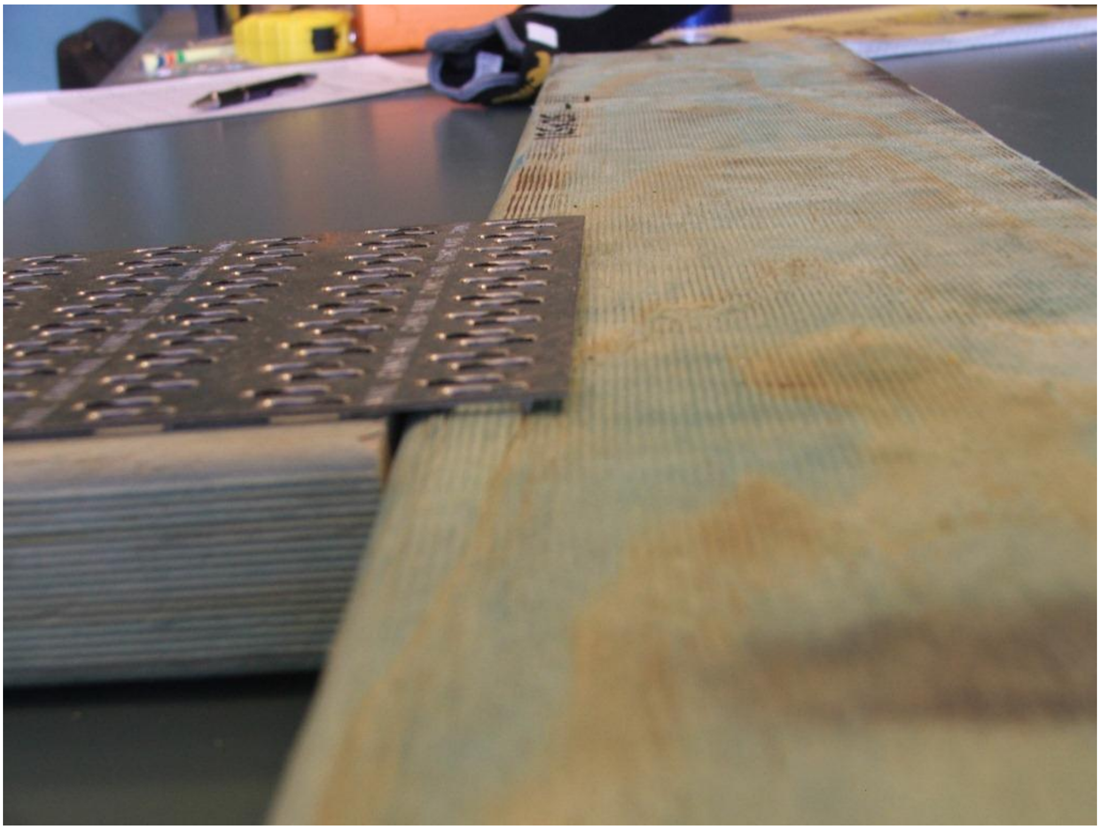


Figure 4.6 - Timber fibres failure laterally with appearing like plate withdrawal

4.3.2 75 mm Width Range

Using the second plate width of 75 mm again all depths did produce a tension perpendicular failure. Similarly to the wider 125 mm plate, the larger the depth, the greater the effect of the failure.

With a bite of 65 mm, major failures were produced in all four samples. All failed along the bottom row of teeth and followed the grain of the timber (Figure 4.7), including around timber knots that were outside the test region (Figure 4.8).

Figure 4.7 - Fracture follows grain in cross section

Figure 4.8 - Fractures following grain around knots and other defects

The 45 mm bite produced a range of results and even different results on either side of the member. ID17 on the front produced a tension perpendicular failure along the bottom and top of the bottom row of teeth (Figure 4.9), while the other side had a major fracture through the bottom edge of teeth only. Again the failure followed the grain around a knot until the top broke. The other end appeared to have stopped at the over-strap locations. ID19 and 20 also had failure through the bottom row of teeth and stopped due to the over-straps (Figure 4.10, 4.11). ID22 was the only member to have a major failure with full fracture (Figure 4.12).

Figure 4.9 - Two noticeable fracture lines on front

Figure 4.10 – Tension perpendicular failure restricted by support from over straps

Figure 4.11 - Possible fracture restricted by over straps

Figure 4.12 - Full fracture following grain around defects

Testing of the 25 mm bite resulted in only minor tension perpendicular failures within the vicinity of the plate. All failures did occur through the bottom row of teeth with some additional failures through the fibres closer to the timber edge. While plate withdrawal again was expected, none did actually occur. Similar to the 125x25 mm bite, there was some lateral movement of the timber, however the teeth were still firmly embedded in the timber.

Figure 4.13 - Lateral movement of timber fibres. Minor plate bending

Figure 4.14 - Minor fracture along bottom row of teeth both top and bottom

4.3.3 Rotated at 45 degrees Range

Testing of the plates rotated at 45 degrees to the test sample produced some varying results. While the largest depth of 70 mm produced similar failures to the square plates, the smaller bite depths were greatly reduced.

With a bite of 70 mm, small cracks began to appear at forces between 8 and 10 kN (Figure 4.15). This didn’t have a significant reduction in the rate the force was applied. The final failure also varied from a major failure, with fracture within the bottom 15mm of the plate that followed the grain of the timber, to several failure lines at varying depths within the plate area (Figure 4.16). It was also noted that ID33 developed cracking within the bottom quarter of the member (i.e. within the area of the sample that would have been under compression) (Figure 4.17).

Figure 4.15 - Small crack appeared as dark lines at 8 - 10 kN

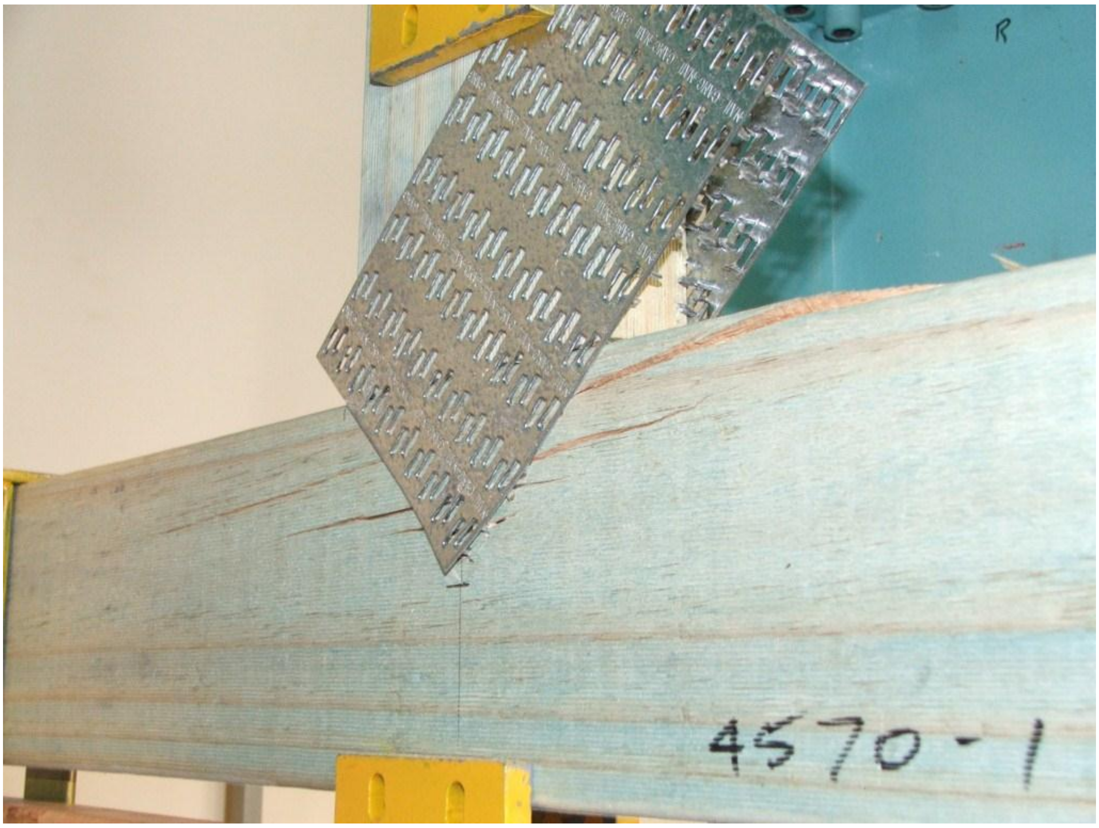


Figure 4.16 - Final failure at varying depths

Figure 4.17 - Cracks appeared in area that was under compressive forces - bottom 1/4 of member

A major issue began to occur with the lower bite depths from 50 mm. The first sample (ID 31) was tested without issue, with small cracks appearing at 8 kN for a failure at 8.7 kN. Some minor plate withdrawal occurred as the load was continued to be applied after the initial failure. The second sample (ID 32) began to have plate withdrawal at approximately 8 kN however, as the test continued, a tension perpendicular failure still occurred (Figures 4.18 and 4.19).

Figure 4.18 - Tension perpendicular failure even after plate withdrawal

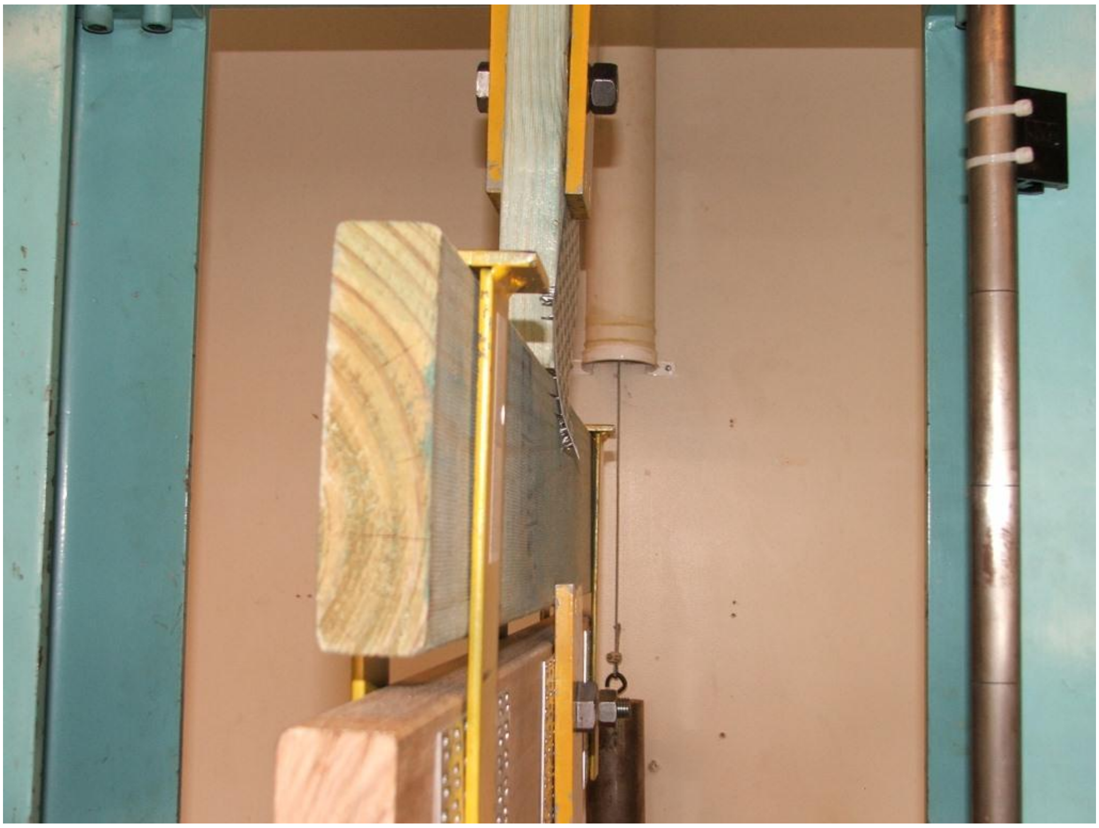


Figure 4.19 - Occurrence of substantial plate withdrawal

The final two samples were tested with 12mm ply clamped to the non-test member to limit plate withdrawal occurring, as recommended by Robert Tan, Technical Services Manager from MiTek Australia. However the force at which the plate withdrawal was occurring was greater than that which the clamp and ply could apply, so plate withdrawal still occurred. A tension perpendicular failure was still achieved in both cases (Figure 4.20).

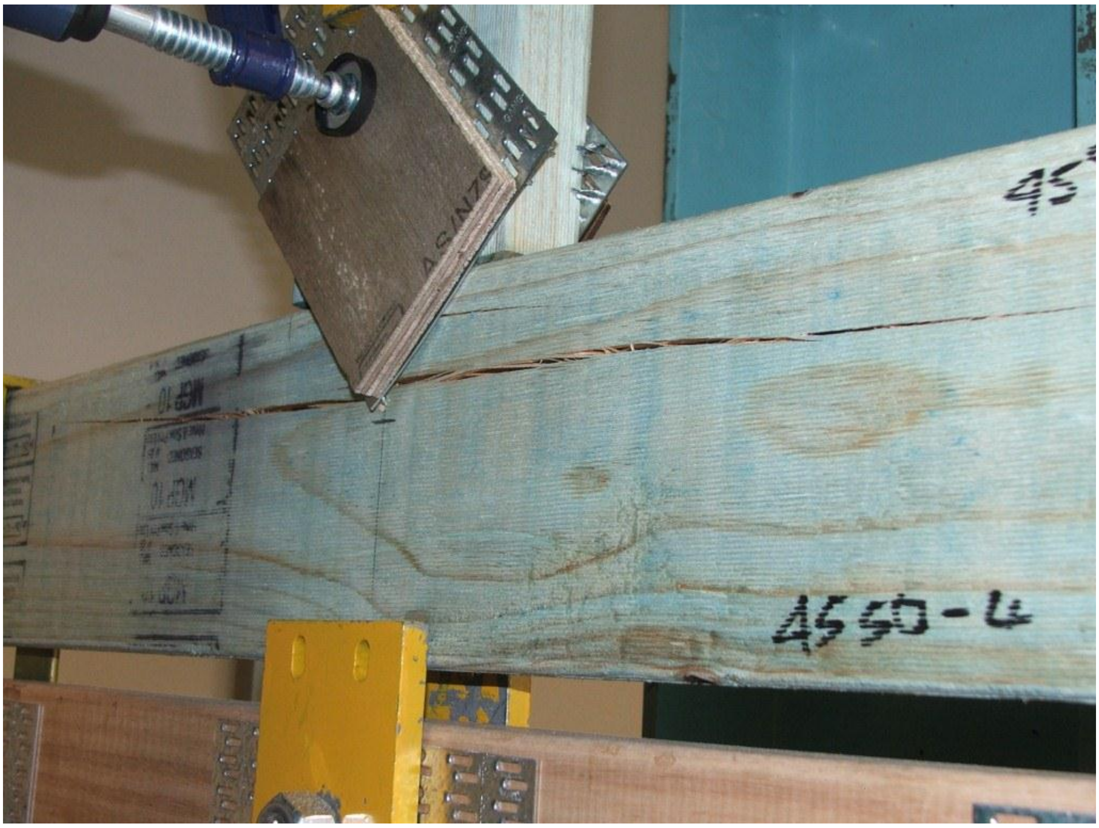


Figure 4.20 - Even with ply, plate withdrawal still occurred

The first test of the 30 mm bite was conducted without the ply, however based on the previous tests, plate withdrawal was expected and occurred at approximately 2.5 kN with a failure at 2.9 kN. Ply was used for the remaining three tests, however, plate withdrawal could not be restricted. In each case, withdrawal occurred at approximately 3 kN with evidence of tension perpendicular failures occurring within the bottom area of the bite.

Figure 4.21 - Unable to restrict withdrawal

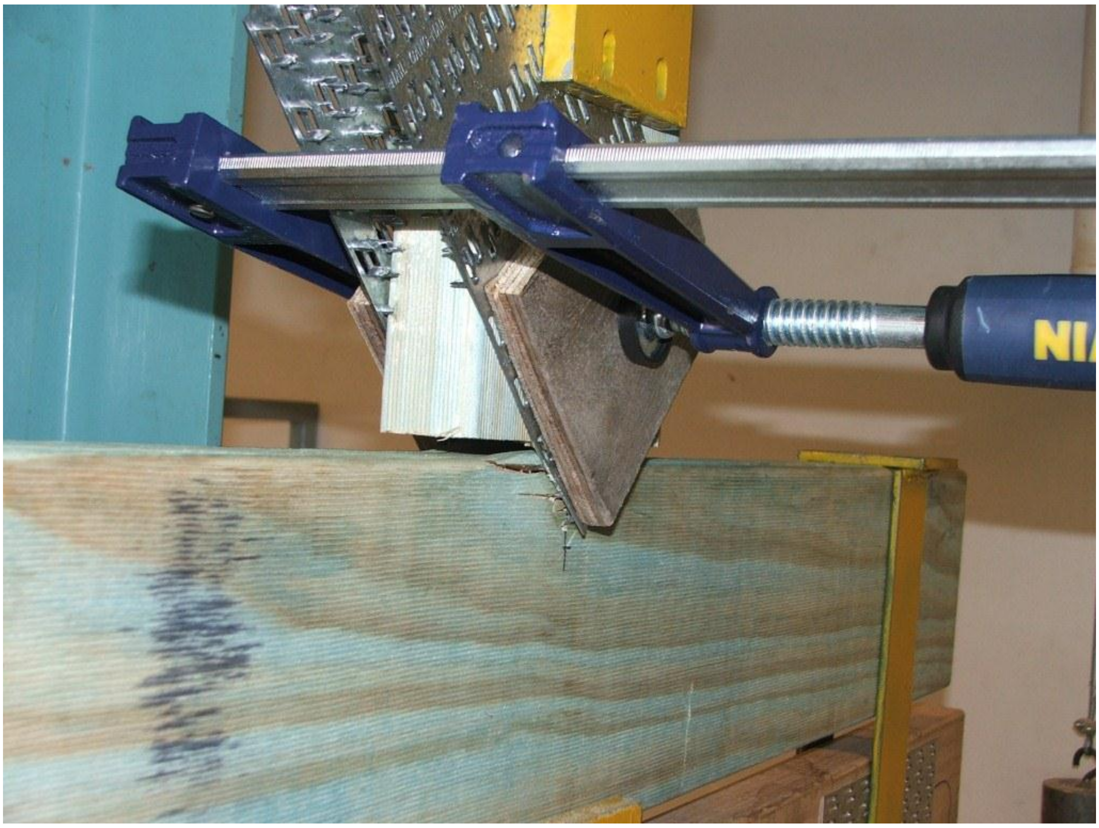


Figure 4.22 - Continued force after withdrawal and achieved failure, but not reliable values.

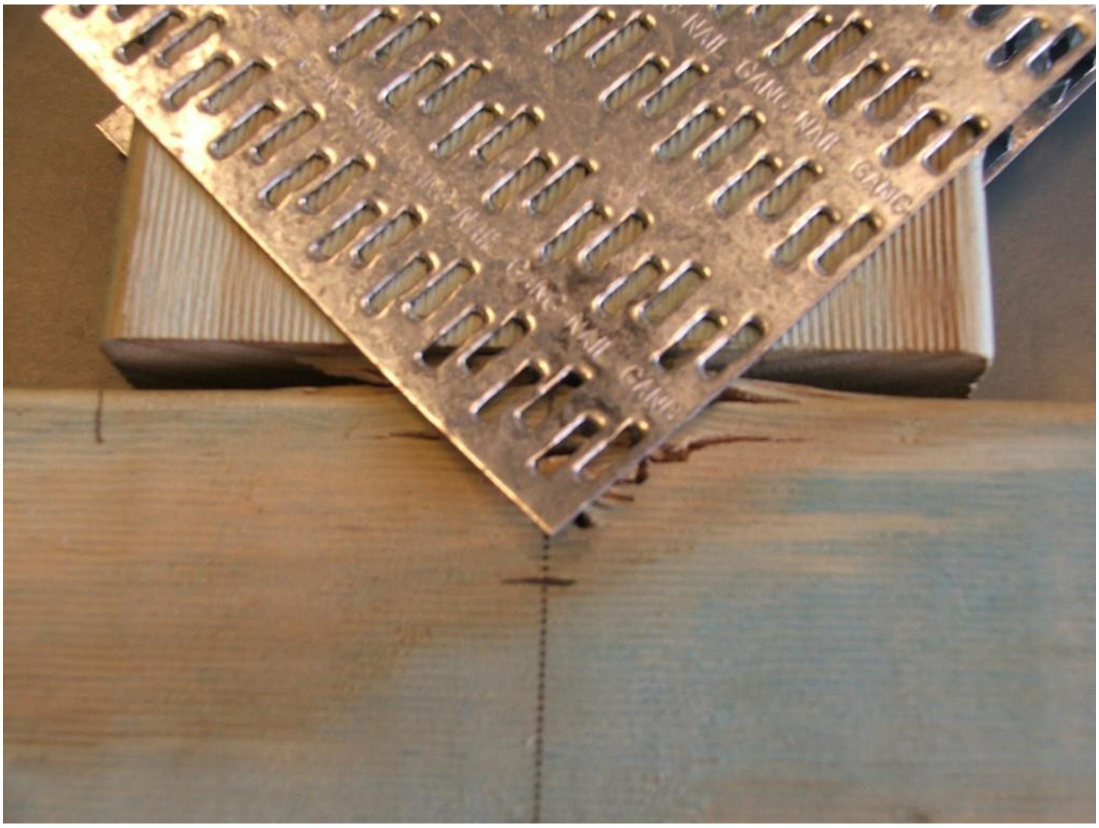


Figure 4.23 - Minor failure after withdrawal

4.3.4 Conclusion of Observation

In all cases, tension perpendicular failures were achieved during the testing, however the results of the 45 degree rotated plates at 30 mm may not be reliable due to the occurrence of plate withdrawal, even with ply restraints. It was also noted that no tension parallel failures occurred in any of the non-test members and there was no physical appearance of any metal failure of the plate, so all failures can be attributed to a tension perpendicular failure.

It is also noted that there was some minor deflection in both the bending beam and the test member, however, it is concluded that these were only minor deflections and would not have had a great bearing on the final results (Figure 4.24).

Figure 4.24- Noticeable deflection of both bending beam and sample

Chapter 5 Discussion

5.1 Introduction

In order to verify the current MiTek method or propose a new calculation, the results of the testing require analysis to find a common trend that occurs between the different sample setups. By comparing the current MiTek method where there was only a small variation in force when changing bite depths, the average results of the testing showed a higher variation could be expected. The variation is the estimated v average actual from the testing as shown in Table 5.1.

Table 5.1 - Estimated v Average Actual UFL

Bite Width	Bite Depth	Estimated Ultimate Failure Load (kN)	Average Actual Ultimate Failure Load (kN)
125	25	12.23	9.815
125	45	12.82	17.794
125	65	13.65	22.290
75	25	9.34	6.587
75	45	10.37	13.936
75	65	11.47	19.480
60	30	5.01	3.987
100	50	6.80	9.956
140	70	8.33	15.676

The average actual will be analysed based on a range of available variation in design factors to see if there is any correlation between:

- Bite depth
- Bite width
- Plate angle
- Bite area
- Timber properties
- Number of gang-nail teeth

The relationship of the ultimate failure force and the bite depth has been plotted in Figure 5.1. Apart from a larger scatter for the plates rotated at 45 degrees, other test results appear to be relatively consistent.

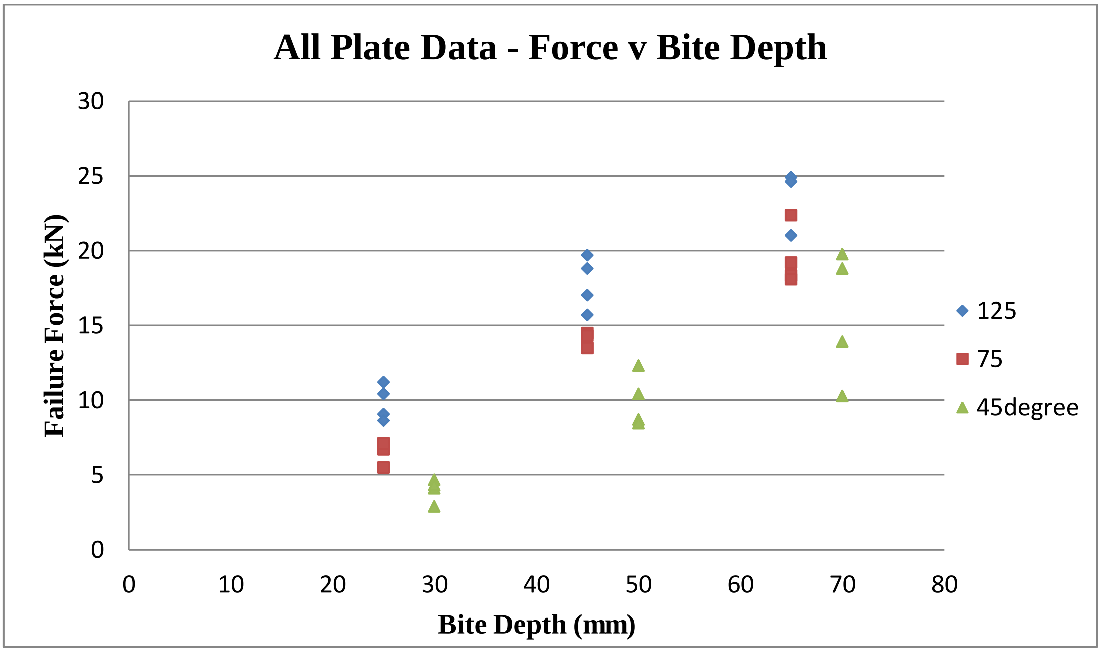


Figure 5.1 – Relationship of failure load and bite depth for all tests

5.2 Effect of Bite Depth on Strength and Failure Mechanism

From observations and results of the testing, it appears that the depth of bite has a large effect on the behaviour of the joint. As the bite depth is increased, the load that the timber can withstand prior to a tension perpendicular failure also increases.

The failure of the timber at the greater bite depths also occurred with greater force. The audio sound of the failure was a much louder “break” at the 65 mm bite than that of the 25 mm bites. The timber also generally fractured the full length of the test sample at the greater depths.

In order to evaluate the force per mm of bite depth, the values per mm needed to be calculated. This has been done in Table 5.2, based on the average force for each bite depth.

Table 5.2 - Strength per mm bite depth

Bite Width	Bite Depth	Force	Strength/mm bite depth	Strength/mm bite depth / mm bite width
75	25	6.59	0.263	0.00157
75	45	13.93	0.310	0.00158
75	65	19.48	0.300	0.00137
125	25	9.815	0.196	0.00176
125	45	17.79	0.198	0.00206
125	65	22.29	0.191	0.00200
60	30	3.98	0.132	0.00221
100	50	9.95	0.199	0.00199
140	70	15.67	0.224	0.00160

By taking the average across the two different plate widths, and finding the standard deviation, it was found that the covariance of the force per mm was 8.4% and 7.8% respectively for the 75 mm and 125 mm plates when perpendicular to the test sample. This ratio is considered to be an acceptable percentage range for test results (A. Manalo, 2012).

However, when rotated at 45 degrees, the covariance is as high as 25%. Although due to some unreliable results in tension perpendicular at the 30 mm bite due to plate withdrawal occurring, the covariance based on the 50 mm and 70 mm bite depths is again 8.4%, which is acceptable.

5.3 Effect of Bite Width on Strength and Failure Mechanism

From observations and results, the bite width also appears to have a large effect on the behaviour of the joint. The 125 mm wide plates exhibited a higher failure load than the 75 mm plates for the same bite depth.

At the larger bite depths, the differing plate width did not appear to display a great difference in failure mechanism. However, at the smaller bite depths of 25 mm, the fracture of the 75 mm bite width was more localised to the joint, whereas the 125 mm width still fractured to the hold down straps.

Again referring to Table 5.2, the covariance of the bite depth and width ratio was also 8.4% and 7.8% respectively.

As the bite width was reduced further utilising the 125 mm plated rotated at 45 degrees, again it was observed that the strength was reducing. As the bite width reduces by twice the bite depth due to the 45 degree orientation, the actual bite width and depth to use for analysis will require further investigation which is outside the scope of this project. One option was to assume that the length through the centroid of the triangular bite area. This will reduce the bite widths to 40, 67 and 93 mm for depths of 30, 50 and 70 mm.

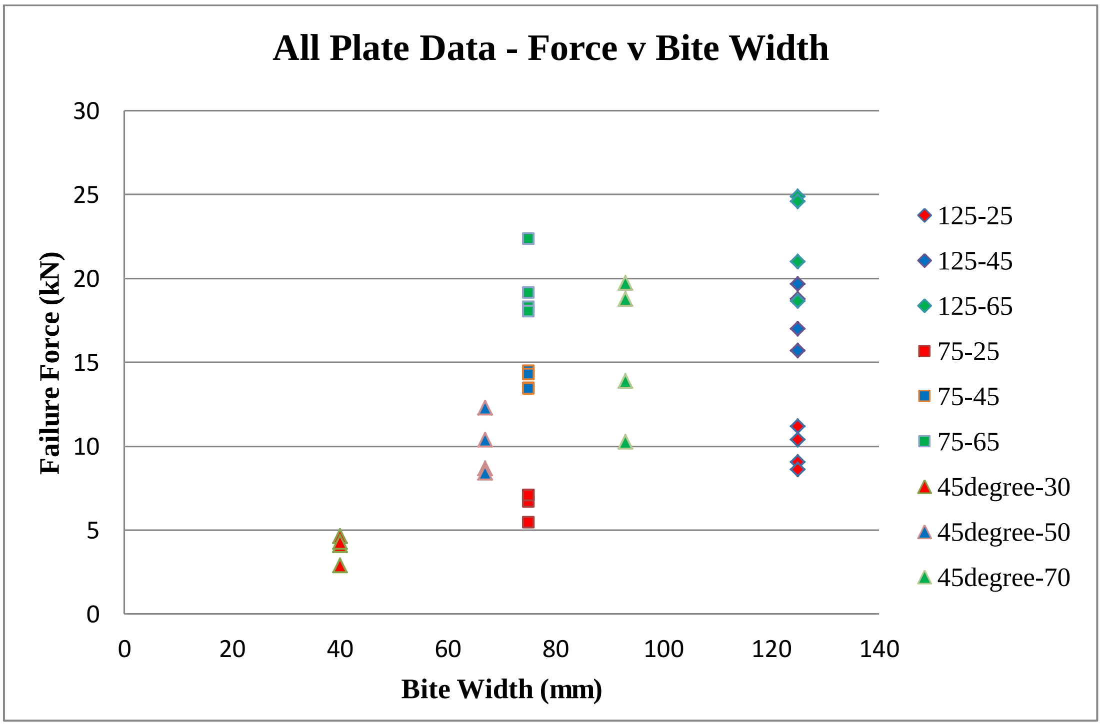


Figure 5.2 - Relationship of Force to bite width

5.4 Effect of Bite Area on Strength and Failure Mechanism

During analysis, the bite area also exhibited an effect on the behaviour of the joint. This became evident when comparing several of the different combinations in Table 5.3 where the area of bite is similar. For example, a 75 mm wide plate with 65 mm bites has a similar area to the 45 degree plate at 70 mm, however the average load differs by approximately 4 kN. Similarly, when comparing the 125 mm plate with 25 mm bite to the 75 mm plate with 45 mm bite, they also vary by approximately 4 kN.

Table 5.3 - Bite area and loads

Bite Width	Bite Depth	Bite Area	Average Actual Ultimate Failure Load (kN)
125	25	3125	9.815
125	45	5625	17.794
125	65	8125	22.290
75	25	1875	6.587
75	45	3375	13.936
75	65	4875	19.480
60	30	900	3.987
100	50	2500	9.956
140	70	4900	15.676

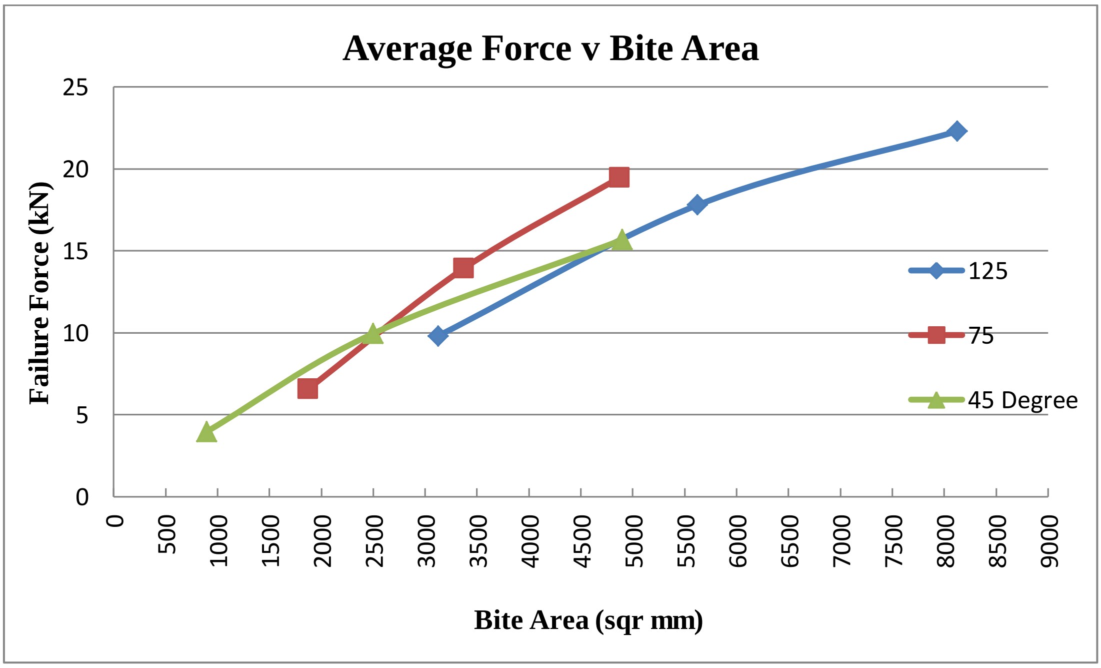


Figure 5.3 - Average force v Bite Area

From these results, bite area alone cannot be considered to be an accurate method for determining the failure load, as similar areas vary greatly as a function of the bite depth.

5.5 Effect of Plate Angle on Strength and Failure Mechanism

The 45 degree plate angle appears to have an effect on the strength, however it could also be related to the bite depth: width ratio. As the bite depth reduces, so too does the bite width. For example, when the bite depth is 30 mm, the width is only 60 mm at the timber edge, reducing in width by twice the distance away from the timber edge until an effective width of zero at the maximum depth.

By having the plate at 45 degrees as per the test samples, the area of bite is one half when compared to a perpendicular plate at the same width and depth.

5.6 Effect of Timber Properties on Strength and Failure Mechanism

Due to time restraints in performing the testing, only one species and density have been used for the tests. However, based on previous testing for tension perpendicular for other fastening methods as shown in AS1720.1, the properties of the material could be expected to have an effect on the results.

The higher the density, the greater the grip by the plate into the timber will be. This density will assist the fibres of the timber to hold together withstanding a higher tension perpendicular force.

The higher density may also assist in testing the smaller bite depths in future tests by helping to minimise the effect of plate withdrawal that occurred in some of the testing.

The characteristic value for various materials in AS1720.1 – 2010 are as follows in Table 5.4. As only MGP material has been tested, I cannot say if the other species/grade will perform in a similar manor. It could be reasonably expected that material with a similar strength group (SD value) will perform in a similar manor, however, further testing will be required. Other engineered wood product materials (e.g. LVL) may also have differing values based on the manufacturer's specifications.

Table 5.4 - Tension Perpendicular Characteristic Values

Material	Tension Perpendicular Characteristic Value (MPa)
MGP Radiata Pine (As per sample material) SD5/SD6	0.5
A17 Hardwood	0.6
Seasoned F-Grade Material SD1 / SD2	0.8
Seasoned F-Grade Material SD3 / SD4	0.6
Seasoned F-Grade Material SD5 / SD6	0.5
Seasoned F-Grade Material SD7 / SD8	0.4

5.7 Effect of Tooth Quantity on Strength and Failure Mechanism

It was considered that each tooth could transfer a similar force per tooth. To prove this, the number of teeth that existed in the test sample member for each bite depth was counted and the force per tooth calculated. The results are in Table 5.5.

Table 5.5 - Force per tooth

Bite Width	Bite Depth	No. of Teeth	UFL	Force per tooth
75	25	48	6.59	0.137
75	45	84	13.93	0.166
75	65	108	19.48	0.161
125	25	80	9.82	0.122
125	45	140	17.79	0.127
125	65	200	22.29	0.112
60	30	18	3.99	0.221
100	50	54	9.96	0.184
140	70	116	15.68	0.135

A covariance of 6.7% was found for the 125mm wide plate, but a value of 13.6% was found for the 75 mm plate. While this was considered to be satisfactory, it was on the limit of being outside the acceptable range.

However, it would be expected to see a common value between the different bite depths. The average difference is around 24% which is considered to be too high of a variation in results. Therefore, calculating based on the number of teeth would not be an accurate way of determining the tension perpendicular value.

5.8 Conclusion

Through the analysis of the results, there does appear to be a correlation between the bite depth, width and angle which may have an effect on the behaviour of a gang-nail plated timber joint. These parameters will be used in Section 6 in order to propose a new calculation method.

Chapter 6 Proposed Design Calculation

6.1 Introduction

While the depth, width and area appear to be the main factors to be considered in the proposal of a new calculation method, the properties of the timber should also be included. Therefore the new calculation will be based on:

- Bite depth
- Bite width
- Bite angle

Once a correlation equation can be achieved for the ultimate failure force, then a proposed new calculation for the design force should be constructed using:

- Any applicable capacity factors in accordance with AS1720
- Any applicable k values in accordance with AS1720

6.2 New method to achieve Ultimate Failure Force

To propose a new calculation method, AS1649-2001 cl 3.2.5.1 *Basic lateral loads for Category C fasteners—Failure in timber* will need to be followed. This clause states that:

> *Basic lateral loads for Category C fasteners, where failure in timber, shall be derived as follows:*
>
> *(a) From the tests conducted on specimens of Parallel Type for one orientation of plate at each of the three moisture conditions, the average maximum load on the assembly, the corresponding percentage standard deviation of individual values and 5th percentile lower probability limit (LPL) shall be computed in accordance with Appendix B.*
>
> *(d) Basic lateral loads shall be derived from the tests on Perpendicular Type specimens as indicated for those of Parallel Type*

Therefore the average maximum load for each test and the 5th percentile lower probability will be used to compute and new equation.

Initially only the square plate values were investigated. To find the relationship of the bite depth and width, the force per mm bite depth (kN/mm) was calculated with this plotted against the bite width as shown in Figure 6.1. To this, a linear trend line was applied and the resulting equation was used as a check for fit against the average failure force from the test results.

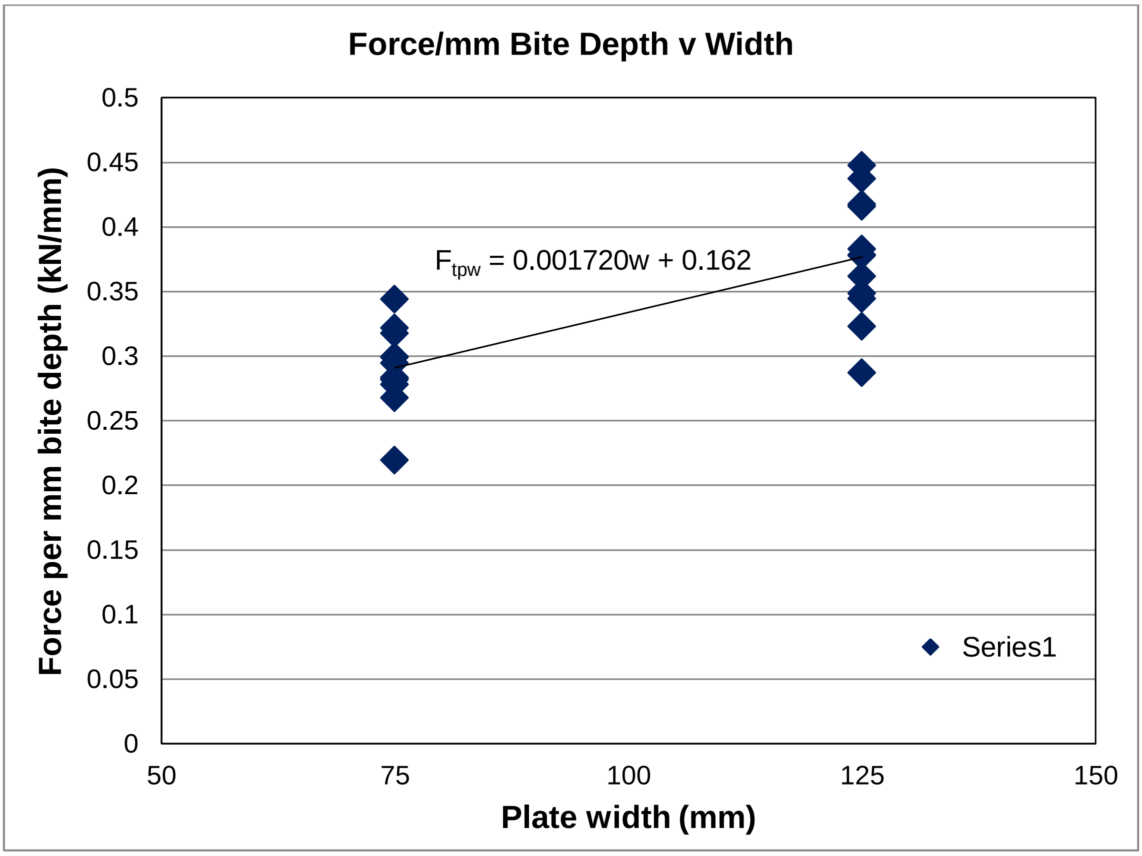


Figure 6.1 - Force/mm bite depth v width plot

The resulting equation for the force per mm bite depth is:

$$F_{tpw} = 0.00172w + 0.162 \tag{6.1}$$

Where:

w = bite width

By multiplying Eq 6.1 by the tested bite depths to give Eq 6.2, the results comparing the proposed and actual are shown in Table 6.2:

$$UF_{ave} = F_{tpw} \times t_p \tag{6.2}$$

Table 6.1 - Proposed ultimate failure force

Bite Width	Bite Depth	Actual Failure Force	Proposed Failure Force (UF_{ave})	Variation between Actual and Proposed
125	25	9.82	9.42	3.99%
125	45	17.79	16.96	4.68%
125	65	22.29	24.50	-9.92%
75	25	6.59	7.27	-10.41%
75	45	13.94	13.09	6.06%
75	65	19.48	18.91	2.92%

If the values for the 45° orientated plates are now added to the plots, the equations vary slightly. The difficulty with this is to find out what the bite depth and limits of a plate not orientated square with the member subject to the tension perpendicular force might be.

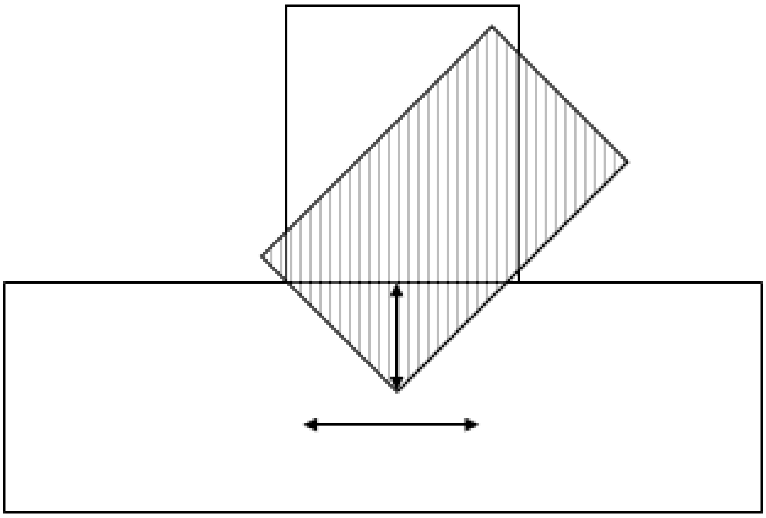


Figure 6.2 - What is the bite depth and width for the rotated plates?

Initially the centroid was trialled as the location where the depth and width of the bite could be measured, however, the results appeared to be lower than the test result, which means that the bite depth needed to be further onto the test member.

Further investigations were completed and if we were to assume that the bite depth and width occurred at 2/3 of the actual bite depth, the results appeared to be more consistent. By plotting the force per mm bite depth against the width, then the resulting equation from Figure 6.3 would be:

$$F_{tpw} = 0.00187w + 0.149 \tag{6.3}$$

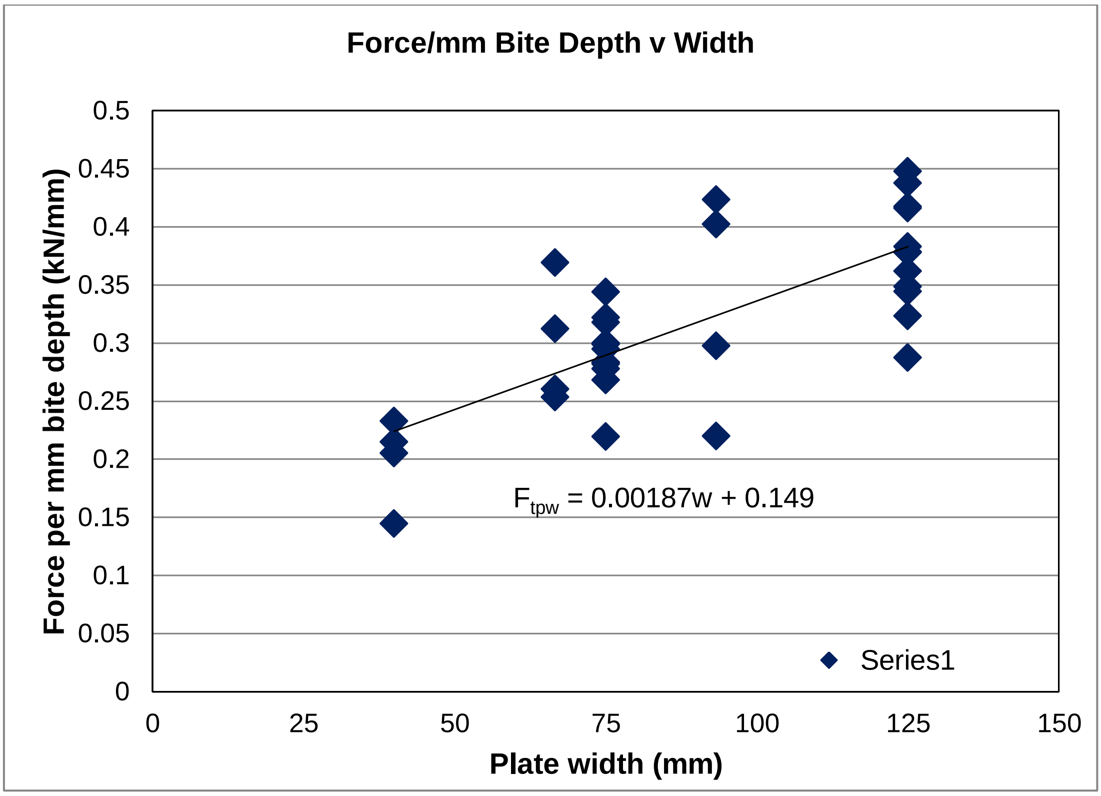


Figure 6.3 - Force/mm bite depth v width including 45 degree orientation plates

By then applying equation 6.3, the results in Table 6.3 show that the results have become more accurate for the smaller bite values, but less conservative for the large bite depths. This could be attributed to the relatively small sample size tested and/or the fact that timber is a natural product with variations in properties, The large variation of -12.35% for the 30mm bite depth of the rotated plate could be attributed to the fact that a tension perpendicular failure was not accurately recorded due to the occurrence of plate withdrawal.

Table 6.2 - Actual v Proposed failure force including 45 degree plates

Bite Width	Bite Depth	Actual Failure Force	Proposed Failure Force (UF_{ave})	Variation between Actual and Proposed
125	25	9.82	9.57	2.47%
125	45	17.79	17.23	3.17%
125	65	22.29	24.89	-11.65%
75	25	6.59	7.23	-9.83%
75	45	13.94	13.02	6.56%
75	65	19.48	18.81	3.44%
60	30	3.98	4.48	-12.35%
100	50	9.96	9.13	8.37%
140	70	15.68	15.11	3.64%

It is proposed to adopt equation 6.3 for the calculation of the ultimate failure force and to conduct further analysis of the 45° orientated plates to determine the bite depth and width that govern tension perpendicular.

However, these equations can only be used with Radiata Pine of stress grade MGP10 as used in the testing. Further testing will need to be conducted on other species and grades to determine if these equations are still a fit, or if further modifications to the proposed methods are required.

Appendix F.1 contains the calculation data for the ultimate failure load.

6.3 New method to achieve Design Failure Force

In order to calculate the design failure force, we must first find the characteristic values for the test members. Equation 6.3, in accordance with AS1649-2001 Appendix B, is required to be reduced to account for the 5th percentile lower probability limit.

This value has been determined to be 0.76 (refer to Appendix F.2 for full calculation details). To determine the characteristic ultimate force, equation 6.2 is then multiplied by the 5th percentile vale resulting in:

$$F_c = UF_{ave} \times 0.76 \tag{6.4}$$

From the characteristic force value, other factors will need to be applied to determine the design failure force. These include a capacity factor and the duration of load (k_1) in accordance with AS1720.1-2010. The characteristic force will be multiplied by these values in order to produce the design capacity for each of the joints.

From AS1720.1 cl 2.3, the capacity factor is used to calculate the design capacity. For a timber joint with mechanical fasteners, Table 2.1 is used. For a category 1 structural member, a capacity factor of 0.9 should be used.

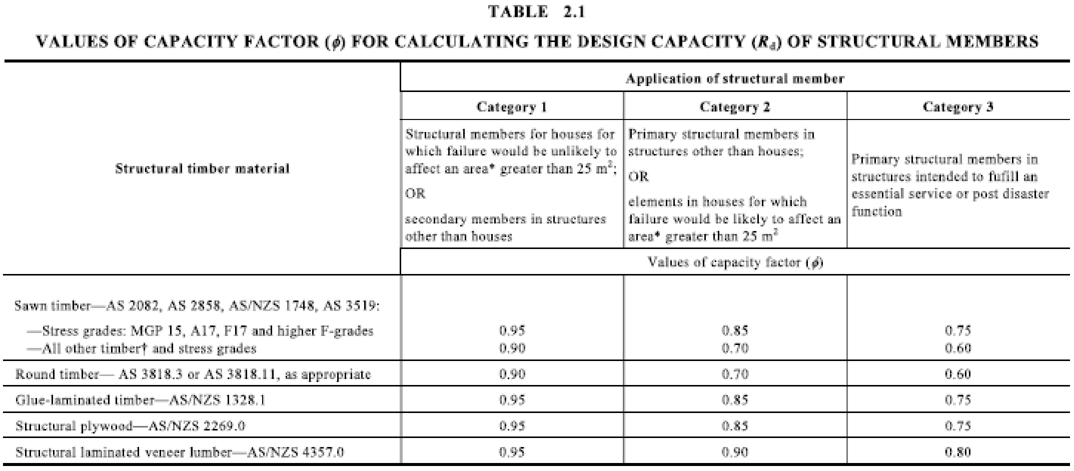


TABLE 2.1

VALUES OF CAPACITY FACTOR (ϕ) FOR CALCULATING THE DESIGN CAPACITY (R_d) OF STRUCTURAL MEMBERS

Structural timber material	**Application of structural member**		
	Category 1	**Category 2**	**Category 3**
	Structural members for houses for which failure would be unlikely to affect an area* greater than 25 m^2; OR secondary members in structures other than houses	Primary structural members in structures other than houses; OR elements in houses for which failure would be likely to affect an area* greater than 25 m^2	Primary structural members in structures intended to fufill an essential service or post disaster function
	Values of capacity factor (ϕ)		
Sawn timber—AS 2082, AS 2858, AS/NZS 1748, AS 3519:			
—Stress grades: MGP 15, A17, F17 and higher F-grades	0.95	0.85	0.75
—All other timber† and stress grades	0.90	0.70	0.60
Round timber— AS 3818.3 or AS 3818.11, as appropriate	0.90	0.70	0.60
Glue-laminated timber—AS/NZS 1328.1	0.95	0.85	0.75
Structural plywood—AS/NZS 2269.0	0.95	0.85	0.75
Structural laminated veneer lumber—AS/NZS 4357.0	0.95	0.90	0.80

Therefore, the proposed design failure force equations will be:

$$F_D = F_c \times k_1 \times \emptyset$$

(6.5)

The results from equation 6.5 as shown in Table 6.4 will provide a more accurate design force when used with Radiata pine of stress grade MGP10. The value of k_1 is from cl 2.4.1 and Table 2.3. From this section the value to be adopted is 0.57 for a duration of load of 50+ years.

Table 6.3 - Proposed Design Failure Force

Bite Width	Bite Depth	Actual Failure Force (kN)	Proposed Design Failure Force F_D (kN)
125	25	9.82	3.73
125	45	17.79	6.72
125	65	22.29	9.70
75	25	6.59	2.82
75	45	13.94	5.08
75	65	19.48	7.33
60	30	3.98	1.75
100	50	9.96	3.56
140	70	15.68	5.89

6.4 Comparison to existing TPIC method

To check for a fit to the international standards, equations 2.1 and 2.2 set out by the TPIC was used to compare results against the test data. The equation for both Spruce Pine and Douglas-Fir were rearranged to find the maximum force. By rearranging these equations to find the force, P, the results are as follows:

Table 6.4- Comparison of Spruce and Douglas-Fir to Actual

Bite Width	Bite Depth	Failure Force Spruce (kN)	Failure Force Douglas-Fir (kN)	Actual Failure Force (kN)
N/A	25	3.525	3.875	2.82 – 3.73
N/A	45	4.345	4.975	5.08 – 6.72
N/A	65	5.165	6.075	7.33 – 9.70

From Table H2.4 of AS1720.1-2010, the strength group of Douglas Fir from North America is SD5, Spruce Pine is SD7 and Radiata Pine from Australia is SD6. Based on the strength group, it could be expected that the proposed equation would provide values in a similar range to the TPIC.

However, the TPIC method does not take into account the bite width and from the testing, it appears that the width does have an effect on the tension perpendicular capacities. Therefore for the Australian conditions, this method can be discounted.

6.4 Conclusion

This proposed new method appears to be a good fit for the material tested. It will also provide a more accurate design method for use in design software, providing a better analysis of the joint in tension perpendicular. A comparison between the current and proposed prediction methods is shown below in Table 6.5. The values at the smaller bite depths are relatively close whereas the larger bite depths show a larger variation between the two methods. This trend fit the testing where the greater the bite width and depth, the greater the force before failure.

Table 6.5 - Comparison of Current method to proposed new method

Plate Size	Bite Width	Bite Depth	Current MiTek Method Design Force (kN)	Proposed New Method Design Force (kN)
125200	125	25	3.30	3.73
125200	125	45	3.46	6.72
125200	125	65	3.68	9.70
75200	75	25	2.52	2.82
75200	75	45	2.80	5.08
75200	75	65	3.09	7.33
125200R	60	30	1.35	1.75
125200R	100	50	1.84	3.56
125200R	140	70	2.25	5.89

Chapter 7 Conclusion and Recommendations

7.1 Summary

A tension perpendicular to the grain failure can cause catastrophic results and has been called the *“evil of all wood connections”* by the American Wood Association. A failure of a joint in a prefabricated roof truss could have a catastrophic consequence. Therefore it is necessary to accurately design Gang-Nail plated timber joints to account for this.

Through a series of destructive testing and an analysis of the results, the effects of plate width and bite depth on the strength and failure mechanisms were investigated. It was found that the failure load increased as both the bite depth and width increased. Failures in tension perpendicular occurred at or just below the bottom row of teeth in the gang-nail plate and tended to follow the grain of the timber.

A new method for the calculation of the tensile force perpendicular to the grain has been found for use with Radiata Pine of stress grade MGP10, that can accurately predict the ultimate failure force and hence a design force equation using AS1720.1-2010. For the ultimate failure force the equation:

$$F_u = (0.00187w + 0.149134) \times t_p \tag{7.1}$$

has been proposed, where w is the bite width and a t_p is the bite depth.

For the design force, the above equation has been multiplied by the duration of load factor k_1 of 0.57 for 50+ years and a capacity factor for MGP graded pine of 0.9. This results in the equation:

$$F_D = (0.00187w + 0.149) \times t_p \times 0.76 \times k_1 \times \emptyset \tag{7.2}$$

This equation does provide a more accurate solution for the calculation of the predicted tensile failure force perpendicular to the grain than the current MiTek method, when used with Radiata Pine of stress grade MGP10 as shown in Table 7.1.

Table 7.1 - Comparison of Current method to proposed new method

Plate Size	Bite Width	Bite Depth	Current MiTek Method Design Force (kN)	Proposed New Method Design Force (kN)
125200	125	25	3.30	3.73
125200	125	45	3.46	6.72
125200	125	65	3.68	9.70
75200	75	25	2.52	2.82
75200	75	45	2.80	5.08
75200	75	65	3.09	7.33
125200R	60	30	1.35	1.75
125200R	100	50	1.84	3.56
125200R	140	70	2.25	5.89

Due to the testing only being conducted using two plate widths of 75 and 125 mm, it is possible that the results outside of this range may also change at a greater rate. Plates are generally available from 40 mm up to 400 mm wide, so a bite width of 400 mm could produce results in a parabolic nature rather than linear as found in this study.

This research has been conducted to observe the behaviour of a gang-nail plated timber joint in tension perpendicular to the grain and to compare these results with current design methods. From these results and the proposed equations for use with MGP10 Radiata Pine, the current method is more conservative as the bite depth increases. A range of recommendations will be discussed in Section 7.4 for this project to proceed further and result in its inclusion in a future Australian Standard.

7.2 Achievement of Project Objectives

This section will detail the objectives of this research and what the outcomes of these objectives were.

1. *Conduct a literature review on references on tension perpendicular design methods and the history of nail plated joints*

Roof trusses can be dated in principal back to the Roman era with the way arch bridges were constructed. Today's designs are the results of the invention of nail plates in 1955. The issue in regards to tension perpendicular is that the forces that act through the truss members are transferred through the nail plate at the joint of two or more members. At some of these joints a tension perpendicular to the grain force may occur, which will act to tear the timber fibres apart causing the timber to fail. Truss design software needs to be able to account for this when designing a joint and locate the plate accordingly. This has been discussed further throughout Chapter 1 and 2.

2. *Study Appendix A of 4063.1 for tension perpendicular test methods*

All testing methods involved had to be in accordance with AS4063.1 and AS1649-2001. Some minor interpretation of the setup for a tension perpendicular joint test was conducted for the span of the sample, as over straps were used and these could have had an inverse effect on the results. This has also been discussed in Chapter 2. However the minimum quantity of tests achieved was less than the allowable of ten.

3. *Conduct material testing program*

All samples were manufactured using timber that was supplied by a commercial saw mill that supplies a large quantity of timber to the roof truss industry. The timber supplied was Radiata Pine – 140x35 MPG10 JD5. From the lengths supplied, clear sections were selected, cut and the densities calculated. All were within the limits.

Samples were produced using two different gang nail plate widths, utilising three bite depths and a series of 45° plate orientation. These samples were then placed into an Avery Tension Testing machine, the cross arm moved and the ultimate failure force and mechanism was recorded. Testing methods have been detailed in Chapter 3.

4. *Reference MiTek tension perpendicular design method for investigation and analysis of test data*

The test results were compared to the current MiTek calculation method and it was found that there was sufficient variation in the results that investigations should proceed for a new calculation method. From the data, only the smaller 25 mm bites exhibited a smaller actual failure than predicted. The remainder of the bites were all quite conservative when compared to the actual failures. Investigations can be found though Chapters 4 and 5.

5. *Propose a new calculation method*

A new calculation method based on the plate width per mm of bite depth has been proposed and discussed in Chapter 6. A reduction value of 0.9 was applied to the equation from the plot to account for the variations of the test results. Results show that this prediction equation can conservatively predict the failure load of the strength of gang-nail plated timber joints.

6. *Suggest other/further/future research area*

This research has only just scratched the surface as a preliminary investigation to see if further research is needed. From the results achieved, further testing on a range of materials should be conducted. This will be discussed further in Chapter 7.4.

Time did not permit the investigation of the extra objectives, however, these should be included in any further investigations.

7.3 Conclusion

The testing results when compared to the current MiTek method have proven that this research is warranted when investigating the behaviour of gang-nail plated timber joints in tension perpendicular to the grain. From the testing, the current method used is generally more conservative resulting in the proposal of a preliminary alternative design method. While this looks promising, further testing will be required on all products used in the manufacture of timber roof trusses to verify that similar trends do occur.

7.4 Recommendations

Before any results can be used commercially, and as this project is relatively new in Australia, there is still much testing to be done to verify the results contained in the dissertation. The testing has confirmed that further investigations are necessary to fully propose an alternative calculation method.

Recommendations for further study:

- Testing to fully comply with AS1649 with a minimum quantity of ten for each sample setup.
- Testing using the full range of timber species, grades and EWP that are currently available for use in the timber roof truss industry. As new EWP become available, should they also be tested or their mechanical properties compared to those already tested.
- Test a wider range of bite widths to verify if the trend remain linear or becomes parabolic.
- Test bite depths beyond the centre line of the test member and verify the results as the bite depth approaches the timber depth
- Verification of the current timber properties should be revisited and verified that those listed in AS1720.1 do still accurately represent what is in use in the industry. For tension perpendicular, these will be shear block tests to verify the tension characteristic values.
- Different plate orientations. In reality, a nail plate can be rotated through the full 90° so must check for fit within all angle ranges
- Effect of the force applied at an angle to the grain when the joints are not exactly perpendicular.

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Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: Craig KLINGE

TOPIC: BEHAVIOUR OF GANG-NAIL PLATED TIMBER JOINTS IN TENSION PERPENDICULAR TO THE GRAIN

SUPERVISORS: Dr. Allan Manalo
Robert Tan, Technical Services Manager, MiTek
Australia

SPONSORSHIP: MiTek Australia Ltd

ENROLMENT: ENG4111 – S1 2012 EXT
ENG4112 – S2 2012 EXT

PROJECT AIM: To examine the behaviour of Gang-Nail plated timber joints in tension perpendicular to the grain and to correlate with the prediction equation using the MiTek method (which is based on clause 3.4.2 in AS1720.1)

PROGRAMME: Issue A, 19 March 2012

Conduct a literature search for:
   a. references on tension perpendicular design methods; seeking timber design text books and overseas timber/truss design standards
   b. History of nail plated joints and joint restraint
2. Study Appendix A in AS4063.1 for tension perpendicular test method, and §3.4.2 in AS1720.1 for tension perpendicular calculation method and current characteristic values
3. Conduct material testing programme:
   i. Calculate sample material densities. Use only relatively clear MGP Radiata Pine test samples within the band of densities defined by JD5
   ii. Obtain connector plate test data to establish correlation/accuracy of MiTek design method. The connector plate tests would comprise
      i. A series of 90° plate orientation of various width and depth of bite into chord – 2 x plate width and 3 x bite grip lengths
      ii. A series of 45° plates orientation of various depth of bite into chord (the base width will automatically be double the depth)

4. Reference MiTek tension perpendicular design method for investigation and analyse the data for fit with the current MiTek method
5. Propose a more accurate calculation method
6. Suggest other/further/future areas of research

As time permits

1. Conduct shear block tests to verify characteristic values
2. Batten screw tests (a range of penetration) to establish correlation/accuracy of existing AS1720.1 design method
3. Test other timber species/densities/grades and engineered wood products (LVL)

AGREED ………………………. (Student) ……………………(Supervisor)

……./........./........ ……../……./……..

(Agreed by Student and Supervisor on 20 April 2012)

Appendix B – Sample Material Densities

Sample ID	Length (m)	Depth (m)	Breadth (m)	Mass (kg)	ρ (kg/m³)
1	1.003	0.138	0.035	2.612	539.169
2	1.001	0.141	0.035	2.746	555.878
3	1.000	0.140	0.035	2.267	462.653
4	1.001	0.141	0.036	2.205	433.963
5	1.001	0.140	0.035	2.053	418.561
6	1.001	0.139	0.035	2.391	490.979
7	1.001	0.140	0.035	2.414	492.161
8	1.002	0.141	0.035	2.708	547.638
9	1.000	0.141	0.035	2.094	424.316
10	1.000	0.140	0.036	2.208	438.095
11	1.001	0.140	0.035	2.387	486.656
12	1.000	0.140	0.035	1.917	391.224
13	1.001	0.140	0.035	2.373	483.802
14	1.002	0.140	0.036	2.388	472.864
15	1.001	0.140	0.035	2.231	454.851
16	1.000	0.140	0.035	2.380	485.714
17	1.000	0.140	0.035	2.260	461.224
18	1.001	0.140	0.035	2.713	553.120
19	1.001	0.139	0.035	2.441	501.246
20	1.001	0.138	0.035	2.626	543.142
21	1.002	0.140	0.035	2.277	463.766
22	1.001	0.141	0.035	2.077	420.451
23	1.001	0.140	0.036	2.191	434.288
24	1.001	0.140	0.036	2.140	424.179
25	1.001	0.140	0.036	1.982	392.861
26	1.001	0.138	0.035	2.477	512.324
27	1.001	0.138	0.035	2.746	567.962
28	1.002	0.140	0.035	2.238	455.823
29	1.000	0.140	0.035	2.433	496.531
30	1.000	0.140	0.035	2.376	484.898
31	1.002	0.139	0.035	2.045	419.510
32	1.005	0.139	0.035	2.114	432.371
33	1.002	0.140	0.035	2.281	464.581
34	1.000	0.140	0.035	2.028	413.878
35	1.001	0.140	0.035	2.064	420.804
36	1.002	0.140	0.035	2.108	429.345
37	1.002	0.141	0.036	2.290	450.242
38	1.002	0.140	0.036	2.369	469.101
39	1.000	0.141	0.036	2.083	410.362

Appendix C.1 – Avery Testing Machine Reports

16/01/2008

Sample ID:	45-30-4.mss	Test Date:	15/01/2008
Method:	FOES Tensile.msm	Operator:	Mohan Trada

Sample Information:

Name	Value
Sample Information 1	
Sample Information 2	
Sample Information 3	
Sample Information 4	
Sample Information 5	
Sample Information 6	
Sample Information 7	
Sample Information 8	
Sample Information 9	
Sample Information 10	
SampleID	

Memo:

Sample Results:

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Modulus MPa	Load At Offset Yield N	Stress At Offset Yield MPa	Load At Yield N
1	40.00000	100.00000	4000.00000	46.20323	15731.07011	3.93277	18671.83408
2	40.00000	100.00000	4000.00000	53.22142	19403.66695	4.85092	24593.64408
3	40.00000	100.00000	4000.00000	53.90515	21965.08541	5.49127	24892.42107
4	40.00000	100.00000	4000.00000	50.51057	5493.45502	1.37336	21001.61651
5	40.00000	100.00000	4000.00000	49.19695	563.31014	0.14083	241.70618
6	40.00000	100.00000	4000.00000	50.06297	33.56995	0.00839	224.92100
7	40.00000	100.00000	4000.00000	46.54672	10920.43734	2.73011	251.77728
8	40.00000	100.00000	4000.00000	45.88203	10037.53731	2.50938	208.13582
9	40.00000	100.00000	4000.00000	43.38349	-704.97794	-0.17624	231.63507
10	40.00000	100.00000	4000.00000	28.53670	2846.76611	0.71169	5458.53992
11	40.00000	100.00000	4000.00000	44.08643	6972.56328	1.74314	3424.17627
12	40.00000	100.00000	4000.00000	39.97229	2323.06856	0.58077	6700.64346
13	40.00000	100.00000	4000.00000	46.11090	10554.52071	2.63863	13488.56986
14	40.00000	100.00000	4000.00000	50.61396	2051.14865	0.51279	2363.35286
15	40.00000	100.00000	4000.00000	47.85866	14190.19033	3.54755	14485.60963
16	40.00000	100.00000	4000.00000	49.38005	13082.36889	3.27059	3340.25036
17	40.00000	100.00000	4000.00000	51.69782	18832.97109	4.70824	19165.31704
18	40.00000	100.00000	4000.00000	51.01126	17100.74114	4.27519	18067.56736

19	40.00000	100.00000	4000.00000	50.59090	20477.91810	5.11948	22371.28696
20	40.00000	100.00000	4000.00000	50.10391	3887.44730	0.97186	2031.00628
21	40.00000	100.00000	4000.00000	46.08208	-696.92122	-0.17423	15694.14289
22	40.00000	100.00000	4000.00000	52.60873	1305.88756	0.32647	2118.28927
23	40.00000	100.00000	4000.00000	51.62965	1043.36636	0.26084	18785.97249
24	40.00000	100.00000	4000.00000	52.61375	587.48089	0.14687	17003.38701
25	6.37000	12.00000	76.44000	2373.02010	9886.47149	129.33636	2823.26796
26	6.37000	12.00000	76.44000	2614.23965	-1466.35259	-19.18305	11521.34827
27	6.37000	12.00000	76.44000	2432.75091	11705.98496	153.13952	2125.00447
28	6.37000	12.00000	76.44000	2576.70865	974.88380	12.75358	18785.97401
29	6.37000	12.00000	76.44000	1879.20523	8265.02321	108.12432	2047.79262
30	6.37000	12.00000	76.44000	2137.51235	7422.40705	97.10109	7741.32575
31	6.37000	12.00000	76.44000	2646.85419	9483.62707	124.06629	9715.26292
32	6.37000	12.00000	76.44000	2387.23027	9241.92061	120.90425	9483.62707
33	6.37000	12.00000	76.44000	1203.24046	1658.37644	21.69514	2890.40854
34	6.37000	12.00000	76.44000	1618.13514	2974.33450	38.91071	3273.11078
35	6.37000	12.00000	76.44000	1630.21386	3343.60839	43.74161	4642.78142
36	6.37000	12.00000	76.44000	1781.95846	3373.82189	44.13686	946.68479
Mean	28.79000	70.66667	2692.14667	734.24664	7357.41052	25.67298	9189.23309
Std. Dev.	16.07822	42.07205	1875.82046	1019.45464	6792.68461	46.02655	8191.90030

Specimen #	Stress At Yield MPa	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa	Strain At Break %	
1	4.66796	18671.83408	4.66796	18614.76468	4.65369	10.40393	
2	6.14841	24593.64408	6.14841	24519.79002	6.12995	12.43702	
3	6.22311	24892.42107	6.22311	24858.85174	6.21471	11.90836	
4	5.25040	21001.61651	5.25040	20927.76092	5.23194	10.48017	
5	0.06043	9050.56892	2.26264	9050.56854	2.26264	4.56544	
6	0.05623	8614.15421	2.15354	8459.72993	2.11493	4.35437	
7	0.06294	11192.35754	2.79809	10823.08379	2.70577	6.38253	
8	0.05203	10403.45394	2.60086	9476.91206	2.36923	5.99197	
9	0.05791	7079.98820	1.77000	7079.98820	1.77000	4.12915	
10	1.36463	5458.53992	1.36463	5226.90445	1.30673	6.06085	
11	0.85604	7083.34523	1.77084	6975.92031	1.74398	4.23251	
12	1.67516	6700.64346	1.67516	6700.64346	1.67516	4.23900	
13	3.37214	13488.56986	3.37214	13270.36232	3.31759	7.70440	
14	0.59084	14307.68682	3.57692	14307.68682	3.57692	7.15692	
15	3.62140	14485.60963	3.62140	14485.60963	3.62140	7.68600	
16	0.83506	13461.71344	3.36543	13327.43229	3.33186	6.97981	
17	4.79133	19165.31704	4.79133	18826.25722	4.70656	9.35536	
18	4.51689	18067.56736	4.51689	18067.56736	4.51689	9.04522	
19	5.59282	22371.28696	5.59282	22371.28696	5.59282	11.41842	
20	0.50775	18315.98806	4.57900	18295.84646	4.57396	9.18129	
21	3.92354	15694.14289	3.92354	15536.36206	3.88409	8.51391	
22	0.52957	19689.01583	4.92225	19689.01583	4.92225	9.47196	
23	4.69649	18785.97249	4.69649	18785.97249	4.69649	9.14256	
24	4.25085	17003.38701	4.25085	17003.38701	4.25085	8.01789	
25	36.93443	10269.17355	134.34293	9389.63007	122.83660	6.55554	

26	150.72407	19756.15641	258.45312	19739.37174	258.23354	10.04721	
27	27.79964	13982.05530	182.91543	13982.05530	182.91543	7.54855	
28	245.76104	18785.97401	245.76104	18695.33452	244.57528	9.52103	
29	26.78954	8677.93823	113.52614	8513.44392	111.37420	6.06331	
30	101.27323	8442.94621	110.45194	7670.82767	100.35096	5.22383	
31	127.09658	12303.53705	160.95679	12303.53705	160.95679	6.14725	
32	124.06629	10410.16914	136.18746	9920.04178	129.77553	6.55571	
33	37.81278	2890.40854	37.81278	1581.16460	20.68504	5.28726	
34	42.81935	4105.65585	53.71083	4001.58748	52.34939	4.43140	
35	60.73759	4656.20954	60.91326	4568.92679	59.77141	5.01258	
36	12.38468	4293.64947	56.17019	3917.66157	51.25146	4.02798	
Mean	29.38620	13282.01938	45.58602	13082.36908	44.00684	7.36891	
Std. Dev.	54.53142	6157.89972	72.70267	6297.00633	71.77395	2.41202	

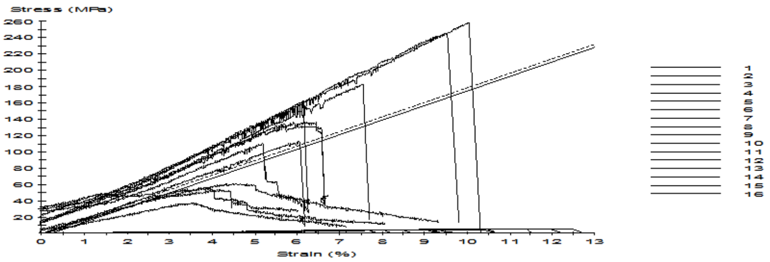
Calculation Inputs:

Name	Value	Units
Break Marker Drop	10.0	%
Break Marker Elongation	0.00100	mm
Chord Modulus Elongation Point 1	0.25400	mm
Chord Modulus Elongation Point 2	12.70000	mm
Chord Modulus Strain Point 1	0.02000	mm/mm
Chord Modulus Strain Point 2	0.05000	mm/mm
Nominal Gage Length	100.00000	mm
Secant Modulus Elongation Point 1	0.25400	mm
Secant Modulus Strain Point 1	0.05000	mm/mm
Secant Modulus Strain Point 2	0.05000	mm/mm
Slack Pre-Load	0.22500	lbf
Slope Segment Length	50.000	%
Strain Point 01	0.05000	mm/mm
Strain Point 02	0.05000	mm/mm
Strain Point 03	0.05000	mm/mm
Strain Point 04	0.05000	mm/mm
Strain Point 05	0.05000	mm/mm
Strain Point 06	0.05000	mm/mm
Strain Point 07	0.05000	mm/mm
Strain Point 08	0.05000	mm/mm
Yield Angle	0.00000	rad
Yield Offset	0.00200	mm/mm
Yield Segment Length	2.0	%

Test Inputs:

Name	Value	Units
Break Sensitivity	95	%
Break Threshold	200.00000	kN
Data Acq. Rate	10.0	Hz
Extension Endpoint	0.50000	mm
Gage Adjustment Pre-Load	0.44500	N

Gage Adjustment Speed	1.30000	mm/min
Initial Speed	1.30000	mm/min
Load Endpoint	500.00000	kN
Outer Loop Rate	100	Hz
Secondary Speed	1.30000	mm/min
Strain Endpoint	0.10000	mm/mm



Appendix C.2 – Sample individual test output

```
"Test Method","FOES Tensile.msm"
"Sample I. D.","125-25-1.mss"
"Specimen Number","5"

"Time (s)","Extension (mm)","Strain (%)","Load (kN)","Stress
(MPa)"

0.60000,-2.14256,-2.14256,0.06043,0.01511
1.00000,-2.12656,-2.12656,0.11750,0.02937
1.40000,-2.11856,-2.11856,0.24171,0.06043
1.80000,-2.11056,-2.11056,0.20478,0.05119
2.20000,-2.09856,-2.09856,0.07721,0.01930
2.60000,-2.09056,-2.09056,0.06378,0.01595
3.00000,-2.08256,-2.08256,0.13428,0.03357
3.40000,-2.07456,-2.07456,0.23164,0.05791
3.80000,-2.06256,-2.06256,0.17792,0.04448
4.20000,-2.05456,-2.05456,0.12085,0.03021
4.60000,-2.04656,-2.04656,0.10407,0.02602
5.00000,-2.03856,-2.03856,0.13428,0.03357
5.40000,-2.03056,-2.03056,0.21485,0.05371
5.80000,-2.02256,-2.02256,0.23835,0.05959
6.20000,-2.01056,-2.01056,0.10742,0.02686
6.60000,-2.00256,-2.00256,0.03357,0.00839
7.00000,-1.99456,-1.99456,0.10071,0.02518
7.40000,-1.98256,-1.98256,0.19806,0.04952
7.80000,-1.97456,-1.97456,0.23499,0.05875
8.20000,-1.97056,-1.97056,0.16449,0.04112
8.60000,-1.95856,-1.95856,0.09064,0.02266
9.00000,-1.95056,-1.95056,0.06714,0.01679
9.40000,-1.94256,-1.94256,0.19471,0.04868
9.80000,-1.93456,-1.93456,0.23835,0.05959
10.20000,-1.92256,-1.92256,0.14100,0.03525
10.60000,-1.91856,-1.91856,0.05036,0.01259
11.00000,-1.90256,-1.90256,0.06714,0.01679
11.40000,-1.90256,-1.90256,0.15442,0.03861
11.80000,-1.89056,-1.89056,0.23835,0.05959
12.20000,-1.87856,-1.87856,0.15442,0.03861
12.60000,-1.87456,-1.87456,0.06043,0.01511
13.00000,-1.86256,-1.86256,0.03357,0.00839
13.40000,-1.85056,-1.85056,0.15442,0.03861
13.80000,-1.85056,-1.85056,0.24842,0.06211
14.20000,-1.83856,-1.83856,0.19135,0.04784
14.60000,-1.83056,-1.83056,0.07385,0.01846
15.00000,-1.82256,-1.82256,0.05036,0.01259
15.40000,-1.81056,-1.81056,0.13092,0.03273
15.80000,-1.80256,-1.80256,0.21485,0.05371
16.20000,-1.79456,-1.79456,0.20478,0.05119
16.60000,-1.78656,-1.78656,0.10407,0.02602
17.00000,-1.77856,-1.77856,0.06714,0.01679
17.40000,-1.77056,-1.77056,0.11078,0.02770
17.80000,-1.75856,-1.75856,0.18799,0.04700
18.20000,-1.75056,-1.75056,0.21485,0.05371
18.60000,-1.73456,-1.73456,0.17457,0.04364
19.00000,-1.73456,-1.73456,0.03357,0.00839
19.40000,-1.72256,-1.72256,0.08728,0.02182
19.80000,-1.71456,-1.71456,0.15442,0.03861
20.20000,-1.70656,-1.70656,0.20478,0.05119
20.60000,-1.70256,-1.70256,0.15442,0.03861
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21.00000,-1.69056,-1.69056,0.10071,0.02518
21.40000,-1.68256,-1.68256,0.05371,0.01343
21.80000,-1.67456,-1.67456,0.17792,0.04448
22.20000,-1.66656,-1.66656,0.23164,0.05791
22.60000,-1.65856,-1.65856,0.21485,0.05371
23.00000,-1.64656,-1.64656,0.06714,0.01679
23.40000,-1.63856,-1.63856,0.05707,0.01427
23.80000,-1.63056,-1.63056,0.12757,0.03189
24.20000,-1.62256,-1.62256,0.22156,0.05539
24.60000,-1.61056,-1.61056,0.20814,0.05203
25.00000,-1.59856,-1.59856,0.11750,0.02937
25.40000,-1.59856,-1.59856,0.05036,0.01259
25.80000,-1.58656,-1.58656,0.11078,0.02770
26.20000,-1.57856,-1.57856,0.19471,0.04868
26.60000,-1.56656,-1.56656,0.20142,0.05036
27.00000,-1.55856,-1.55856,0.15107,0.03777
27.40000,-1.55456,-1.55456,0.05036,0.01259
27.80000,-1.54256,-1.54256,0.09064,0.02266
28.20000,-1.53456,-1.53456,0.14771,0.03693
28.60000,-1.52656,-1.52656,0.20478,0.05119
29.00000,-1.51456,-1.51456,0.16785,0.04196
29.40000,-1.50656,-1.50656,0.06378,0.01595
29.80000,-1.49856,-1.49856,0.02014,0.00504
30.20000,-1.49056,-1.49056,0.15107,0.03777
30.60000,-1.47856,-1.47856,0.23499,0.05875
31.00000,-1.47456,-1.47456,0.16785,0.04196
31.40000,-1.46656,-1.46656,0.06043,0.01511
31.80000,-1.45856,-1.45856,0.06378,0.01595
32.20000,-1.44656,-1.44656,0.18128,0.04532
32.60000,-1.43456,-1.43456,0.20142,0.05036
33.00000,-1.43456,-1.43456,0.11750,0.02937
33.40000,-1.42256,-1.42256,0.05707,0.01427
33.80000,-1.41456,-1.41456,0.13764,0.03441
34.20000,-1.40256,-1.40256,0.22828,0.05707
34.60000,-1.39456,-1.39456,0.23835,0.05959
35.00000,-1.38656,-1.38656,0.15107,0.03777
35.40000,-1.37856,-1.37856,0.08057,0.02014
35.80000,-1.37056,-1.37056,0.19806,0.04952
36.20000,-1.36256,-1.36256,0.30213,0.07553
36.60000,-1.35456,-1.35456,0.24842,0.06211
37.00000,-1.33856,-1.33856,0.11750,0.02937
37.40000,-1.33456,-1.33456,0.14771,0.03693
37.80000,-1.32256,-1.32256,0.28870,0.07218
38.20000,-1.31856,-1.31856,0.30549,0.07637
38.60000,-1.31056,-1.31056,0.20478,0.05119
39.00000,-1.29856,-1.29856,0.16785,0.04196
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41.00000,-1.25856,-1.25856,0.18464,0.04616
41.40000,-1.24656,-1.24656,0.28535,0.07134
41.80000,-1.23856,-1.23856,0.34242,0.08560
42.20000,-1.23456,-1.23456,0.26185,0.06546
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43.00000,-1.21456,-1.21456,0.21821,0.05455
43.40000,-1.20656,-1.20656,0.33235,0.08309
43.80000,-1.19456,-1.19456,0.37934,0.09484
44.20000,-1.18656,-1.18656,0.22492,0.05623
44.60000,-1.17856,-1.17856,0.18128,0.04532
45.00000,-1.17056,-1.17056,0.21821,0.05455
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45.40000,-1.16256,-1.16256,0.32563,0.08141
45.80000,-1.15056,-1.15056,0.30885,0.07721
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46.60000,-1.13456,-1.13456,0.18464,0.04616
47.00000,-1.12656,-1.12656,0.23499,0.05875
47.40000,-1.11856,-1.11856,0.33570,0.08393
47.80000,-1.11056,-1.11056,0.37263,0.09316
48.20000,-1.09856,-1.09856,0.30549,0.07637
48.60000,-1.09456,-1.09456,0.24171,0.06043
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57.00000,-0.91056,-0.91056,0.35249,0.08812
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59.00000,-0.86656,-0.86656,0.45320,0.11330
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61.80000,-0.81056,-0.81056,0.44313,0.11078
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63.00000,-0.78256,-0.78256,0.58748,0.14687
63.40000,-0.77056,-0.77056,0.53713,0.13428
63.80000,-0.76256,-0.76256,0.48677,0.12169
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65.80000,-0.72256,-0.72256,0.55055,0.13764
66.20000,-0.71056,-0.71056,0.55727,0.13932
66.60000,-0.69856,-0.69856,0.61769,0.15442
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67.40000,-0.68656,-0.68656,0.70833,0.17708
67.80000,-0.67856,-0.67856,0.63784,0.15946
68.20000,-0.66656,-0.66656,0.58748,0.14687
68.60000,-0.66256,-0.66256,0.66805,0.16701
69.00000,-0.65056,-0.65056,0.75533,0.18883
69.40000,-0.64256,-0.64256,0.79897,0.19974
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69.80000,-0.63456,-0.63456,0.73183,0.18296
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71.00000,-0.61056,-0.61056,0.80569,0.20142
71.40000,-0.59856,-0.59856,0.87283,0.21821
71.80000,-0.59056,-0.59056,0.84262,0.21065
72.20000,-0.58256,-0.58256,0.76876,0.19219
72.60000,-0.57056,-0.57056,0.73855,0.18464
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75.40000,-0.51056,-0.51056,0.92654,0.23164
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77.80000,-0.46256,-0.46256,1.00375,0.25094
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78.60000,-0.44256,-0.44256,1.01047,0.25262
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79.80000,-0.41456,-0.41456,1.03397,0.25849
80.20000,-0.40656,-0.40656,1.05747,0.26437
80.60000,-0.39856,-0.39856,1.06754,0.26688
81.00000,-0.38656,-0.38656,1.02390,0.25597
81.40000,-0.38256,-0.38256,0.99033,0.24758
81.80000,-0.37456,-0.37456,1.04739,0.26185
82.20000,-0.36656,-0.36656,1.10111,0.27528
82.60000,-0.35456,-0.35456,1.18168,0.29542
83.00000,-0.34656,-0.34656,1.10782,0.27696
83.40000,-0.33856,-0.33856,1.03732,0.25933
83.80000,-0.33056,-0.33056,1.08432,0.27108
84.20000,-0.31856,-0.31856,1.07089,0.26772
84.60000,-0.31456,-0.31456,1.21860,0.30465
85.00000,-0.30256,-0.30256,1.15818,0.28954
85.40000,-0.29456,-0.29456,1.11789,0.27947
85.80000,-0.28656,-0.28656,1.10782,0.27696
86.20000,-0.27856,-0.27856,1.12796,0.28199
86.60000,-0.27056,-0.27056,1.20518,0.30129
87.00000,-0.25856,-0.25856,1.24210,0.31053
87.40000,-0.25056,-0.25056,1.20182,0.30045
87.80000,-0.24256,-0.24256,1.17832,0.29458
88.20000,-0.23456,-0.23456,1.13132,0.28283
88.60000,-0.22656,-0.22656,1.21860,0.30465
89.00000,-0.21456,-0.21456,1.25889,0.31472
89.40000,-0.21056,-0.21056,1.32939,0.33235
89.80000,-0.20256,-0.20256,1.25553,0.31388
90.20000,-0.19056,-0.19056,1.20518,0.30129
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Appendix D – Testing Results

Sample ID	Density ρ (kg/m³)	Plate Size	Label	Bite Width (mm)	Bite Depth (mm)	Max Force (kN)	Visible Signs of Failure	Test Order
1	539.169	125200	4	125	25	10.403	Small failure. Under 100mm either side of vertical. No plate withdrawal but timber to move laterally as well as vertical.	8
2	555.878	125200	1	125	25	9.051	Failure Parallel, but grain is sloping. Tensile fracture. Not actually breaking. Fracture 500mm long. 100mm to one side.	5
3	462.653	125200	2	125	25	8.614	Tension Perpendicular Failure	6
4 (36)	429.345	125200	3	125	25	11.192	Parallel to grain. 200mm either side of vertical member.	7
5	418.561	125200	1	125	45	15.694	Full Fracture along grain. At teeth on 1 side. Below teeth on the other. Follows grain angle	21
6 (39)	410.362	125200	3	125	45	18.789		23
7	492.161	125200	2	125	45	19.689	Full failure along grain (follows back up at the ends). Bottom of teeth.	22
8	547.638	125200	4	125	45	17.003		24
9	424.316	125200	4	125	65	21.002	Similar Tensile fracture to others. Failure along grain.	4

10	438.095	125200	3	125	65	24.892	creaking at 18kN.Tensile Fracture sloping along grain. Failure occurring at bottom edge of bottom row of teeth. Failure between teeth was closer to the top of member than where the teeth are.	3
11	486.656	125200	2	125	65	24.594	Major tensile fracture. Grain more parallel to member. No visible plate withdrawal	2
12	391.224	125200	1	125	65	18.672	Cracking sound at 10kN. Tensile fracture at Failure force. No visible plate withdrawal. Some minor but possibly due to failure	1
13	483.802	75200	1	75	25	7.08	Failure through bottom of plate and next row of teeth	9
14	472.864	75200	4	75	25	6.701	Initial split appeared at teeth, then major failure.	12
15	454.851	75200	2	75	25	5.485	Original tension perp failure at 5.485 with small fibre tear. Continued load after initial drop then plate withdrawal at 3kN. Timber still failed tension perp around this value as well. (photo 61-64)	10
16	485.714	75200	3	75	25	7.083	TP Failure at teeth	11
17	461.224	75200	1	75	45	13.489	Tension Perp Failure Parallel to grain. 300 one side, 200mm other. 300 stopped due to over straps?	13
18	553.12	75200	4	75	45	13.462	Major TP failure. Full fracture along grain.	16
19	501.246	75200	3	75	45	14.486	TP Failure, trough to over strap location.	15
20	543.142	75200	2	75	45	14.308	Tension Perp Failure. Bottom row of teeth. Failed through to strap locations	14
21	463.766	75200	1	75	65	19.165	Major TP Failure. Full fracture. Bottom edge of teeth and along grain. (around knot that was approx 50mm inside of over strap)	17
22	420.451	75200	4	75	65	18.316	Major TP Failure.	20

23	434.288	75200	3	75	65	22.371	Major TP Failure along grain	19
24	424.179	75200	2	75	65	18.068	Major TP failure. Sloping along the grain. Stopped by over straps	18
25	392.861	125200R	1	40	30	2.89	No ply used....Plate withdrawal at approx 2.5 kN.	33
26	512.324	125200R	2	40	30	4.106	**Ply used...still minor plate withdrawal on 1 side. Plate withdrawal continued to failure load, but no real TP failure. So fibre tearing near edge of timber.	34
27	567.962	125200R	3	40	30	4.656	Ply used. Again minor plate withdrawal at 3 kN. Plate withdrawal continued until bite failure. Small evidence of TP failure as grip reduced	35
28	455.823	125200R	4	40	30	4.294	Ply used. Dropped clamp down to close to bottom of vertical member to attempt to reduce withdrawal. Still minor withdrawal at 3kN.	36
29	496.531	125200R	3	67	50	12.303	**used ply of plate after previous failure** Small cracks appeared then TP failure.	31
30	484.898	125200R	4	67	50	10.41	**Used Ply** at approx 9 kN with ply...minor plate withdrawal on 1 side only.	32
31	419.51	125200R	1	67	50	8.678	some small cracks approx 8kN. Major Failure.**no ply was used...*	29
32	432.371	125200R	2	67	50	8.443	plate withdrawal approx 8kN. Still had a TP failure.**No Ply	30
33	464.371	125200R	4	93	70	18.786	small cracks appear approx 15kN. Large visible in compression area just above bend beam bracket. Major fail.	28
34	413.878	125200R	1	93	70	10.269	crack appearing at 9kN. Final failure minor. No breakage.	25

35	420.804	125200R	3	93	70	13.892	cracks appearing about 10.5 kN. Major failure along grain.	27
36 (37)	450.242	125200R	2	93	70	19.756	major TP Failure along grain	26

Appendix E – Analysis Data

Sample ID	Plate Size	Label	Density ρ (kg/m³)	Bite Width (mm)	Bite Depth (mm)	Bite Area	No of teeth	Max Force (kN)	Average Force	Standard Deviation of Force	Normalised force (Bite depth per mm width)	Normalised force (Width per mm bite depth)
1	125200	4	539.169	125	25	6250	80	10.403			0.083224	0.41612
2	125200	1	555.878	125	25	6250	80	9.051			0.072408	0.36204
3	125200	2	462.653	125	25	6250	80	8.614			0.068912	0.34456
4 (36)	125200	3	429.345	125	25	6250	80	11.192	9.815	1.193	0.089536	0.44768
5	125200	1	418.561	125	45	11250	140	15.694			0.125552	0.34875556
6 (39)	125200	3	410.362	125	45	11250	140	18.789			0.150312	0.41753333
7	125200	2	492.161	125	45	11250	140	19.689			0.157512	0.43753333
8	125200	4	547.638	125	45	11250	140	17.003	17.79375	1.790	0.136024	0.37784444
9	125200	4	424.316	125	65	16250	200	21.002			0.168016	0.32310769
10	125200	3	438.095	125	65	16250	200	24.892			0.199136	0.38295385

11	125200	2	486.656	125	65	16250	200	24.594			0.196752	0.37836923
12	125200	1	391.224	125	65	16250	200	18.672	22.29	2.990	0.149376	0.28726154
13	75200	1	483.802	75	25	3750	48	7.08			0.0944	0.2832
14	75200	4	472.864	75	25	3750	48	6.701			0.08934667	0.26804
15	75200	2	454.851	75	25	3750	48	5.485			0.07313333	0.2194
16	75200	3	485.714	75	25	3750	48	7.083	6.58725	0.756	0.09444	0.28332
17	75200	1	461.224	75	45	6750	84	13.489			0.17985333	0.29975556
18	75200	4	553.12	75	45	6750	84	13.462			0.17949333	0.29915556
19	75200	3	501.246	75	45	6750	84	14.486			0.19314667	0.32191111
20	75200	2	543.142	75	45	6750	84	14.308	13.93625	0.537	0.19077333	0.31795556
21	75200	1	463.766	75	65	9750	108	19.165			0.25553333	0.29484615
22	75200	4	420.451	75	65	9750	108	18.316			0.24421333	0.28178462
23	75200	3	434.288	75	65	9750	108	22.371			0.29828	0.34416923

24	75200	2	424.179	75	65	9750	108	18.068	19.48	1.984	0.24090667	0.27796923
25	125200R	1	392.861	40	20	800	18	2.89			0.07225	0.1445
26	125200R	2	512.324	40	20	800	18	4.106			0.10265	0.2053
27	125200R	3	567.962	40	20	800	18	4.656			0.1164	0.2328
28	125200R	4	455.823	40	20	800	18	4.294	3.9865	0.766	0.10735	0.2147
29	125200R	3	496.531	66.66	33.33	2221.7778	54	12.303			0.18456346	0.36912691
30	125200R	4	484.898	66.66	33.33	2221.7778	54	10.41			0.15616562	0.31233123
31	125200R	1	419.51	66.66	33.33	2221.7778	54	8.678			0.13018302	0.26036604
32	125200R	2	432.371	66.66	33.33	2221.7778	54	8.443	9.9585	1.792	0.12665767	0.25331533
33	125200R	4	464.371	93.33	46.67	4355.7111	116	18.786			0.20128576	0.40252839
34	125200R	1	413.878	93.33	46.67	4355.7111	116	10.269			0.11002893	0.22003428
35	125200R	3	420.804	93.33	46.67	4355.7111	116	13.892			0.14884817	0.29766445
36	125200R	2	450.242	93.33	46.67	4355.7111	116	19.756	15.67575	4.425	0.21167899	0.42331262

Appendix F.1 – New Calculation Method

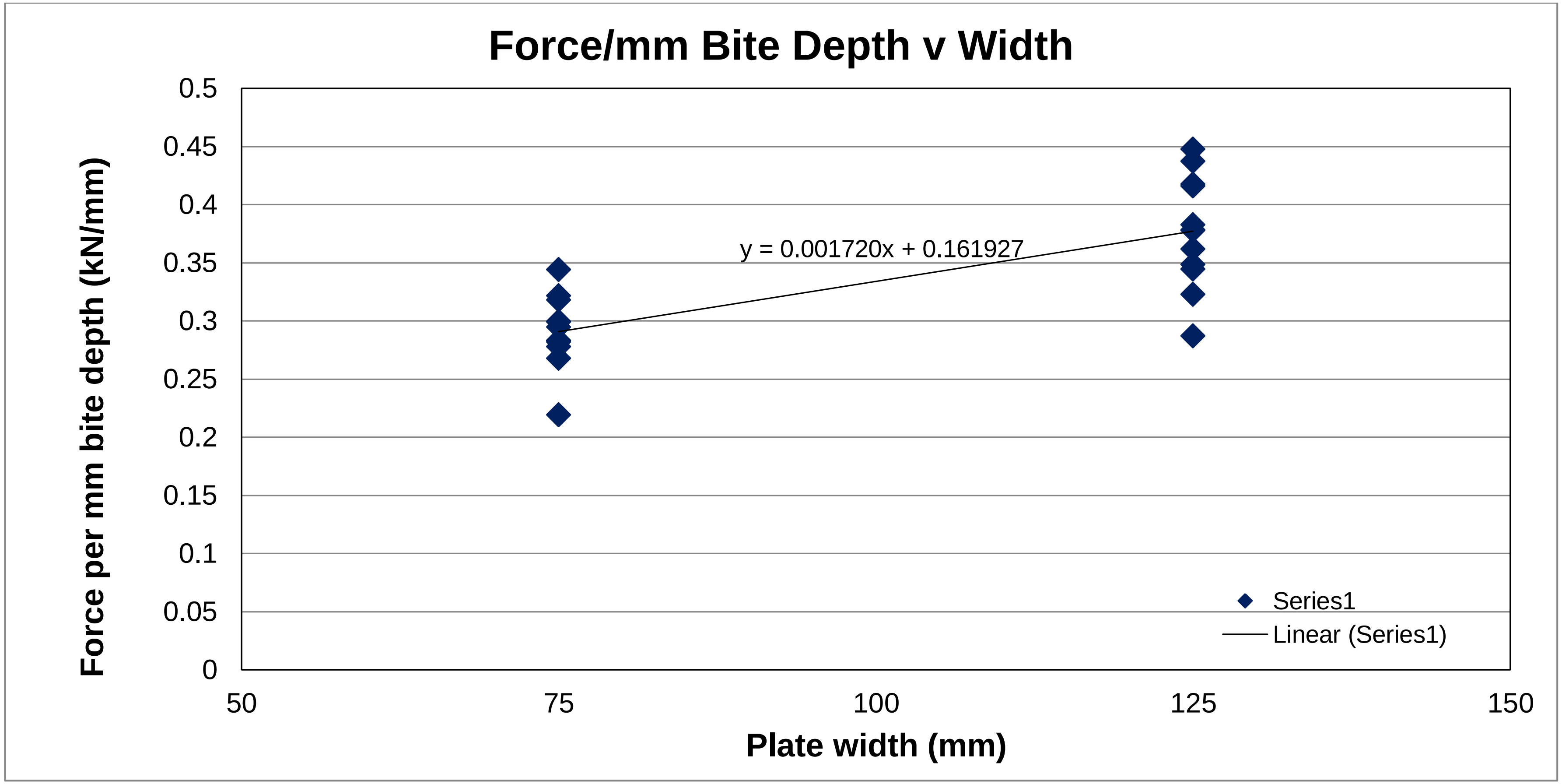

Figure F.1 - Plot of Force/mm bite depth v width for square plates only

Table F.1 - Calculation of Force for all orientations using equation from Figure F.1

Depth	Width	Area	Actual Force	***Width: 0.00172w+0.16193***	**Force**	**% Difference between proposed and Actual**
25	125	6250	9.82	0.376927	9.42	3.99%
45	125	11250	17.79	0.376927	16.96	4.68%
65	125	16250	22.29	0.376927	24.50	-9.92%
25	75	3750	6.59	0.290927	7.27	-10.41%
45	75	6750	13.94	0.290927	13.09	6.06%
65	75	9750	19.48	0.290927	18.91	2.92%
20	40	1600	3.9865	0.230727	4.15	-4.18%
33.33	66.66	4443.556	9.9585	0.2765822	8.30	16.69%
46.67	93.33	8711.422	15.67575	0.3224546	13.54	13.60%

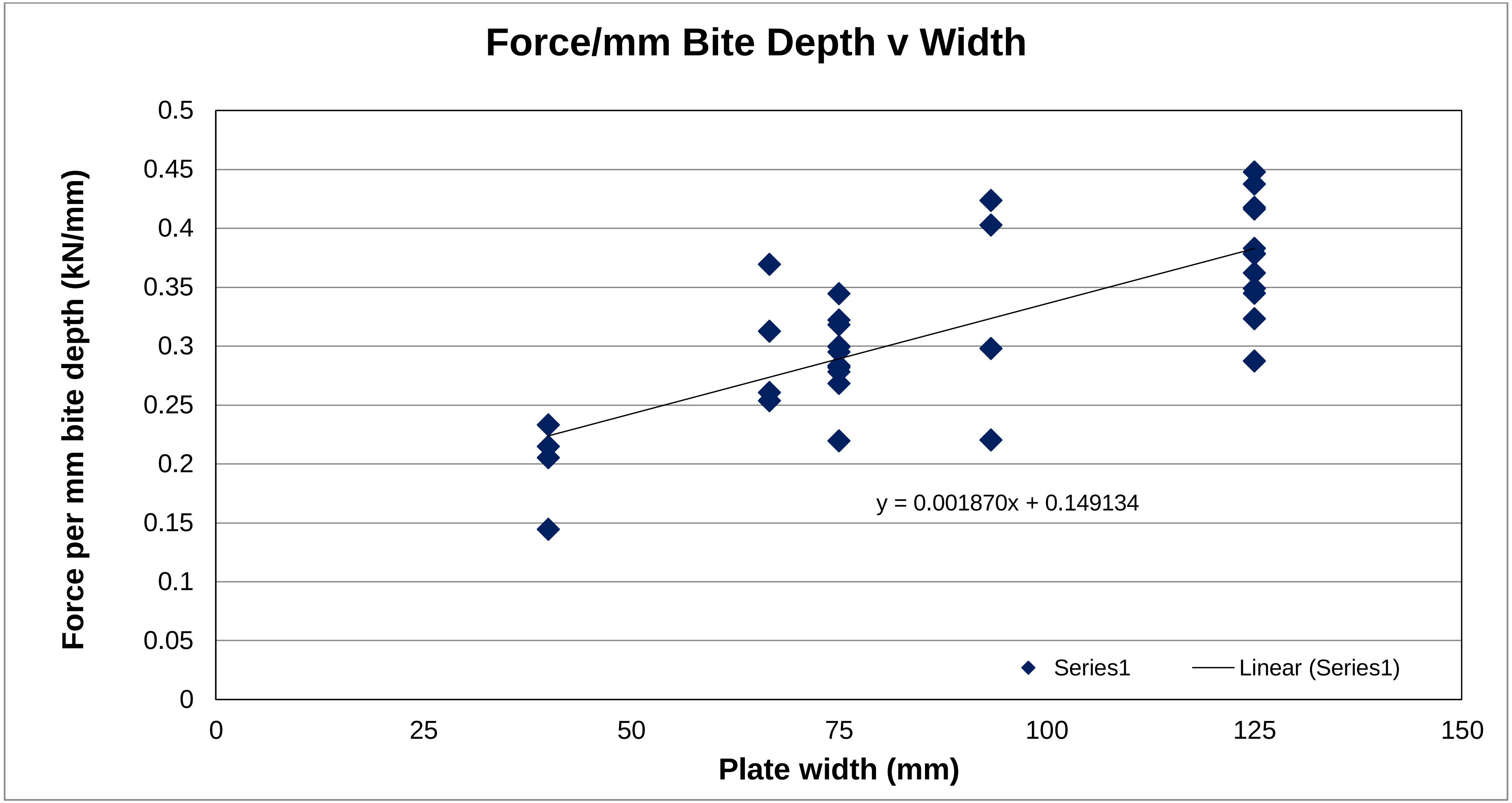

Figure F.2 - Plot of Force/mm bite depth v width including 45 degree orientation plates

Table F.2 - Force based on proposed equation from Figure F.2

Depth	Width	Area	Actual Force	*Width: 0.00187w+0.149134*	Proposed Force	% Difference between proposed and Actual
25	125	6250	9.82	0.382884	9.57	2.47%
45	125	11250	17.79	0.382884	17.23	3.17%
65	125	16250	22.29	0.382884	24.89	-11.65%
25	75	3750	6.59	0.289384	7.23	-9.83%
45	75	6750	13.94	0.289384	13.02	6.56%
65	75	9750	19.48	0.289384	18.81	3.44%
20	40	1600	3.9865	0.223934	4.48	-12.35%
33.33	66.66	4443.556	9.9585	0.2737882	9.13	8.37%
46.67	93.33	8711.422	15.6758	0.3236611	15.11	3.64%

Appendix F.2 – New Design Calculation Method – 5th Percentile Probability

in Accordance with AS1649-2001 Appendix B

$$y_{5\ percent} = \bar{y} - ks$$

Where:

$y_{5\ percent}$ = logarithm value of the 5th LPL

$\bar{y}$ = logarithm value of the average ultimate load

s = percentage coefficient of variation (%CoV)/230

k = see Table 1.

Table 1 – Values of k

Number of test results (n)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
k	7.73	3.37	2.63	2.34	2.18	2.08	2.01	1.96	1.92

The 5th LPL and the average ultimate load (UL_{ave}) is the antilog of $y_{5\ percent}$ and $\bar{y}$ respectively.

$$5^{th}LPL = 10^{\bar{y}-ks}$$

$$5^{th}LPL = \frac{10^{\bar{y}}}{10^{ks}}$$

$$5^{th}LPL = \frac{UL_{ave}}{10^{k\left(\frac{\%Cov}{230}\right)}}$$

$$5^{th}LPL = K \times UL_{ave}$$

Where:

$$K = \frac{1}{10^{k\left(\frac{\%Cov}{230}\right)}}$$

Therefore:

n = 9

k = 1.96

Bite Width	Bite Depth	Average Actual Ultimate Failure Load (kN)	Standard Deviation	%Cov
125	25	9.815	1.193	12
125	45	17.794	1.790	10
125	65	22.290	2.990	13
75	25	6.587	0.756	11
75	45	13.936	0.537	4
75	65	19.480	1.984	10
60	30	3.987	0.766	19
100	50	9.956	1.792	18
140	70	15.676	4.425	28

Average %Cov = 14

K = 0.76

So take $5^{th}LPL = 0.76 \times UF_{ave}$

Appendix G – Risk Assessment

Measure of consequence used for decision making

The table below shows the measures of consequence attributed to the identified hazards.

Table G.1 - Measure of consequence

LEVEL	DESCRIPTOR	OUTCOME DESCRIPTION	INJURY EXAMPLE
1	Catastrophic	Disaster with potential to lead to collapse	Death
2	Major	Critical event which, with proper management, will be endured	Permanent Disability
3	Severe	Significant event which can be managed under normal procedures	Medical treatment required with lost time
4	Minor	Consequences can be readily absorbed but management effort is still required to minimise impact	First Aid treatment
5	Insignificant	Not worth worrying about	No injuries

Measure of Likelihood used for decision making

The table below shows the measures of likelihood of occurrence attributed to the identified hazards.

Table G.2 - Measure of Likelihood

LEVEL	DESCRIPTOR	DESCRIPTION
A	Almost certain	The event is expected to occur in most circumstances
B	Likely	The event will probably occur in most circumstances
C	Moderate	The event should occur at some time
D	Unlikely	The event could occur at some time
E	Rare	The event may only occur in exceptional circumstances

Risk Assessment Matrix

The matrix below was used to calculate the risk level according to the consequence and likelihood for each hazard.

Table G.3 - Risk Assessment Matrix

	Consequences - Low to high				
Likelihood	**5**	**4**	**3**	**2**	**1**
A	M	M	H	H	H
B	S	M	M	H	H
C	L	S	M	H	H
D	L	L	S	M	H
E	L	L	S	M	M
	Risk Assessment				

Table G.4 - Legend for Risk Level

Legend

DESCRIPTOR	**DESCRIPTION**	**ACTION**
H	High Risk	Detailed research and management planning required at senior levels
M	Moderate Risk	Senior management attention required
S	Significant risk	Management responsibility must be specified
L	Low risk	Manage by routine procedure

Radiata Pine (T2 Treated)

ITEM	HAZARD	CONSEQNCE	LIKELI-HOOD	RISK LEVEL	EXISTING PROTECTION &/OR REQUIRED ACTION
1	Back Injury caused by the weight of pre-cut samples	5	B	M	MANAGEMENT: Ordered material in lengths up to 2.4m so single person can handle
2	Fingers/feet – Crush injury while handling	5	D	L	MANAGEMENT: Ordered material in lengths up to 2.4m so single person can handle
3	T2 Treatment	4	D	L	MANAGEMENT: Use appropriate PPE as described in the Material Safety Data Sheet (MSDS)

Gang-Nail Plates

ITEM	HAZARD	CONSEQNCE	LIKELI-HOOD	RISK LEVEL	EXISTING PROTECTION &/OR REQUIRED ACTION
1	Cuts from plates while handling plates	4	B	M	MANAGEMENT: A safety data sheet is available for nail plates, wear appropriate PPE (gloves) and ensure that appropriate treatment available for cuts etc.

Drop Saw

ITEM	HAZARD	CONSEQNCE	LIKELI - HOOD	RISK LEVEL	EXISTING PROTECTION &/OR REQUIRED ACTION
1	Risk of cutting	5	D	L	MANAGEMENT: Ensure required guards are in place and working prior to connection to power
2	Dust during timber cutting – Eye and breathing risk	4	A	M	MANAGEMENT: Wear appropriate PPE as described in MSDS
3	Noise – Ears	4	A	M	MANAGEMENT: Use appropriate PPE

Drill Press

ITEM	HAZARD	CONSEQNCE	LIKELI-HOOD	RISK LEVEL	EXISTING PROTECTION &/OR REQUIRED ACTION
1	Risk of cutting	5	D	L	MANAGEMENT: Ensure required guards are in place and working prior to connection to power
2	Drill bit gripping in material, causing material to spin	5	D	L	MANAGEMENT: Ensure that material is gripped in suitable vice and/or is positioned so that if drill bit grips, material cannot spin.

Auto 10 Table Press

Press is located at TrussTec Pty.Ltd.

ITEM	**HAZARD**	**CONSEQNCE**	**LIKELI - HOOD**	**RISK LEVEL**	**EXISTING PROTECTION &/OR REQUIRED ACTION**
1	Fingers, hands, limbs in hydraulic press - crushing	2	E	M	MACHINE: Operator cannot reach press whilst operating the machine. TRAINING: To prevent damage to someone other than the press operator, only one operator is to use the machine at a given time.
2	Fingers, hands, limbs caught between roller wheels and table.	2	D	M	MACHINE: Operator has clear view of the roller trapping points that occur on both sides of the press head. The operator cannot reach the rollers whilst operating the machine. The operator must stand on the carriage of the press to move the press head on the table. TRAINING: To prevent damage to someone other than the press operator, only one operator is to use the machine at a given time.
3	Fingers, hands, limbs between mechanical linkages shearing action.	2	E	M	MACHINE: Guarding prevents the operator from touching the linkages whilst operating the machine. The Operator must not climb above the machine to the linkages and operate the machine

					at the same time. TRAINING: To prevent damage to someone other than the press operator, only one operator is to use the machine at a given time.
4	Being struck by press as it is moved by operator	5	C	L	TRAINING: Operator to watch for others in path of press before moving it.
5	Press moved by operator could trap another person between the press head and floor	2	E	M	Training: Operator is to lock out press head and electrical isolator before anyone climbs under the table. MANAGEMENT: Site Management is to ensure that procedures to lock out the machine are followed before any one climbs under the table.
6	Press moved by operator could trap another person between the press head and table	2	E		Training: Operator is to lock out press head and electrical isolator before anyone climbs under the table. MANAGEMENT: Site Management is to ensure that procedures to lock out the machine are followed before any one climbs under the table.
7	High voltage electrical source inside motor starter box – shock or electrocution	2	D	M	TRAINING: Operators must not access the electrical box. The control box is a standard unit that requires tools for opening. Electrical work or fault-finding must only be performed by a

					qualified electrician. Operators never to reach under table unless press is locked out. Operator is to lock out press head and electrical isolator before anyone reaches or climbs under the table or removes the end covers.
8	High voltage electrical source on busbars underneath table – shock or electrocution	2	D	M	Training: Operator is to lock out press head and electrical isolator before anyone reaches or climbs under the table or removes the end covers. MANAGEMENT: Site Management is to ensure that procedures to lock out the machine are followed before any one climbs under the table or the end covers are removed.
9	High pressure hydraulic fluid - leaks or burst hoses - skin penetration, damage to eyes, striking by hoses.	2	D	M	TRAINING: Operators must report leaks immediately. Hydraulic leaks should be address immediately by a qualified person. Fittings and hoses must only be tightened or replaced with the hydraulic pump electrically isolated. Suitable eye-wear must be worn whilst testing the hydraulic system after maintenance work.
10	Site specific issues of housekeeping and workstation layout - potential for slip/trip/fall due to nail plates or	2	C	H	TRAINING: Operators are encouraged to keep a tidy workstation. MANAGEMENT: Site management responsible for providing adequate waste bins and systems for good

	timber on floor, or inappropriate or contaminated floor surface.				housekeeping.
11	Site specific issues of lighting and operator fatigue.	3	C	M	MANAGEMENT: Site management is responsible for providing adequate lighting at the operator's workstation.
12	Site specific issues of hot or cold operator causing discomfort or fatigue	3	C	M	MANAGEMENT: Site management is responsible for providing appropriate climate control at the operator's workstation.
13	Sawdust not generated by machine, but common to machine locations and can cause respiratory conditions.	3	A	H	MANAGEMENT: Site management responsible for workstation air quality.
14	The Auto 8 & 10 does not generate noise levels requiring hearing protection, but excess noise created by saws is common to the machine environment and usually requires hearing protection	3	B	M	MANAGEMENT: Site management responsible for providing hearing protection where appropriate. The dB reading during normal operation is

(MiTek Australia Auto 10 Operators Manual)

Avery Testing Machine

Machine is located at USQ, Toowoomba

[ALARP = As Low As Reasonably Practicable]

Element or Sub Element/ Process Step	**The Risk: What can happen and what will be the result**	**EXISTING CONTROLS**	**Risk Rating with existing controls? See next page**			**Is it ALARP? Yes/No**	ADDITIONAL CONTROLS REQUIRED	**Risk Rating with additional controls?**			**Is it ALARP? Yes/No**	**Risk Decision: Accept Transfer Treat**
List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers Existing emergency procedures	**Consequences**	**Likelihood**	**Rating**		Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses Specific induction / training	**Consequences**	**Likelihood**	**Rating**		
Turn on the tensile machine	Electrical shock	Building fitted with RCD. Trained personnel operates machine / Task is supervised. Safe Operating Procedures (SOP) have been developed and are readily available. Risk Management Plan (RMP) has been developed and is readily available. Emergency procedures are in place.	3	E	L	**YES**	NA	NA	NA	NA	NA	**Accept**
Placing the	Pinching	Sample is manually	3	D	M	**No**	Take extreme care while placing	2	D	L	Yes	**Accept**

sample on the machine	Cutting Hitting Crushing	placed into position by trained personnel/ Task is supervised. Clamps are manually operated by the trained personnel. The trained personnel will operate machine. Safe Work Procedures (SWP) have been developed and is readily available. Safe Operating Procedures (SOP) have been developed and are readily available. Risk Management Plan (RMP) has been developed and is readily available. Emergency procedures are in place.					samples. Keep body as much as practical outside of the machine incase of power failure causing cross arm to drop Wear appropriate PPE (Glasses, Gloves, Safety Boots)					
Perform the tensile testing												
Breaking the sample	Debris could fly from the fracture	Wearing eye protection during the tensile testing process or should be far from machine by about 1m distance. Safe Work Procedures (SWP) have been developed and is readily available. Safe Operating	2	E	L	**YES**	NA	NA	NA	NA	NA	**Accept**

		Procedures (SOP) have been developed and are readily available. Risk Management Plan (RMP) has been developed and is readily available. Task is supervised by trained personnel. Emergency procedures are in place.										
Turing off the machine	Electrical shock	Building fitted with RCD. Trained personnel operates machine. Safe Operating Procedures (SOP) have been developed and are readily available. Risk Management Plan (RMP) has been developed and is readily available. Task is supervised. Emergency procedures are in place.	3	E	L	**YES**	NA	NA	NA	NA	NA	**Accept**
Remove the sample	Pinching Cutting Hitting Crushing	Sample is manually removed by trained personnel/ Task is supervised. Clamps are manually operated by the trained personnel. The trained personnel will operate machine. Safe Work Procedures	3	D	M	**No**	Take extreme care while removing samples. Keep body as much as practical outside of the machine incase of power failure causing cross arm to drop Wear appropriate PPE (Glasses, Gloves, Safety Boots)	2	D	L	Yes	**Accept**

		(SWP) have been developed and is readily available. Safe Operating Procedures (SOP) have been developed and are readily available. Risk Management Plan (RMP) has been developed and is readily available. Emergency procedures are in place.										