BEHAVIOUR OF PLANK (TONGUE AND GROOVE) WOOD DECKING UNDER THE EFFECTS OF UNIFORMLY DISTRIBUTED AND CONCENTRATED LOADS

by
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Thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements for the degree of
Master of Applied Science
in Civil Engineering

Under the auspices of the Ottawa-Carleton Institute for Civil Engineering

uOttawa

Departments of Civil Engineering
University of Ottawa
September 2013

ABSTRACT

Plank (tongue and groove) wood decking is a product that is commonly used in post and beam timber construction to transfer gravity loads on roofs and floors. In 2010, The National Building Code of Canada changed the application area of the specified concentrated roof live loads from 750 mm x 750 mm to 200 mm x 200 mm. The change was made to better reflect the area which a construction worker with equipment occupies. Preliminary analysis showed that the change in the application area of concentrated loads may have a significant impact on the design of decking systems. Little research or development has been done on plank decking since the 1950's and 1960's.

An experimental program was undertaken at the University of Ottawa's structural laboratory to better understand the behaviour of plank decking under uniformly distributed and concentrated loads. Non-destructive and destructive tests were conducted on plank decking systems to investigate their stiffness and failure mode characteristics under uniformly distributed as well as concentrated loads. The experimental test program was complimented with a detailed finite element model in order to predict the behaviour of a plank decking system, especially the force transfer between decks through the tongue and groove joint.

The study showed that the published deflection coefficients for uniformly distributed loads can accurately predict the three types of decking layup patterns specified in the Canadian Design Standard (CSA O86, 2009). For unbalanced uniformly distributed loads on two-span continuous layup, it was found that the deflection coefficient of 0.42 was non-conservative.

It was also found that under concentrated loads, the stiffness of the decking system increased significantly as more boards were added. A deflection coefficient of 0.40 is appropriate to calculate the deflection for the three types of decking layup patterns specified in the Canadian Design Standard (CSA O86, 2009) under concentrated load on an area of 200 mm by 200 mm.

Significant load sharing was observed for plank decking under concentrated loads. An increase in capacity of about 1.5 to 2.5 times the capacity of the loaded boards was found.

Furthermore, it was found that placing sheathing on top of a decking system had a significant effect in the case of concentrated load with an increase of over 50% in stiffness and over 100% in ultimate capacity.

ACKNOWLEDGEMENTS

I would like to thank my thesis supervisor, Dr. Ghasan Doudak, for his review and guidance throughout my studies.

I would like to thank Mr. Gary Williams from Timber Systems Limited, Mr. Steve Boyd from Quaile Engineering Limited, and the Canadian Wood Council for their input on the testing program. Furthermore, I would like to acknowledge the financial support received from the NSERC ENGAGE program and The University of Ottawa. I would also like to thank Boise Cascade and Filler King for donating material. A special thanks to Mr. Dominic Lavoie from Boise Cascade for overseeing the process.

I would like to extend my appreciation to all those that helped me with the experimental testing, including Mr. Daniel Lacroix, Mr. Alan Lloyd, Mr. Eric Jacques, Dr. Muslim Majeed, Mr. Dominic Cote, and Mr. David Batky.

In closing, I would like to thank my parents, grandparents, siblings, and friends for their moral and financial support during my academic career. Finally, I would like to thank my partner and best friend, Lindsay, for her encouragement and friendship throughout this journey.

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GLOSSARY

Acronym		Definition
4PB	=	Four Point Bending
AITC	=	American Institute of Timber Construction
ASTM	=	American society for testing and materials
AYC	=	Alaskan Yellow Cedar
CL127	=	Concentrated load (127x127)
CL200	=	Concentrated load (200x200)
COV	=	Coefficient of variation
CR	=	Controlled Random
CWC	=	Canadian Wood Council
D	=	Destructive
DG	=	Dial Gauge
DLF	=	Douglas-Fir-Larch
FEM	=	Finite element model
HSS	=	Hollow Structural Section
L2	=	Laminated (127 mm x 36 mm)
L3	=	Laminated (131 mm x 55 mm)
MOE	=	Modulus of elasticity
MOR	=	Modulus of rupture
ND	=	Non-Destructive
NBCC	=	National Building Code of Canada
NLMA	=	National Lumber Manufacturers Association
OSB	=	Oriented-strand-board
POP	=	Ponderosa Pine
S2	=	Solid Sawn (127 mm x 36 mm)
SPF	=	Spruce-Pine-Fir
SS	=	Simple Span
SSS	=	Simple span with sheathing
ST	=	Combination Simple Span and Two-span continuous

TS	=	Two-span continuous
U2	=	Linear link directional property 2
UDL	=	Uniformly distributed load
WG	=	Wire gauge

Symbol		Definition
ϕ	=	Material safety factor
γ	=	Deflection coefficient
Δ	=	Deflection
f_b	=	Specified bending strength (MPa)
b	=	Board width
d	=	Board thickness
w	=	Specified uniform load
E_s	=	Modulus of elasticity
L	=	Distance between supports
I	=	Moment of inertia
K_D	=	Load duration factor
K_H	=	Load sharing factor
K_S	=	Serviceability factor
K_T	=	Treatment factor
K_{Zb}	=	Size factor due to bending

CHAPTER 1-Introduction and Research Needs

1.1 General

Light-frame wood structures behave as assemblages of plates stiffened by ribs. In most North American constructions, the primary plate elements are wood-based sheathing materials such as plywood or Oriented Strand Board (OSB) manufactured in 1.22 x 2.44 m sheets. Ribs consist of dimension lumber, wood I-joists, or open-web trusses. Typically, plate elements are structurally attached to ribs by steel nails and/or glue. Light-frame wood structures provide a high degree of redundancy and load sharing because the element that connects the members together, for instance sheathing, acts in conjunction with the main structural members to produce a larger effective cross section. This composite action is usually only partly effective because complete shear transfer between the connected sheathing element and the main member is difficult to achieve.

Design of wood light-frame structures is based on an assessment of the capacity of isolated rib components such as floor joists, wall studs, or roof trusses. System effects includes load sharing and composite action and are allowed for by multiplying the bare rib capacity by a series of factors that reflect the rib spacing, the nature of the plate, the type of connection between the plate and ribs, and whether ribs are single piece or mechanically laminated (Foschi, Folz, & Yao, 1989). For example, the bending capacity of dimension lumber ribs can be increased by up to 40% if such members are spaced less than 610 mm apart, if at least three members resisting a common load, and if a plate is providing sufficient connection between the ribs (CSA O86, 2009), as illustrated in *Figure 1.1*.

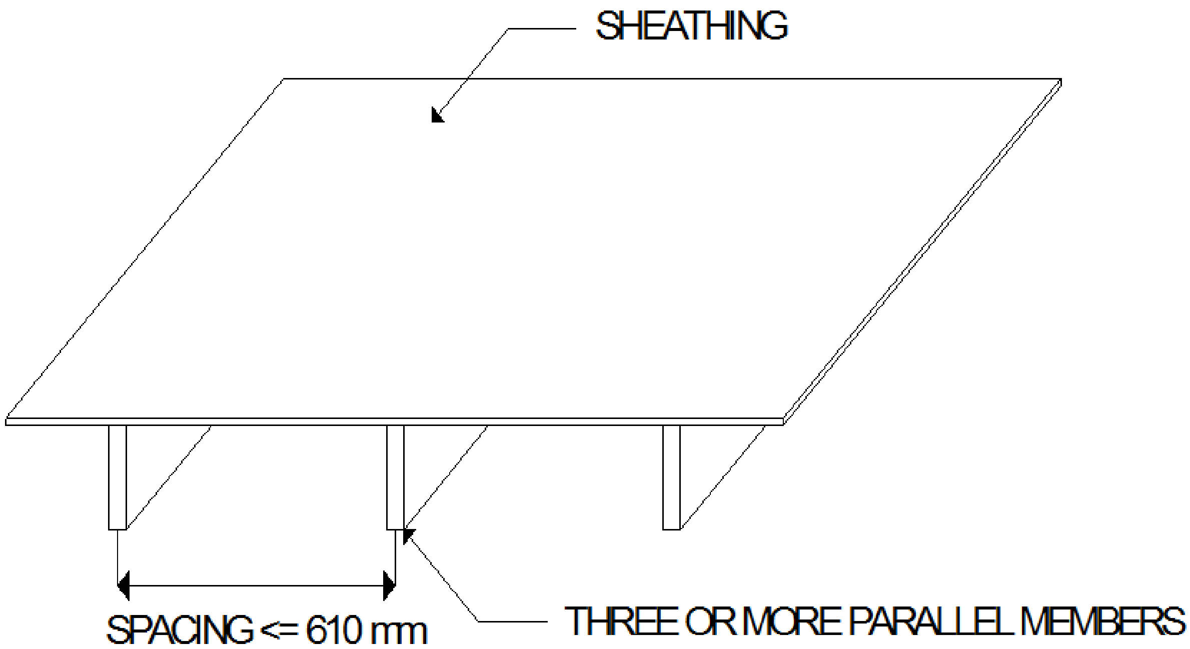


Figure 1.1: Typical Light Frame Wood Floor System with Sheathing Panel

A construction method commonly used in commercial wood structures is known as "Post and Beam". The most common roof and floor systems used in post and beam construction consist of wood decking supported by purlins or beams. This system allows for larger spacing between supporting elements than that shown in *Figure 1.1*. This decking system is required to be finished with a tongue and groove or splined cross section and is typically placed on solid-sawn or glue-laminated beams in such a way that the decking elements span perpendicular to the supporting beams. A sketch of a plank decking system and their support can be seen in *Figure 1.2*. It should be noted that sheathing is typically nailed on top of plank decking systems as to resist lateral forces acting on the diaphragm.

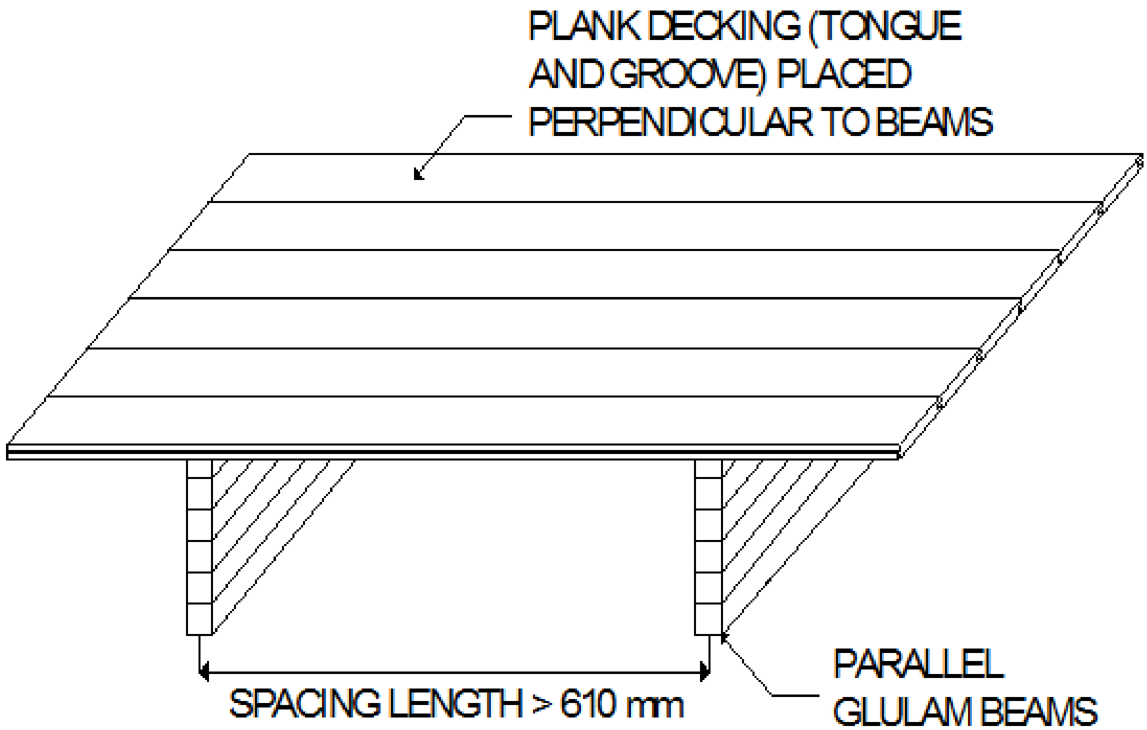
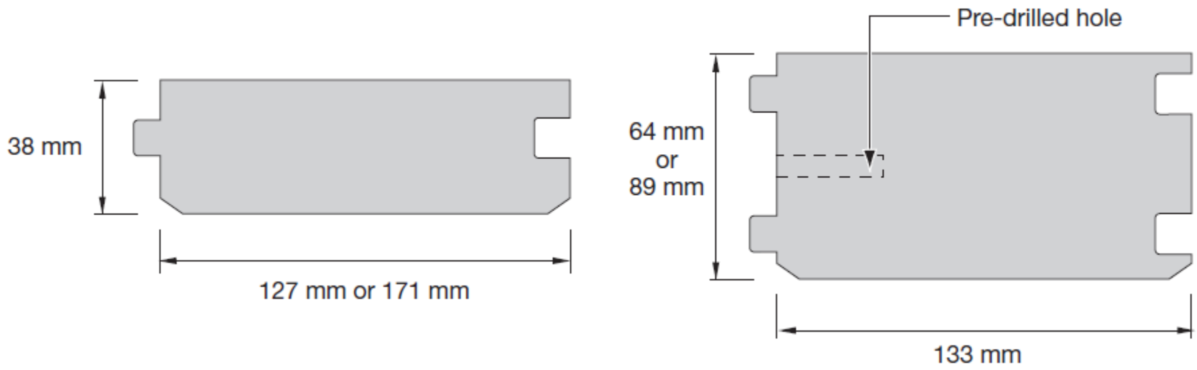


Figure 1.2: Plank Decking and Beam System

1.2 Decking Details

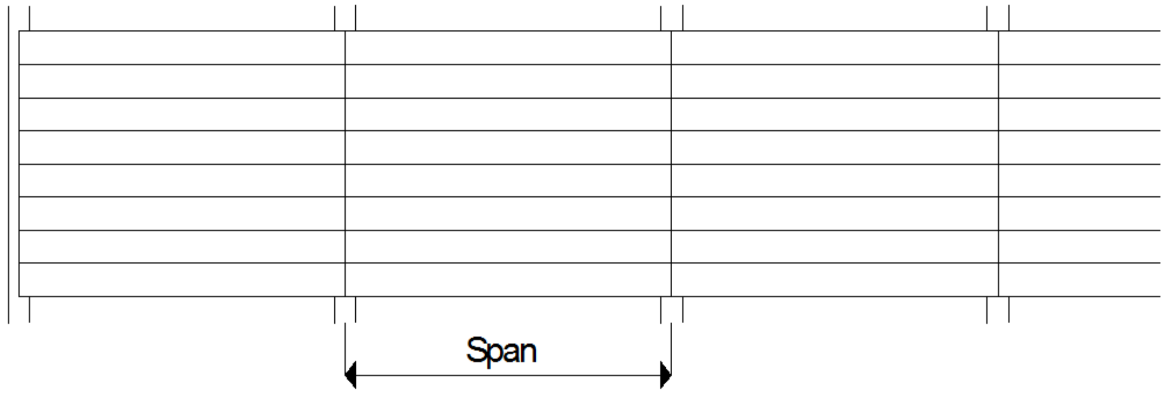
The nominal size of plank decking is based on nominal lumber dimensions prior to milling. The lumber used for decking is milled to single tongue and groove or double tongue and groove. The 38 mm decking members are often manufactured using 38 mm lumber, which results in slightly thinner decking (36 mm). The 64 and 89 mm decks are typically manufactured with 6 mm pre-drilled holes spaced at 762 mm so that each piece can be nailed to the adjacent one using No. 3, 203.4 mm (8 in.) long spikes. *Figures 1.3(a) and (b)* show the standard sizes for plank decking (CWC, 2010).



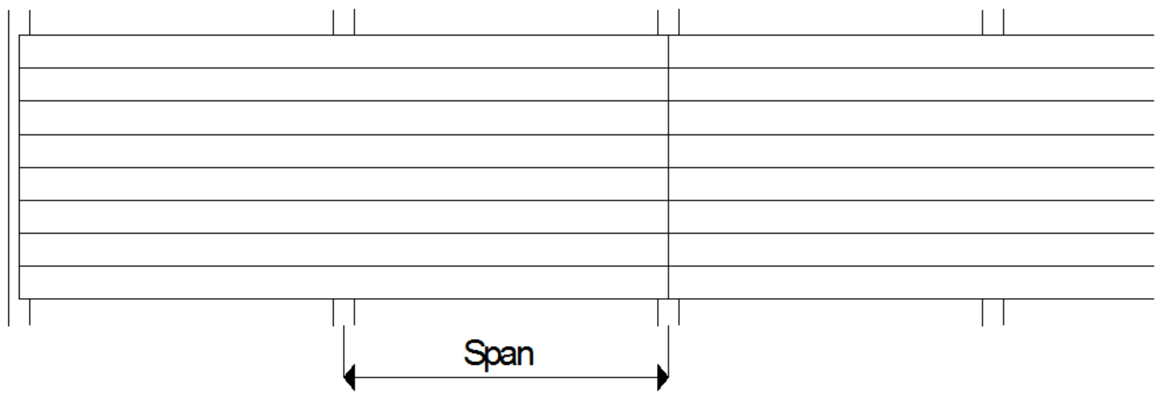
(a) Single Tongue and Groove (b) Double Tongue and Groove

Figure 1.3: Standard Plank Decking Sizes (CWC, 2010)

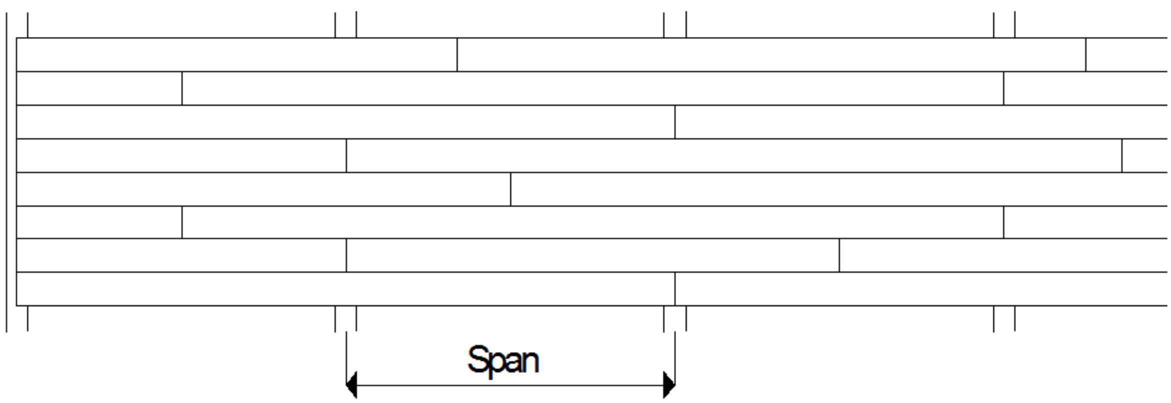
Plank decking is commonly available in lengths of 1.8 to 6.1 m, and in species such as Douglas Fir-Larch, Pacific Coast Hemlock, Spruce-Pine-Fir, or Western Red Cedar. Decking is most often available in two grades, namely Select Structural and Commercial Grade (No.2) (CWC, 2010). Decking can be laid in a number of different layup patterns such as simple span, two-span continuous and controlled random (CWC, 2010). The simple span and the two-span continuous layup patterns require decking to have exact lengths which may not be efficient and can be more costly. The most economical and commonly used pattern is the controlled random layup, which can be constructed using random length pieces for different span lengths. The American Institute of Timber Construction (AITC 112-93, 1993) lists two other types of layups, namely “combination simple and two-span continuous” and “cantilevered intermixed”. These layup patterns are less common as they produce more waste during installation than the controlled random layup pattern. The current research study investigates four types of layup patterns: simple span, two-span continuous, controlled random, and combination simple and two-span continuous. *Figures 1.4(a)-(d)* illustrates the various layup patterns.



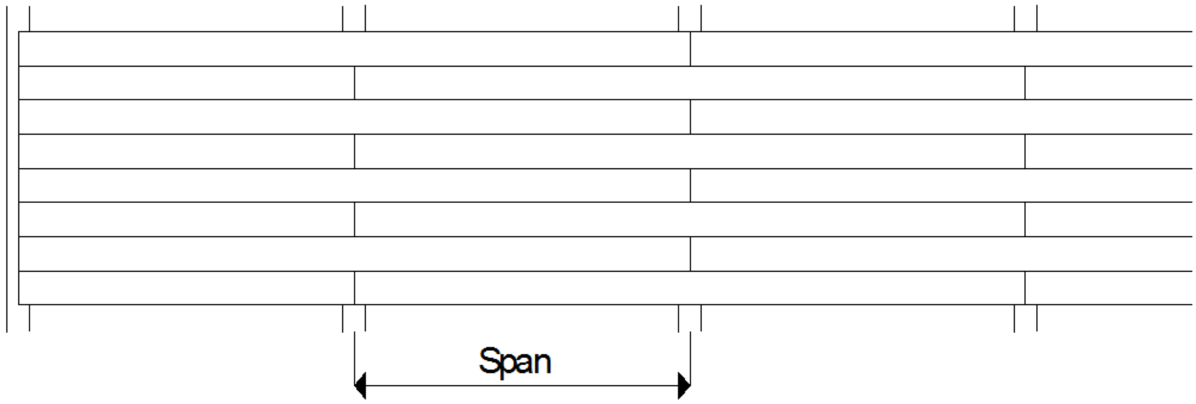
(a) Simple Span Layup Pattern



(b) Two-Span Continuous Layup Pattern



(c) Controlled Random Layup Pattern



(d) Combination Simple and Two-span Continuous Layup Pattern

Figure 1.4: Layup Patterns for Tongue and Groove Decking Systems

The Canadian Wood Council's Wood Design Manual (CWC, 2010) specifies requirements that must be met for the controlled random layup pattern. These requirements would ensure consistency in constructions and avoids localized weak areas where small length pieces would cluster. For example, it is required that the deck extends over at least three spans, and where end joints occur in adjacent courses they must be staggered by 610 mm or more. Obviously these requirements are prescriptive and are based on good practice and common sense rather than a mechanics based approach. An illustration is provided in the CWC Wood Design Manual (reproduced in *Figure 1.5*) to aid in the understanding of these prescriptive requirements. It should be noted that even though different patterns are possible for the controlled random decking system, the ones tested in the current project all adhered to the prescriptive requirements illustrated in *Figure 1.5*.

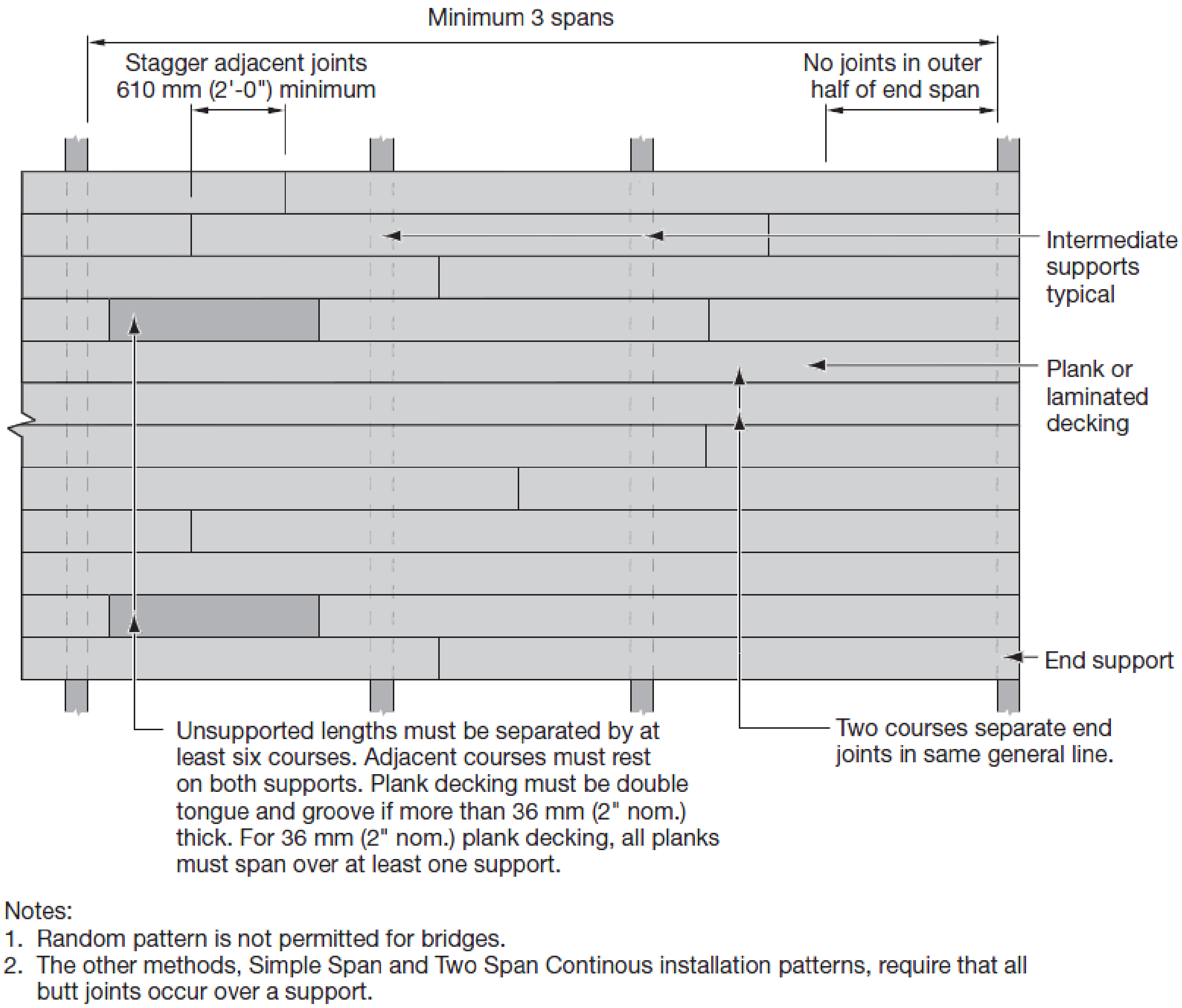


Figure 1.5: Controlled Random Layup Requirements (CWC, 2010)

Prescriptive requirements are also provided for joining the decking members together and to the supporting elements. For the 36 mm decking, no requirements exist to nail adjacent boards at the mid-span, however for boards larger than 36 mm, nails are required to be placed between adjacent boards at a spacing of 762 mm. *Figure 1.6* shows the nailing arrangement suggested in the Canadian Wood Councils Wood Design Manual (CWC, 2010).

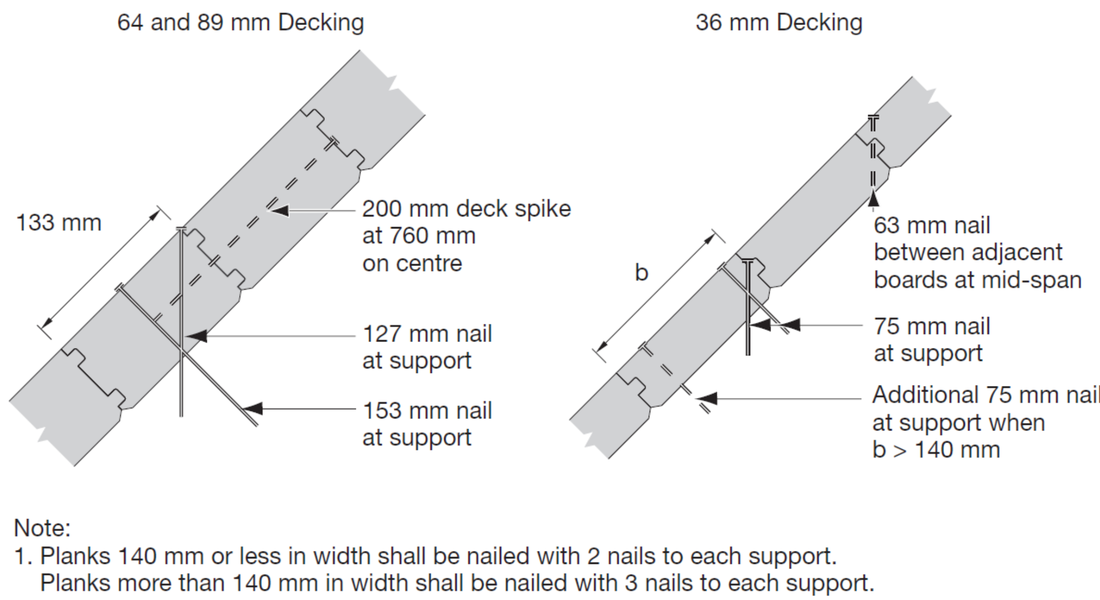


Figure 1.6: Suggested nailing arrangement in WDM (CWC, 2010)

The ends of plank decking boards are typically manufactured as end-matched joints or square joints. End-matched joints have an additional tongue or groove at the end of the boards, so that they can interlock with one another when laid in the controlled random layup. Square joints are manufactured with a straight edge and are more commonly used. The current study focuses on the square end joints. It is expected that the end-matched joints would have the same or better performance especially for the controlled random layup.

1.3 Design Requirements for Tongue-and-Groove Plank Decking

Plank decking is usually governed by the flexural failure or by a maximum deflection limit. Due to their relatively long spans, shear is generally not a typical failure mode. The deflection criterion typically governs unless decking is heavily loaded on a small span. The deflection limit for roof decking is based on L/240, where L is the distance between supports.

The Canadian Wood Council’s Wood Design Manual includes decking span tables that provide the maximum factored uniform load that can be applied on a decking system. The equation is based on equating the bending resistance to the maximum moment for uniformly distributed loading, as shown in *Equation [1.1]*. For uniform loading, and as expected, that the equation is not a function of the width of a board, *b*, but rather only a function of the span length and the board depth.

$$W_{FR} = \frac{8x10^{-3}\phi f_b(K_D K_H K_S K_T)K_{Zb}d^2}{6L^2} \quad [1.1]$$

Where, ϕ is a material safety factor (0.9 for bending), f_b is the specified bending strength (MPa), d is the thickness of the decking (mm), and L is the distance between supports (m). K_D is a load duration factor and K_H is the system factor. A Case 1 system is usually applied to decking systems, as it is assumed that at least three boards are arranged so that they mutually support the load. K_S is the service condition factor and K_T is the treatment factor. K_{Zb} is a size factor in bending and is based on the dimensions of the decking.

The current provisions in the CSA O86 for deflection calculation of decking members are based on considering a simple span layup with uniformly distributed load. Previous research (Currier, 1955) helped establish a deflection coefficient (denoted in the current study as γ) that expresses the ratio of the measured deflection in a test to the theoretical deflection calculated using the mechanics-based equation. The research was limited to uniformly distributed load and pinned end conditions. The deflection coefficient was established as a simplification to describe the deflected shape of plank decking under uniformly distributed loads. *Table 1.1* provides the deflection formula that may be used, where Δ is the deflection (mm), w is the specified uniform load (kN/m), L is the distance between supports (mm), E_S is the modulus of elasticity (MPa), and I is the moment of inertia of the decking (mm^4). As seen in *Table 1.1,* the deflection of, for example, a decking system with controlled random layup can be achieved by applying a deflection coefficient factor of γ_{UDL} = 0.77 to the calculated deflection for a single decking element in a simple span layup pattern. Similarly, a factor of γ_{UDL} =0.42 may be applied to obtain the deflection of a two-span continuous layup.

Table 1.1: Layup Patterns and Uniform Load Deflection Coefficients (CSA O86, 2009)

Layup Pattern	**Deflection Formula**
Simple Span	$\Delta_1 = \dfrac{5wL^4}{384E_S I}$
Controlled Random	$\Delta_2 = 0.77\Delta_1$
Continuous over Two Spans	$\Delta_3 = 0.42\Delta_1$

1.4 Research Needs

During the latest code cycle, the National Building Code of Canada (NBCC) changed the application area specified concentrated design live loads on roofs from 750 mm x 750 mm to 200 mm x 200 mm (NBCC 2010). The change was done to better reflect the loaded area which a construction worker with equipment occupies (1.3 kN). Preliminary analysis showed that the change in the application area of concentrated loads may have a significant impact on the design of decking systems, and that the concentrated load check may govern the design for a wide range of typical spans. This is partly due to the increased stress imposed on the decking by the smaller loaded area, but it is also due to the assumptions made on the analysis and design side. For example, the decks are assumed to deflect as individual members with no considerations for the system effects and with disregard to the potential increase stiffness due to the tongue and groove connection between boards. Currently, there is no design method for decking under a concentrated load. To the author’s knowledge, there have not been any reports of failure in roof decking systems due to loads stemming from workers during construction. The fact that the analysis indicates that such failures (or excessive deflection) are to be expected on existing decking spans is a clear indicator that the current assumptions made in the design of decking members are inadequate.

1.5 Research Goals

The objective of this research project is to establish the behaviour of tongue and groove plank decking systems, and develop design guidelines that incorporate the interaction between decking elements through the tongue and groove joint. More specifically, the study aims to:

1) Investigate the current provisions for deflection of decking systems; specifically whether current deflection coefficients for uniformly distributed loads are appropriate;

2) Establish the increase in capacity of decks as a function of number of boards in order to develop a deflection coefficient that is appropriate for the case of concentrated load and that reflects the load sharing effect in the decking system;

3) Investigate failure modes of decking systems under uniformly distributed and concentrated loads for different layup patters, and quantify the load increase due to the load sharing effects in the decking system relative to the capacity of individual decking elements; and

4) Develop a Finite Element model with a material predictive relationship that includes the tongue and groove joints and that is capable of mimicking the behaviour of a decking system.

1.6 Scope

The above stated objectives are achieved through the following:

- A detailed literature review of the behaviour of decking systems;
- A review of the analysis and design procedures;

- Determining the required inputs to the material predictive model by conducting component tests;
- Testing of individual decking elements and decking systems non-destructively and destructively, under uniformly distributed and concentrated loading;
- Comparing the modelling and experimental results and formulating design recommendations for a system factor under concentrated loads; and
- Discussing the results and implications on the code.

1.7 Structure of Thesis

Chapter 1 provides an introduction to the topic of decking analysis and design, and presents the research needs and objectives.

Chapter 2 presents the literature review including previous test programs on decking systems.

Chapter 3 presents the experimental methodology employed in the research program, and provides a detailed description of the components and specimens tested, as well as the test setups used.

Chapter 4 presents the test results for material evaluation, non-destructive tests, destructive tests, and a description of the methodology used in the development of the finite element model.

Chapter 5 discusses the analysis and results from the experimental and analytical program, and the implications of results on the analysis and design approaches for decking systems.

Chapter 6 consists of a summary of the most important findings and defines potential future work.

CHAPTER 2-Literature Review

2.1 Full-scale Tests and Related Research on Wood Plank Decking

The number of full scale studies on the behaviour of tongue and groove decking has been very limited, with the majority of the work being undertaken during the 1950's and 1960's.

One of the first studies that investigated the behaviour of wood decking was conducted at the Oregon Forests Products Laboratory (Currier, 1955). The goal of the study was to determine the strength and stiffness of controlled random layup patterns using 2-by-6 nominal size solid sawn Douglas-Fir decking. Four layup patterns were tested and they consisted of 9 courses of boards. Two of the layup patterns were constructed using a combination of simple and two-span continuous and two other layups were assembled using the controlled random layup pattern. Observations from the tests indicated that the combination simple span and two-span continuous layup pattern deflected less than the controlled random pattern. This testing program provided the first set of data that was used to establish the deflection coefficients for wood decking systems.

In 1958, the National Lumber Manufacturers Association (NLMA) sponsored a research study to confirm the findings from the report done by Currier in 1955. Seven different controlled random layup patterns were tested. All of the tests consisted of three spans and 10 courses (boards) in width. The focus of the testing was to quantify the difference in deflection between layups that included "floaters" (i.e. unsupported boards), and those that did not. The study also investigated the effect of long term uniform loading. A number of important observations were reported following this study. It was found that the addition of floaters did not have a significant effect on increasing the deflection. Under the long term loading (three months), it was found that the average deflection increased 21% in the center span, and 28% in the end spans. Overall, the test results matched fairly well with the study conducted by Currier (1955).

The Douglas Fir Use Book was published in 1958 and included information on grading, sizes, and typical nailing pattern, as well as design provisions on plank and laminated decks. The Douglas Fir Use Book was the publication where the deflection coefficients for different layup patterns first appeared. The book also includes the first set of design tables for plank solid sawn and laminated decking. *Table 2.1* includes the layup pattern as well as the published deflection coefficients.

Table 2.1: Douglas Fir Use Book Deflection Coefficients (D.Fir Use, 1958)

Layup Pattern	Deflection Formula
Simple Spans	$\Delta_1 = \frac{5wl^4}{384E_S I}$
Two-Span Continuous	$\Delta_2 = 0.42\Delta_1$
Cantilevered Pieces Intermixed	$\Delta_3 = 0.73\Delta_1$
Combination Simple and Two-Span Continuous	$\Delta_4 = 0.70\Delta_1$
Random Length	$\Delta_5 = 0.77\Delta_1$

Potlatch Forests Inc. (1959) investigated the effects of vertical loads on inland red cedar lock-deck. The purpose of the study was to investigate simple span and a so-called "cantilevered pieces intermixed" layup patterns. *Figure 2.1* illustrates the cantilevered intermixed layup pattern. It should be noted that this layup pattern was not investigated in the current study. The pattern involves laying pieces in the starter course and every third course as simple span. Pieces in other courses are cantilevered over the supports with end joints at alternate quarter or third points of the span, and each piece rests on at least one support (AITC 112-93, 1993).

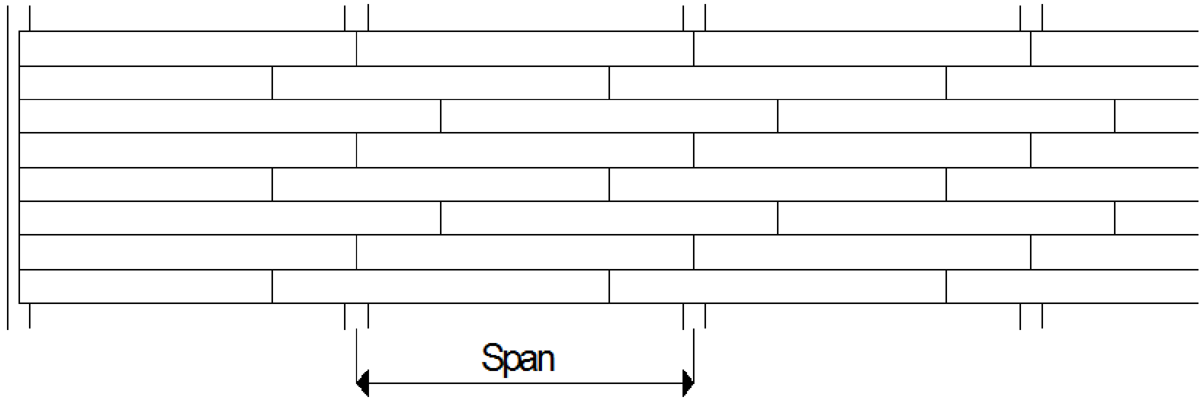


Figure 2.1: Cantilevered Intermixed Layup Pattern (AITC 112-93, 1993)

Six different tests were done each consisting of 6 rows of boards. One test set-up was done with the simple span pattern, and five tests were conducted on the cantilevered pieces intermixed pattern. The study concluded that for simple span layup pattern there was close correlation between the actual and the theoretical deflections. The study also confirmed that the deflection coefficients published in the Douglas Fir Use Book (D.Fir Use, 1958) are appropriate. The study also concluded that there was very little difference between the two nailing patterns using slant driven 16d (89 mm) common nails at a spacing of 762 mm (30 in.) and horizontally driven 178 mm (7 in.) spikes also at 762 mm (30 in.) spacing. It was also noted that nails between boards aided in transmitting the loads around end joints and helped keep the tongue and groove joint from spreading apart.

In 1960, the research department at Potlatch Forest Inc. investigated the performance of slant driven nails used in the tongue and groove (lock-deck) installations. The test specimens consisted of 3 courses that were nailed in different patterns, and loaded to failure. Laminated Douglas-Fir and Cedar species were tested. The results showed, as anticipated, that the capacity of test conducted using Douglas-Fir was greater than that of tests conducted with Cedar. It was found that the lateral resistance of slant driven nails was consistent with previously published values.

Werren (1961) evaluated a system consisting of glued-laminated beams with heavy timber decking. The aim of the study was to determine if the heavy timber decking contributed to stiffening of the supporting glue-laminated beams. An 8.5 m by 12.2 m (28 ft by 40 ft) roof was constructed on top a forest products laboratory fire testing building. The roof system consisted of five 133 mm x 464 mm (5-1/4 in x 18-1/4 in) glued laminated beams covered with nominal 3-by-6 western red cedar decking. The decking was laid in a controlled random pattern across four equal spans and loaded using a uniformly distributed load. It was concluded that the heavy timber decking did not contribute significantly to the stiffness of the glue laminated beams. The study also indicated that heavy timber decking in a controlled random layup does not always deflect according to the theory for continuous beams of uniform stiffness. Furthermore, additional tests done with excess decking material from the same roof system showed that the presence of butt joints significantly reduces the stiffness of decking.

Kampe and Stluka (1963) conducted six tests, each consisting of 8 boards using laminated West Coast Hemlock to determine the strength and stiffness of laminated roof decks. Three tests were done on a simple span layup, and the three tests were done for controlled random layups using uniformly distributed load. The study concluded that the theoretical deflection equations can be used to conservatively predict stiffness characteristics of simple span decks. In the case of the controlled random layups, the maximum deflections occurred in the outer spans. This study yielded a deflection coefficient value of 0.59 and showed that the recommended deflection coefficients of 0.66 (AITC 112-93, 1993) and 0.77 (D.Fir Use, 1958) were too conservative. The authors also noted that the load sharing effect of tongue and groove decking is not very noticeable when a uniform load is applied over the whole area, but becomes more pronounced when non uniform loads are applied to the system. The study also concluded that the behaviour of the laminated decking was the same as that of solid sawn lumber decking.

In 1968, Johnson conducted a study on the effects of adding adhesives and openings to laminated nominal 3-inch decking system. Two 6.1 m by 18.3 m (20 ft by 60 ft) roof diaphragms were built specifically for this experimental study. One of the decking systems was built following prescribed construction details, and the other system was constructed with an additional line of elastomeric adhesive that was applied in the tongue and groove joint. Loads were applied stepwise, in order to measure the deformation at different load levels. The study concluded that adding an elastomeric adhesive at the tongue and groove joints greatly improves the strength and stiffness of a plank decking system, although the increase cannot be quantified as the strength of the adhesive is dependent on the manufacturer. When openings were cut into the decking, and no additional reinforcement was added, it was observed that the adhesive was effective in maintaining the stiffness of the diaphragm. The author of this study recommended the use of adhesives due to its significant positive effect on strength and stiffness.

2.2 Research Related to Load Sharing and Concentrated loading

Load sharing is an important aspect of understand the behaviour of light frame wood structural systems. Several research studies have been conducted on light frame wood floor joist and truss systems. As mentioned in the previous section of this chapter, no studies had been undertaken on the failure properties of tongue and groove decking systems especially under concentrated loading. The following section provides an overview on the research work dealing with load sharing under uniformly distributed and concentrated loading. The latter is of particular interest to the current study. It should be noted that the literature presented here is not complete as the main objective here is to present the principles of load sharing, rather than provide a detailed account of the research done in this area.

Research was undertaken by Vanderbilt, Goodman, and Bodig (1974) to develop a rational analysis procedure for wood joist floor systems. Prior to this study, typical wood-joist floor design provisions did not consider the composite action occurring in wood floor joist system. This method was known as the piece by piece design procedure, and was recognized as inefficient and uneconomical. Experimental and modelling work confirmed that the interaction between the joist and sheathing layers could not be considered as a rigid connection due to the interlayer slip between the stud and sheathing panel. A mathematical model was developed and it was found that the proposed modelling approach compared well with the experimental results. The authors conclude that future research should center on the development of design procedures and the evaluation of the effects of variability on the performance of wood joist structural systems.

Polensek, Atherton, Corder, and Jenkins (1971) performed 45 full scale tests on wood floor joist systems. The tests included different species, joist depths, sheathing, and joist lengths. For each floor, a non-destructive concentrated load test was conducted before loading the floors to destruction using a uniformly distributed load. From the concentrated load tests it was found that about 2/3 of a concentrated load applied at the mid-span of a joist was not carried by the joist under load, but rather shared by 6-8 adjacent joists. The spread of the distribution tended to increase for longer floor spans. It was also noted that the addition of a drywall on the underside of the joists allowed for an increase the amount of concentrated load distributed to adjacent joists, but had a negligible effect on the number of joists that deflected. The tests indicated that floors were significantly stronger than would be predicted by contemporary design methods. The authors created a T-beam model that with proper efficiency factors, could be used as a structural model to analyze the performance of the wood-joist floors under uniform load.

Foschi tested 13 wood floors under a uniformly distributed load (Foschi, 1985) using air-filled bags. All joists were tested non-destructively to determine their modulus of elasticity, and 24 joists were selected and tested to failure to determine the bending strength distribution. A finite element model was developed using the computer program known as FAP, which was able to accurately predict the elastic behaviour of the wood floors under uniform loads. In addition to the load sharing between joist elements, the experimental study also established the redistribution of force that occurred when an intermediate joist fails. The study emphasized the importance of considering the reliability of the entire system as opposed to simply considering the strength of an individual joist.

A study was undertaken at the University of Texas' structural laboratories to determine the static behaviour of wood-joist floors at various limit states (Wheat, Gromala & Moody, 1986). Fifteen wood joist floor systems, each consisting of 10 joists, were tested to their ultimate capacities under a uniformly distributed load. The modulus of elasticity was determined before and after the joists were installed in the system. It was found that there was an 8-10% increase in the modulus of elasticity when the boards were end nailed to the header. Deflection ratios calculated from the results indicated a significant increase in floor stiffness compared to that of a single joist. It was noted that there was interaction between the joists and the sheathing panels through partial composite and two-way actions. The test results showed that the most flexible joist did not necessarily fail first, although the joist which failed first during each test was among the least stiff in the system.

Doudak, Hu, McClure, Stathopoulos and Smith (2005) investigated the effects of uniformly distributed and concentrated loads on a wood I-joist roof assembly. The study established different degrees of load sharing that occurs when a structure is subjected to a concentrated and uniform load. The study found that the joist directly under the load only carried about 26% of the load. The remainder of the load was distributed to the adjacent joists in the roof system. Experimental and analytical modeling confirmed that a total of at least 5 unloaded joists on either side of the loaded joist were actively engaged in resisting the applied load.

2.3 Summary of Literature Review

From the literature review, it was apparent that the research conducted on tongue and groove plank decking had been very limited with no advancement since the 1960's. The research focused only on non-destructive uniformly distributed loading with no research studies dealing with the ultimate capacity under uniform loading. Also, no studies dealt with the effects of concentrated loads on the stiffness and capacity of tongue and groove decking systems.

Load sharing effects of different wood floor and roof assemblies have been studied thoroughly in the past few decades. Since floor and roof systems are primarily loaded with uniform pressure, the focus of the studies was mainly on uniform loads with only few studies dealing with concentrated load at low load levels.

The current study aims at investigating the validity of current deflection provisions and extends to establish the failure mechanisms of different layup patterns and under different loading conditions. The focus will be on investigating the behaviour of the decking systems under concentrated loading and establishing the effect of the number of boards on the stiffness and strength of the decking system.

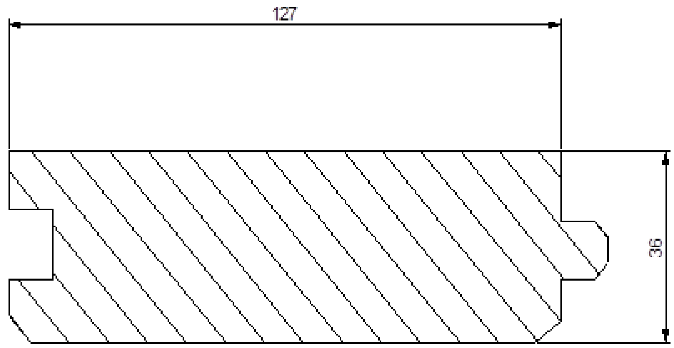
CHAPTER 3-Experimental Program

3.1 General

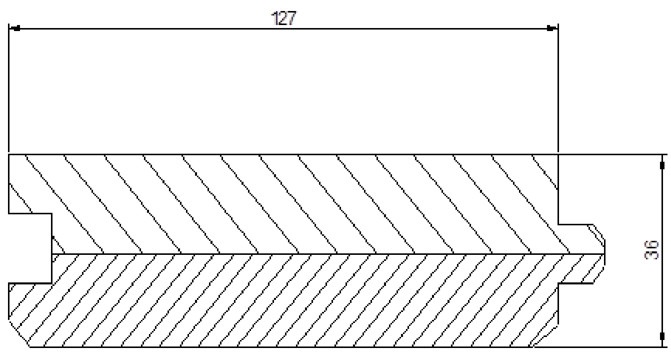
An experimental testing program was undertaken at the University of Ottawa's Structural Laboratory with the aim of investigating the behaviour of plank (tongue and groove) wood decking systems under uniform and concentrated loading. Five different species of wood and two different decking sizes, including solid sawn and laminated decking products, were tested. The solid sawn species included Spruce-Pine-Fir (S-P-F), Douglas-Fir-Larch (D.Fir-L), and Alaskan Yellow Cedar. The laminated species included D.Fir-L and Ponderosa Pine. The decking sizes consisted of 36 mm x 127 mm and 55 mm x 131 mm for D.Fir-L Laminated, while 36 mm x 127 mm was used for all other species. The laminated decking was manufactured in compliance with ASTM D2559. *Table 3.1* summarizes the different species and sizes that were tested, and includes the abbreviations that will be used in this thesis. For example, SPF-S2 represents the test configuration involving **S**pruce **P**ine **F**ir, **S**olid Sawn 6x**2** board elements. *Figures 3.1(a)-(c)* show typical cross sections of the plank decking systems that were studied.

Table 3.1: Tested Species and Abbreviations

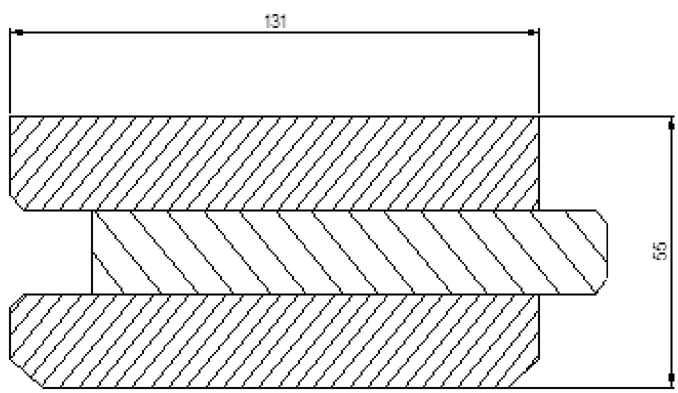
Species	Type	Nominal Size (inches)	Actual Size (inches)	Actual Size (mm)	Abbreviation
Spruce-Pine-Fir	Solid Sawn	2x6	5 x 1-7/16	127 x 36	SPF-S2
Douglas-Fir	Solid Sawn	2x6	5 x 1-7/16	127 x 36	DFL-S2
Alaskan Yellow Cedar	Solid Sawn	2x6	5 x 1-7/16	127 x 36	AYC-S2
Douglas-Fir	Glue-Laminated	2x6	5 x 1-7/16	127 x 36	DFL-L2
Ponderosa Pine	Glue-Laminated	2x6	5 x 1-7/16	127 x 36	POP-L2
Douglas-Fir	Glue-Laminated	3x6	5-1/4 x 2-3/16	131 x 55	DFL-L3



(a) Solid Sawn 127 mm x 36 mm



(b) Glue Laminated 127 mm x 36 mm



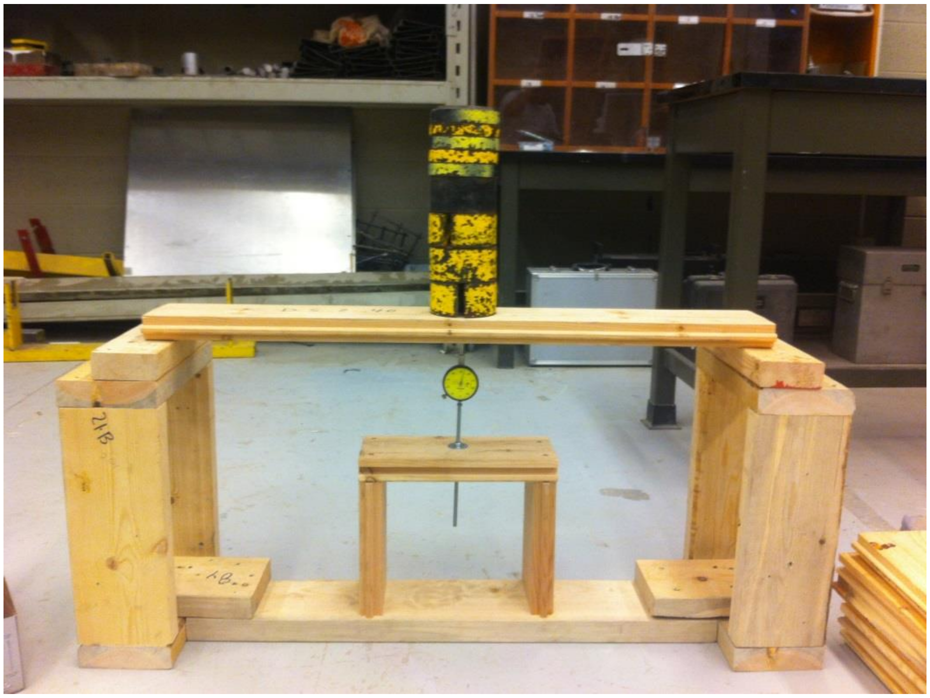
(c) Glue Laminated 131 mm x 55 mm

Figure 3.1: Typical Cross Sections of Plank Decking Elements in Study

Since the majority of test results stem from 127 mm x 36 mm D.Fir-L solid sawn lumber decking, the results presented in the body of the report typically pertain to this type of decking. Results from other species or sizes are presented in the Appendices and only highlighted in cases where there was a significant difference in the behaviour relative to the D.Fir-L solid sawn.

3.2 Determination of Modulus of Elasticity of Individual Boards

The modulus of elasticity (MOE) for each board was determined prior to the full scale testing of the deck system. This was deemed useful for the evaluation of the stiffness of the decking systems, and would serve as input for the finite element modelling (FEM). The boards used in the testing program had an average moisture content of 15% when they were tested, with the moisture content in any specimen not exceeding 19%. The MOE was determined using two different methods: (1) by applying a static load in the elastic region while measuring the associated mid-span deflection, and (2) by using a hand-held timber grader (Brookhuis Micro-Electronics). The deflection was measured at three different loading intervals, and the stiffness (slope of the load-deflection curve) was used to calculate the MOE of each board. The end conditions for this testing were such that the boards were allowed to freely rotate at the supports (pinned end conditions). *Figure 3.2(a)* shows an example of the test setup for a D.Fir-L solid sawn board. The reading from the hand-held timber grader was based on measuring the sound-wave through the decking member. *Figure 3.2(b)* is an example of the timber grader being used on a sample of Alaskan Yellow Cedar solid sawn decking. A summary of the MOE results for each species can be seen in *Appendix A.*



(a) Static Load Test

(b) Brookhouis Timber Grader

Figure 3.2: Modulus of Elasticity for individual boards

3.3 Test Procedure

All full scale decking test specimens were supported on 38 mm x 89 mm wooden knee walls affixed to the laboratory strong floor. The knee walls were braced together to ensure lateral stability. The top plates of the knee walls were replaced periodically throughout the testing to ensure that damage to the plates did not have adverse effect on the test results. Decking span lengths of 1000 mm (3 feet 3-3/8 inches), 1524 mm (5 feet), 1829 mm (6 feet), 2132 mm (7 feet) and 3000 mm (9 feet 10-1/16 inches), were tested. All four layup patterns described in *Chapter 1* (*Figures 1.4(a)-(d)*) were tested non-destructively, whereas, the focus of the destructive testing was on simple span and controlled random layup patterns only. A summary of each test, as well as the layup pattern, MOE of individual boards and failure modes can be seen in *Appendix B* and *C*. *Appendix B* includes all of the non-destructive test results, and *Appendix C* includes all of the destructive test results.

Tests were conducted on samples of plank decking to investigate the difference between using nails, which are typically used in construction of such decks, and screws. Screws are obviously the preferred option for connections when dealing with non-destructive testing, however, it was important that such change in end conditions does not affect the behaviour of the decking system. Two 83 mm long nails and two 89 mm long screws were driven perpendicular to the grain, as seen in *Figures 3.3(a) and (b)*.

(a) Nailed End-condition

(b) Screw End-condition

Figure 3.3: Typical End-Conditions in Study

Figure 3.4 shows the variation in stiffness between the two end-conditions. From this figure it can be observed that there is no significant difference between the two end conditions on the stiffness of the board elements.

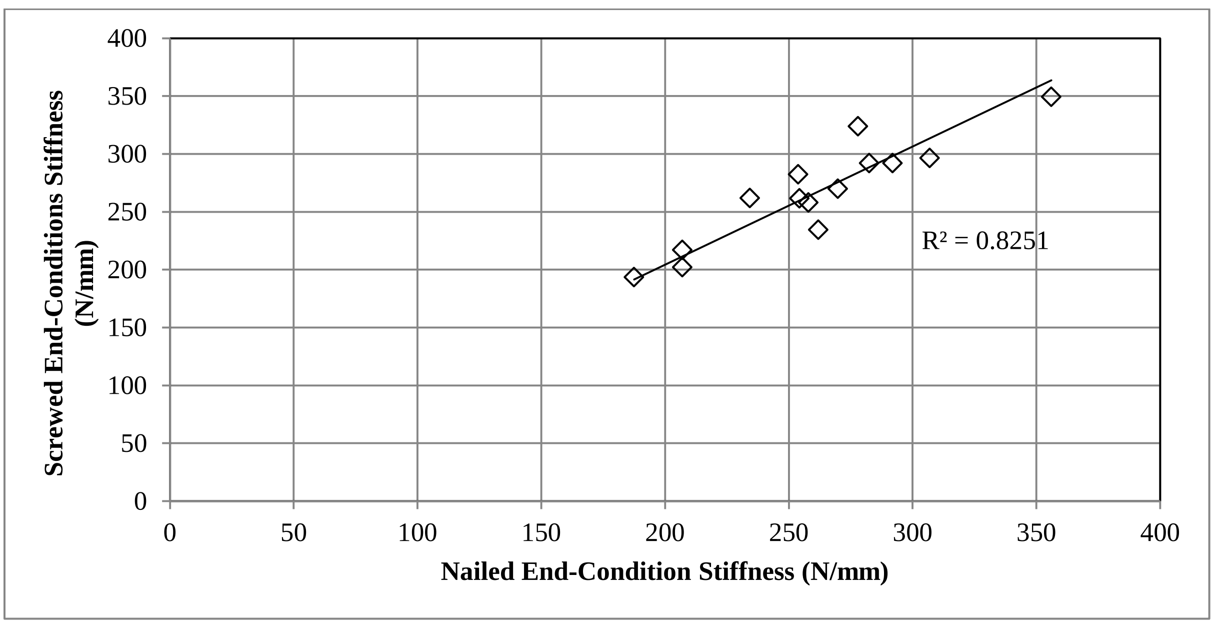


Figure 3.4: Comparison of Pin End-Conditions in Study

It was therefore decided to use the 89 mm long screws to assemble all of the non-destructive test specimens, so that the boards could be dismantled and reused in the destructive tests setups. If a butt joint occurred over a support, two screws were placed in the end of each piece of decking.

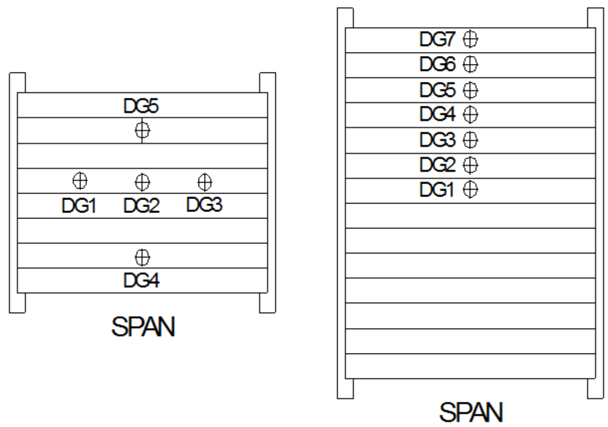
3.3.2 Non-Destructive Tests

3.3.2.1 General

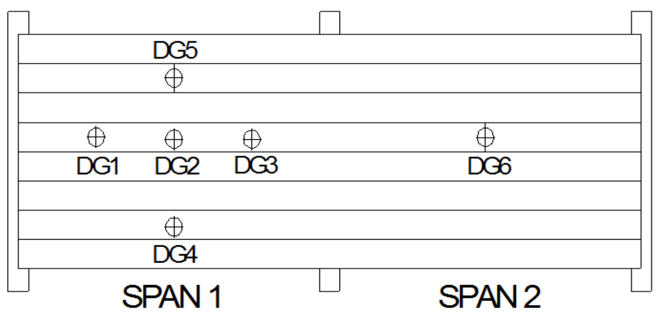
Dial gauges were placed at mid-span, as well as other points of interest, in order to establish a full description of the deflected shape. *Figure 3.5* shows an example of the dial gauges used in the non-destructive testing.

Figure 3.5: Deflection Gauges for Non-Destructive Tests

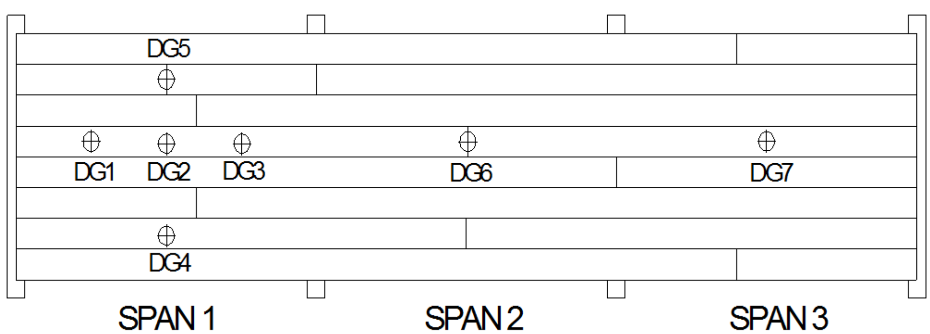
The number of boards was increased (from 2 to 14) in the simple span tests in order to establish the number of boards that would actively participate in resisting the load and contribute to the stiffness of the decking system. The number of boards for the controlled random and two-span continuous layups was kept to eight boards, based on the results obtained from the simple span layup. All controlled random layups consisted of three spans with four supports, and were constructed to meet the prescriptive provisions specified by the CWC's Wood Design Manual (CWC, 2010). The typical dial gauge locations (marked as DG) for the non-destructive simple span, two-span continuous, and controlled random layups can be seen in *Figures 3.6(a)-(c)*, respectively.



(a) Simple Span Layup



(b) Two-Span Continuous Layup



(c) Controlled Random Layup

Figure 3.6: Location of Deflection Gauges for Non-Destructive Tests

3.3.2.2 Uniform Load Tests

A uniformly distributed load was simulated using bags of cement that were weighed prior to the loading. Deflection measurements were recorded when the system was at rest prior to loading, after it was loaded, and once again when the system was unloaded. *Figure 3.7* shows the test setup for simple span tests.

Figure 3.7: Simple Span Layup Non-Destructive Uniform Load Test (3.63 kN/m^2)

For the two-span continuous and control random layups, each span was loaded and unloaded individually as well as in combination with other spans simulating patterned loading. *Figure 3.8* shows the two-span continuous layup under the unbalanced uniform loading (*Figure 3.8(a)*), and balanced uniform loading (*Figure 3.8(b)*). *Figure 3.9* shows the control random layup under the unbalanced uniform loading (*Figure 3.9(a) and (b)*), and balanced uniform loading (*Figure 3.9(c)*).

(a) Unbalanced Loading (2.42 kN/m^2)

(b) Balanced Loading (2.42 kN/m^2)

Figure 3.8: Two-Span Continuous Layup Non-Destructive Uniform Load Test

(a) Unbalanced Loading on Span 1 (2.42 kN/m^2)

(b) Unbalanced Loading on Spans 1 and 2 (2.42 kN/m^2)

(c) Balanced Loading on all 3 spans (1.21 kN/m^2)

Figure 3.9: Control Random Layup Non-Destructive Uniform Load Test

3.3.2.3 Concentrated Load Tests

A concentrated load was applied to the decks by using a loading block with a surface area of 200 mm x 200 mm, placed in the centre of the span. For the two-span continuous layups, only one span was tested under a concentrated load. For controlled random and combination simple and two-span continuous layups, the concentrated load test was performed at each span. *Figures 3.10(a)-(c)* shows the concentrated load test setup for the different layup patterns.

(a) Simple Span Layup (1.1 kN)

(b) Exterior span of a Controlled Random Layup (1.1 kN)

(c) Centre span of a Controlled Random Layup (1.1 kN)

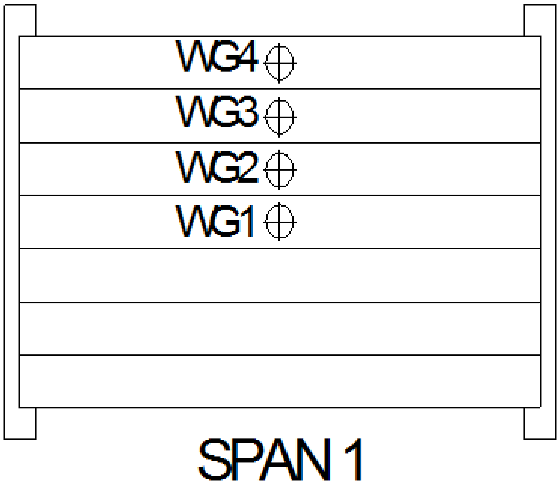
Figure 3.10: Non-Destructive Concentrated Load Tests

3.4 Destructive Tests

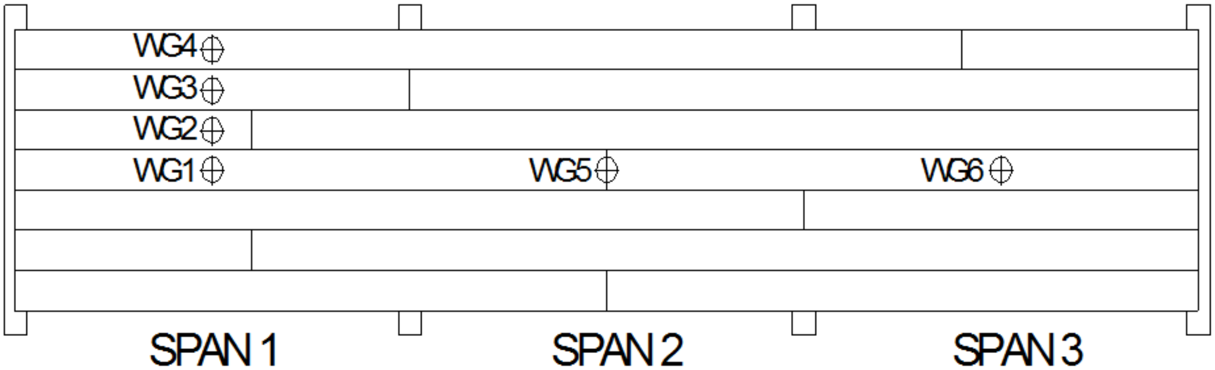
3.4.1 General

The destructive testing followed the ASTM D198-09 standard (ASTM, 2009) with the exception of the end conditions, where the boards in the current study were fastened to the support to mimic actual construction details. The destructive tests were only done on simple span and controlled random layup patterns. It was only possible to load one span at a time to destruction, therefore for the controlled random layup, only the exterior span was loaded. This would yield the most severe load effect and would therefore be conservative for the purpose of developing design provisions. Ideally, a concentrated load with varying size of loaded area would be investigated. However, due to the testing limitations, it was decided to test two areas; 127 mm x 127 mm, which would represent the width of one decking element and 200 mm x 200 mm, which is consistent with the NBCC prescribed loading area. To simulate uniform loading, a four-point bending test was performed, since this loading yields a constant shear-free moment between the loading points. Loads were measured using a load cell connected to the data acquisition. Deflections were recorded using wire gauges, as seen in *Figure 3.11(a)*. For the simple span tests, four wire gauges (marked as WG) were placed at the mid-span of multiple boards, including boards that were not directly under the load, *Figure 3.11(b)*. When the controlled random layup was tested, two additional wire gauges were placed at the mid-span of the centre boards for each of the two unloaded spans, *Figure 3.11(c)*. The duration of the tests until failure was between 2 and 8 minutes, depending on the strength, size and the number of boards being tested.

(a) Wire Gauges



(b) Simple Span Layup

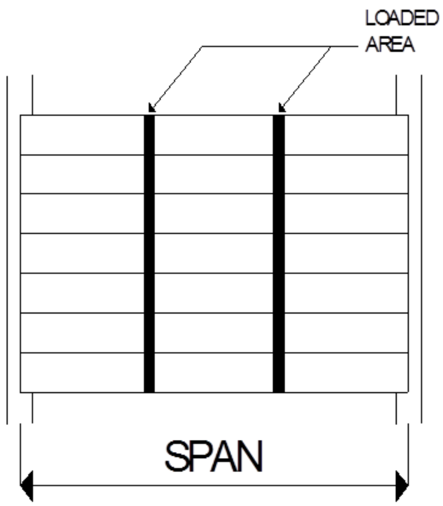


(c) Controlled Random Layup

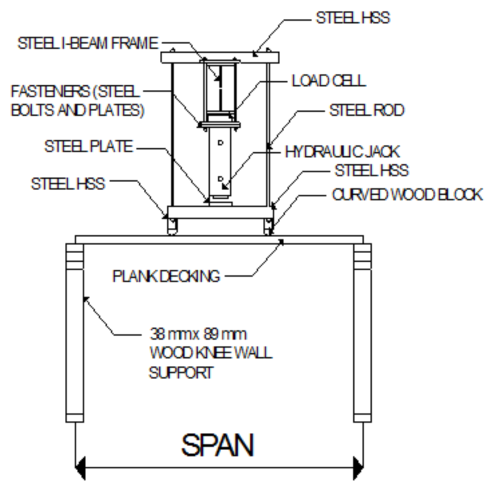
Figure 3.11: Wire Gauge Locations during Destructive Tests

3.4.2 Four Point Bending Tests

Destructive simple span tests were conducted for layups that were 1, 3, 5, and 7 boards wide. The destructive controlled random tests were all 7 boards in width, with the exception of the 55 mm x 131 mm decking, which was only 5 boards in width. The decking boards were fastened to the supports following specifications from the manufacturer. The 127 mm x 36 mm decking was fastened to the supports using 83 mm spiralled nails. The 131 mm x 55 mm decking was fastened to the supports using 102 mm spiralled nails. For tests conducted on the 131 mm x 55 mm decking, additional 63.5 mm spiralled nails were slant driven in between courses of decking on 762 mm centres. The four-point bending setup consisted of two wooden blocks that were equivalent to seven boards in length. The wooden blocks were attached to steel HSS beams, which in turn were connected together at the centre using another steel HSS beam. To protect the wire gauges, the loading block was also attached to four steel rods, as seen in *Figure 3.12*. Top and side views of the single span four point bending test with 7 boards can be seen in *Figures 3.12(a)* and *(b)*. *Figure 3.12(c)* shows a simple span layup before a four-point bending test was performed, and *Figure 3.12(d)* is an image of a controlled random layup before a four point bending test was performed.



(a) Top View



(b): Side View

(c) Simple Span Layup

(d) Controlled Random Layup

Figure 3.12: Destructive Four-Point Bending (4PB) Test

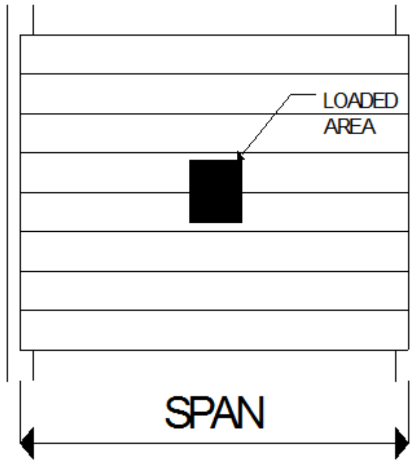
3.4.3 Concentrated Load

The loading area for the concentrated load tests was constructed using a wooden loading block and a steel plate that was placed on top to avoid crushing. Two different loading areas were investigated during the destructive concentrated load tests; (1) 200 mm x 200 mm and (2) 127 mm x 127 mm.

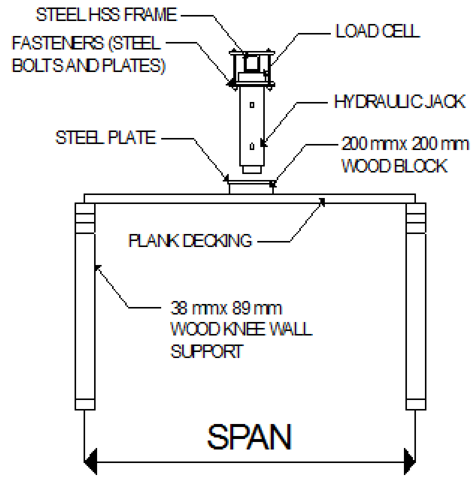
The destructive simple span concentrated load tests with 200 mm x 200 mm loaded area were conducted on systems consisting of 1, 2, 4, 6, and 8 boards, whereas, the controlled random tests were done with 8 boards. Screw end-conditions, similar to those used in the non-destructive tests were used in all of the destructive concentrated load tests with 200 mm x 200 mm area.

The destructive simple span concentrated load with loading area of 127 mm x127 mm were conducted for layups that were 1, 3, 5, and 7 boards wide. The destructive controlled random tests were all 7 boards wide. Nail end-conditions, similar to the destructive four point bending tests were used in all of the destructive concentrated load tests with 127 mm x 127 mm area.

Top and side views of the simple span concentrated load (200x200) test can be seen in *Figures 3.13(a)* and *(b)*. *Figure 3.13(c)* is an image of the test set-up for a simple span layup under a 200 mm x 200 mm concentrated load, and *Figure 3.13(d)* is an image of the test set-up for a controlled random layup under a 127 mm x 127 mm concentrated load.



(a) Top view (CL200)



(b) Side view (CL200)

(c) Simple Span Layup (CL200)

(d) Controlled Random Layup (CL127)

Figure 3.13: Destructive Concentrated Load Test Set-up

3.5 Destructive Tests with Sheathing

3.5.1 General

It can be anticipated that sheathing would typically be placed on top of plank decking to achieve a diaphragm action. Therefore, the effects that the addition of a sheathing panel on the strength and stiffness of a decking system under both a concentrated load (127x127) and a four-point bending loading, were investigated. For both load cases, the sheathing panel consisted of 11 mm oriental-strand-board (OSB). The test began by loading the decking without any sheathing on top to determine the stiffness of the plank decking by itself. Then, the sheathing was fastened on top of the decking, and the system was loaded to failure. The test set-up was the same as described earlier in section 3.4.2 and 3.4.3 for four-point bending and concentrated load (127x127), respectively.

Simple Span Concentrated Load (127x127) tests were done on systems that were 7 boards wide and had OSB sheathing nailed on top of the decking. The sheathing panel was nailed using 63.5 mm spiralled nails spaced 300 mm apart, which is considered typical diaphragm nailing requirements. Six tests were conducted in total, three with D.Fir-L solid sawn decking, and three with Ponderosa Pine laminated decking. An image of the concentrated load (127x127) with sheathing test set-up can be seen in *Figure 3.14(a)*. Simple span four-point bending tests were done on D.Fir-L solid sawn systems that were 5 boards wide, as seen in *Figure 3.14(b)*

(a) Concentrated Load (127x127) (b) Four-point Bending

Figure 3.14: Destructive Test Set-up with Addition of Sheathing

CHAPTER 4-Experimental Results and Numerical Analysis

The following chapter presents the results from the experimental program and the numerical study. Unless noted otherwise, within the main thesis it can be assumed that the presented trends are representative examples of the behaviour of the all board systems tested. More details on individual tests non-destructive and destructive tests can be found in *Appendix B* and *C*, respectively.

4.1 Modulus of Elasticity (MOE) Results

The MOE of all boards were measured and the results were compared with the average MOE values provided by the Canadian wood design standard (CSA O86, 2010). *Figure 4.1* shows the measured MOE values for the D.Fir-L test specimens. For D.Fir-L solid sawn boards, the average published MOE value for Select Structural grade is 12500 MPa. The average measured MOE was found to be 13077 MPa, with a standard deviation of 1116 and a coefficient of variance (COV) of 8.5%. Similar figures from the other species tested can be found in *Appendix A*.

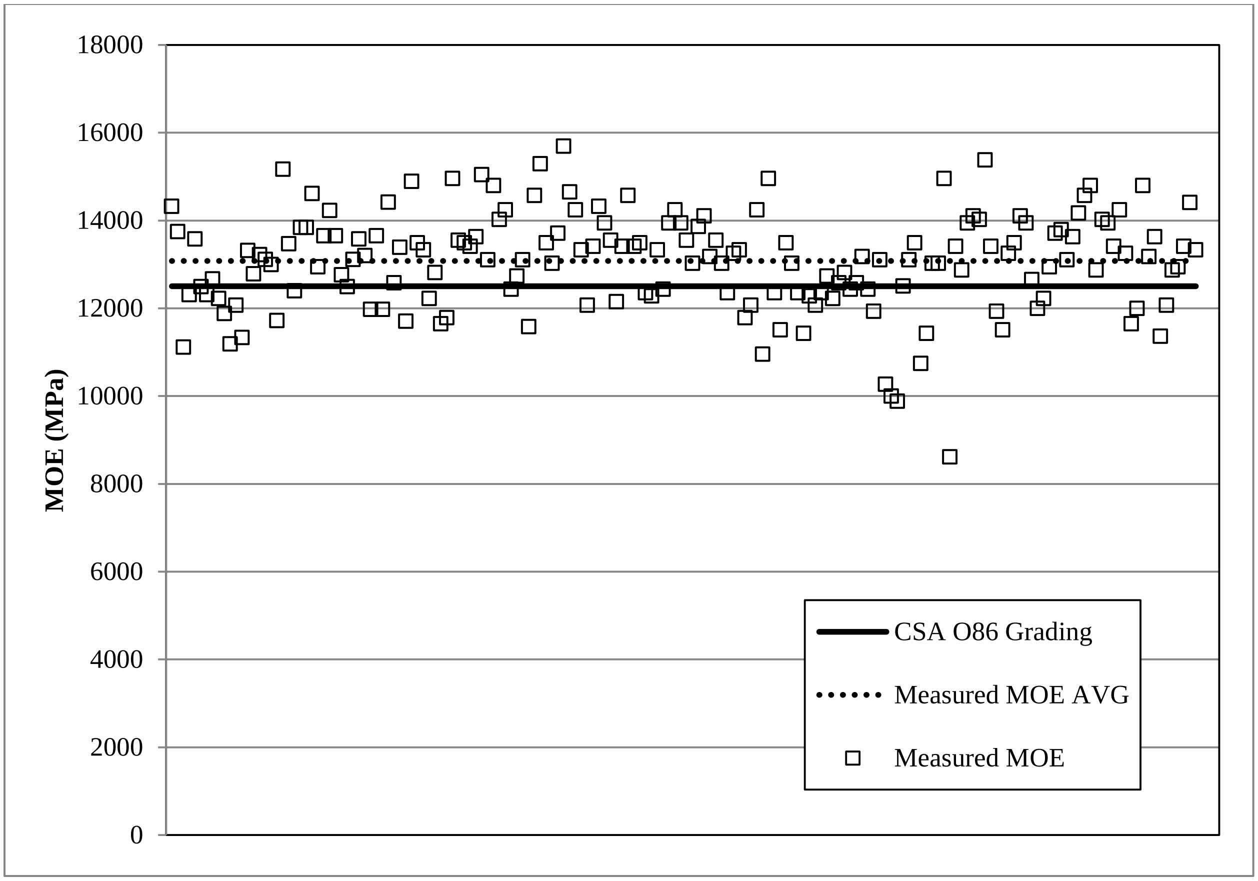


Figure 4.1: D.Fir-L Solid Sawn 127 mm x 36 mm MOE Results

From *Figure 4.1*, it can be seen that the average measured MOE was found to be slightly higher than the average published in the Canadian standard (CSA O86, 2009). Similar trends were found for the other species in the testing program, with the exception of the D-Fir-L 131 mm x 55 mm laminated decking, where the average measured MOE was found to be less than published values. This could be attributed to the relatively low number of samples used to measure the MOE or that the selected samples were not representative of that grade. *Figure 4.2* shows the cumulative probability distribution for the data from *Figure 4.1*. From *Figure 4.2* it can be observed that the MOE data fits a normal distribution well.

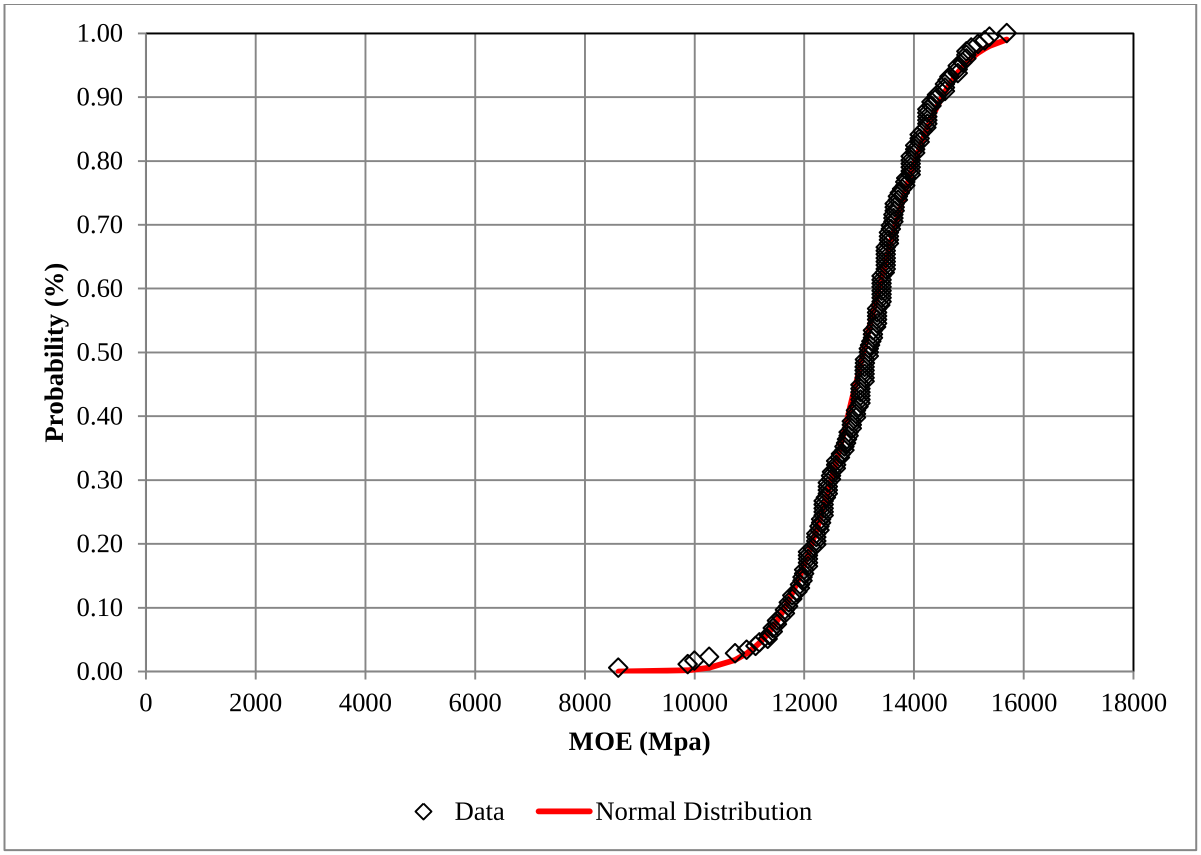


Figure 4.2: D.Fir-L Solid Sawn 127 mm x 36 mm MOE Normal Distribution

4.2 Non-Destructive Tests

4.2.1 Uniform Load

Figure 4.3 shows a typical load versus mid-span deflection curve for a simple span layup with 8 boards subjected to a uniformly distributed load. The graph shown in *Figure 4.3* is for specimen number ND-SS-2-DFL-S2-8. The notation used for the specimens' names in this chapter describes the loading types, layup, species and number of boards. Therefore specimen "ND-SS-2-DFL-S2-8" corresponds to non-destructive testing (ND), simple span (SS), test number 2, D.Fir-L species (DFL), solid sawn 2"x6" (S2), with 8 boards in width. Similar behaviour was observed in all non-destructive uniform load tests, as seen in *Appendix B.*

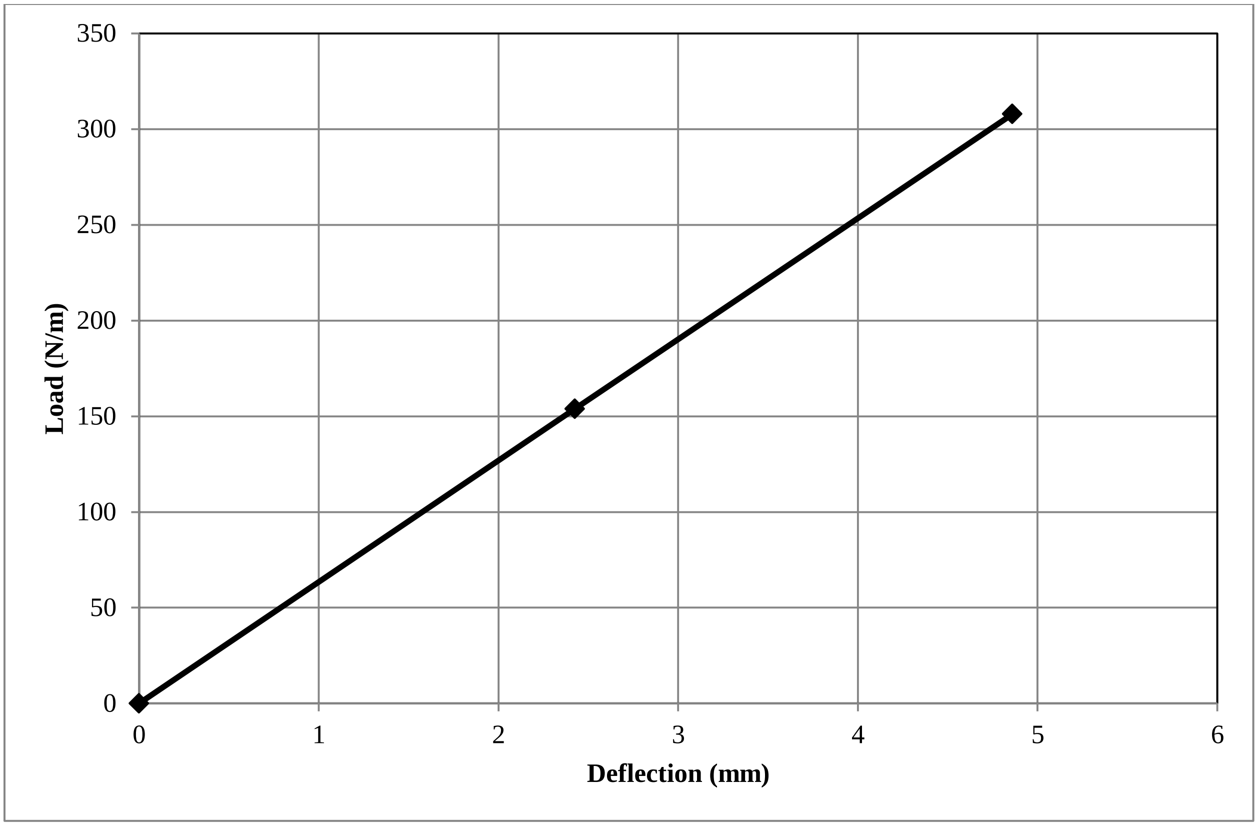


Figure 4.3: UDL vs. Mid-span Deflection Curve – (ND-SS-2-DFL-S2-8)

4.2.1.1 Simple Span Layup

Figure 4.4 shows a typical (exaggerated) deflected shape for a D.Fir-L Laminated 127 mm x 36 mm 8 board decking system. Also included in *Figure 4.4* is the expected theoretical deflected shape under a uniform pressure and pinned end conditions. The theoretical deflected shape was determined using the average MOE of the tested decking system. It can be observed from the figure that the tested decking system deflected less than that predicted using theoretical deflection equation. Similar results were found for the other non-destructive simple span uniform load tests. For the test shown in *Figure 4.4*, the ratio between the experimental deflection and the theoretical deflection was 0.89.

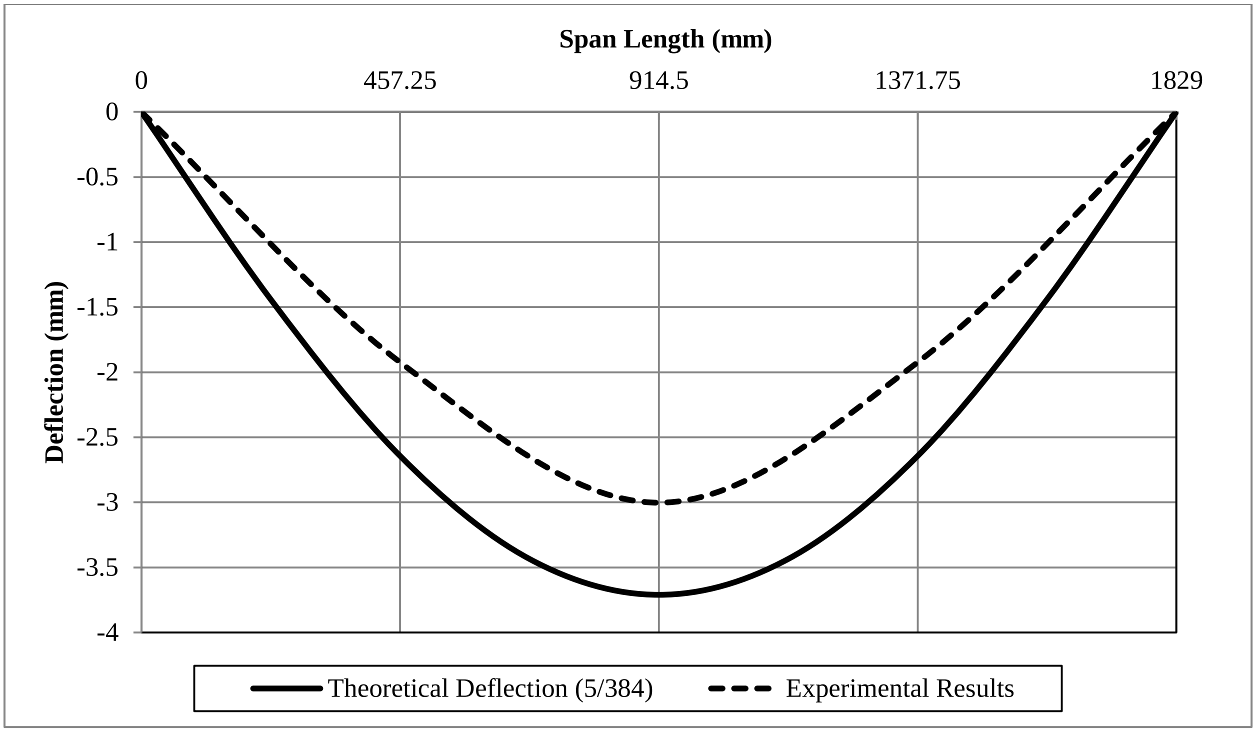


Figure 4.4: UDL Deflection Curve Simple Span Layup – Screw End-Conditions

The simple span uniform load tests were conducted on systems consisting of 2 to 14 boards in width. *Table 4.1* compares the experimental and theoretical deflections when subjected to the same uniform load (0.2 kN/m) from test ND-SS-4-DFL-S2. The deflections were calculated using the theoretical deflection equation for uniform load on a simple span with pin end-conditions. The MOE used in the equation was the average MOE of the boards in the system, and obtained from the experimental test on the individual boards. Similar trends were found for the other non-destructive simple span uniform load tests conducted on the other species.

Table 4.1: Simple Span UDL Deflection Coefficients

Number of Boards in Test	Exp. Δ (mm)	Theo. Δ (mm)	Deflection Coefficient (γ_{UDL})
2	7.46	11.87	0.63
4	9.92	9.81	1.01
6	9.02	9.67	0.93
8	9.03	9.18	0.98
10	8.45	8.7	0.97
12	8.12	8.58	0.95
14	8.18	8.58	0.95

4.2.1.2 Two-Span Continuous Layup

Figure 4.5 shows a typical (exaggerated) deflected shape for a decking system consisting of 8 boards in a two-span continuous layup under uniform loading. In addition to the measured deflection, *Figure 4.5* includes the theoretical deflected shape for a uniformly loaded two-span continuous beam as well as the theoretical deflected shape for a uniform load on a simple span. The latter was included as a reference because, as mentioned in *Chapter 1*, the deflection formula for any layup is determined using the deflection obtained from a simple span multiplied by the appropriate deflection coefficient. The average MOE from the boards in the experimental test was used to calculate the theoretical deflections. From *Figure 4.5*, it can be observed that when a two-span continuous layup is loaded uniformly, the measured deflection was slightly less than that predicted using the theoretical deflection formula. The resultant curve in *Figure 4.5* is for test ND-TS-1-DFL-S2-8, and for this particular test, the calculated deflection coefficient was 0.30.

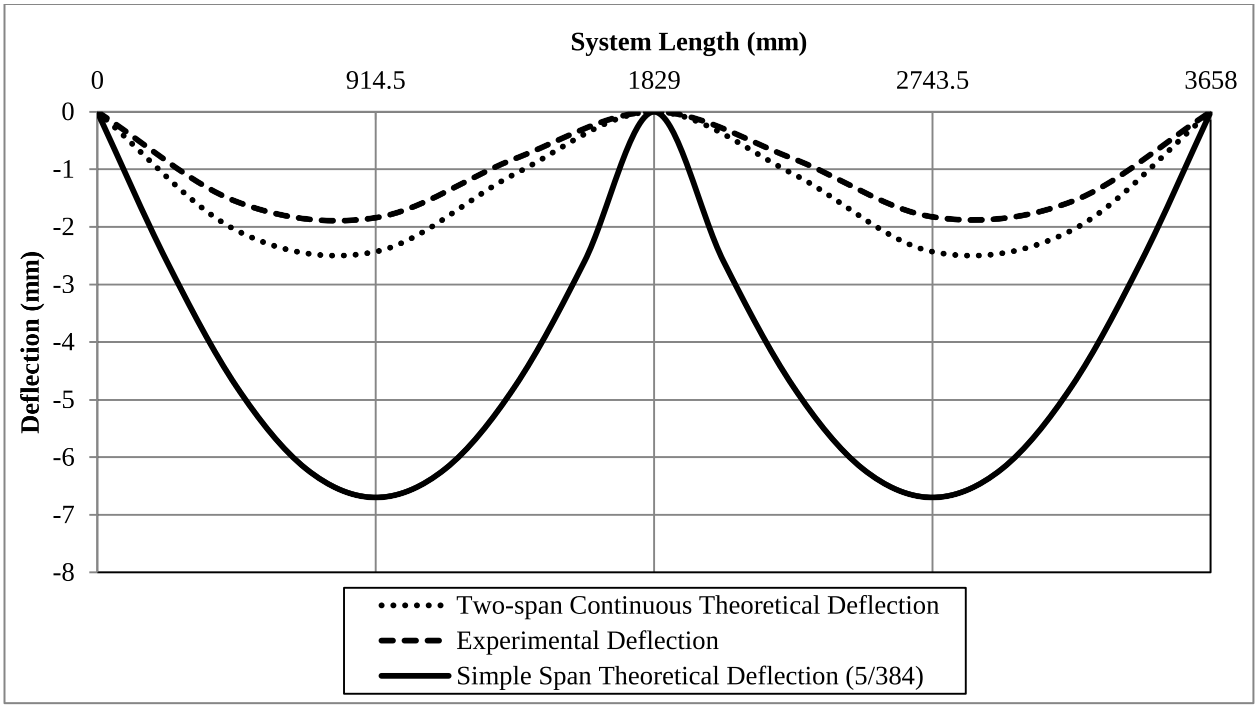


Figure 4.5: UDL Deflection Curve Two-Span Continuous Layup – Screw End-conditions

The resulting deflection coefficients for all non-destructive balanced uniform loads on two-span continuous layups are summarized in *Table 4.2*. The average deflection coefficient of the 6 tests was found to be 0.36 with a standard deviation of 0.052.

Table 4.2: Two-Span Continuous UDL Deflection Coefficients – Screw End-Conditions

Test Name	**Deflection Coefficient (γ_{UDL})**
ND-TS-1-DFL-S2-8	0.30
ND-TS-1-AYC-S2-8	0.39
ND-TS-1-DFL-L2-8	0.38
ND-TS-1-POP-L2-8	0.30
ND-TS-1-SPF-S2-8	0.35
ND-TS-2-DFL-S2-8	0.43

The two-span continuous layup was also subjected to an unbalanced uniform loading, where only one span was loaded. The average deflection coefficient of the 5 tests shown in *Table 4.3* was found to be 0.56 with a standard deviation of 0.037.

Table 4.3: Two-Span Continuous Unbalanced UDL Deflection Coefficients – Screw End-conditions

Test Name	Deflection Coefficient (γ_{UDL})
ND-TS-1-DFL-S2-8	0.59
ND-TS-1-AYC-S2-8	0.52
ND-TS-1-DFL-L2-8	0.56
ND-TS-1-POP-L2-8	0.53
ND-TS-1-SPF-S2-8	0.61

4.2.1.3 Controlled Random Layup

Figure 4.6 shows a typical (exaggerated) deflected shape for an 8 board wide controlled random layup under uniform loading. The results represent test ND-CR-1-DFL-S2-8-B. From the figure, it can be seen that the observed deflection was similar to that calculated from the theoretical equation of a three-span continuous beam, but significantly less than that obtained for a simple span beam. The calculated deflection coefficient obtained from the test specimen shown in *Figure 4.6* was 0.56, based on the maximum deflection measured in the outer spans.

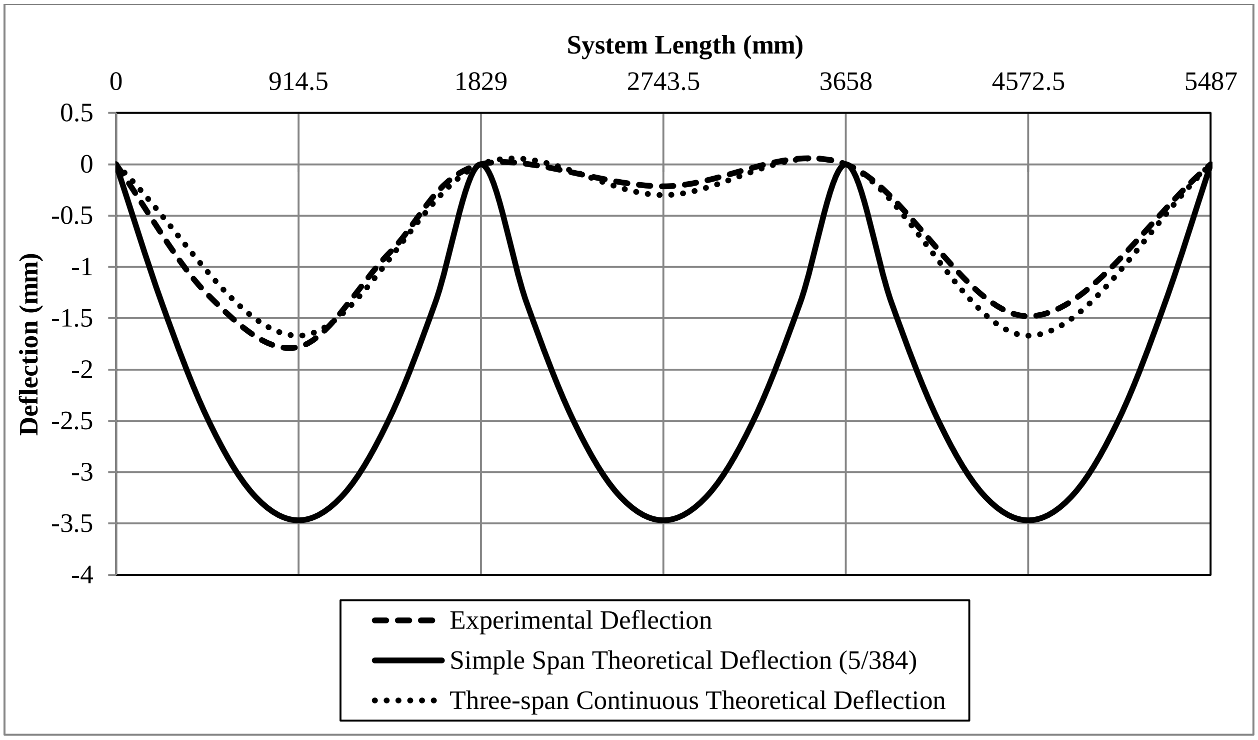


Figure 4.6: UDL Deflection Curve Controlled Random Layup – Screw End-conditions

The calculated deflection coefficients for all balanced uniform load controlled random and combination simple and two-span continuous tests are summarized in *Table 4.4*. The average deflection coefficient from all the 16 tests was found to be 0.57 with a standard deviation of 0.092.

Table 4.4: Controlled Random UDL Deflection Coefficients – Screw End-Conditions

Test Name	Deflection Coefficient (γ_{UDL})	Test Name	Deflection Coefficient (γ_{UDL})
ND-CR-1-DFL-S2-8-B	0.56	**ND-CR-4-DFL-S2-8-B**	0.72
ND-CR-1-AYC-S2-8-B	0.55	**ND-CR-3-SPF-S2-6-B**	0.74
ND-CR-1-DFL-L2-8-B	0.47	**ND-SD-1-DFL-S2-8-B**	0.48
ND-CR-1-POP-L2-8-B	0.55	**ND-SD-1-AYC-S2-8-B**	0.44
ND-CR-1-SPF-S2-8-B	0.52	**ND-SD-1-DFL-L2-8-B**	0.51
ND-CR-2-SPF-S2-8-B	0.63	**ND-SD-1-POP-L2-8-B**	0.49
ND-CR-2-DFL-S2-8-B	0.61	**ND-SD-1-SPF-S2-8-B**	0.54
ND-CR-3-DFL-S2-8-B	0.72	**ND-SD-2-DFL-S2-8-B**	0.56

Similar testing was done on the controlled random layup with unbalanced loading on the exterior span as well as one exterior and one interior span. *Figure 4.7* shows the typical deflected shape from test ND-CR-1-DFL-S2-8-U1. It can be seen that the measured curve followed the theoretical one reasonably well, with measured deflections always being less than those obtained using the theoretical equation for a three span continuous beam.

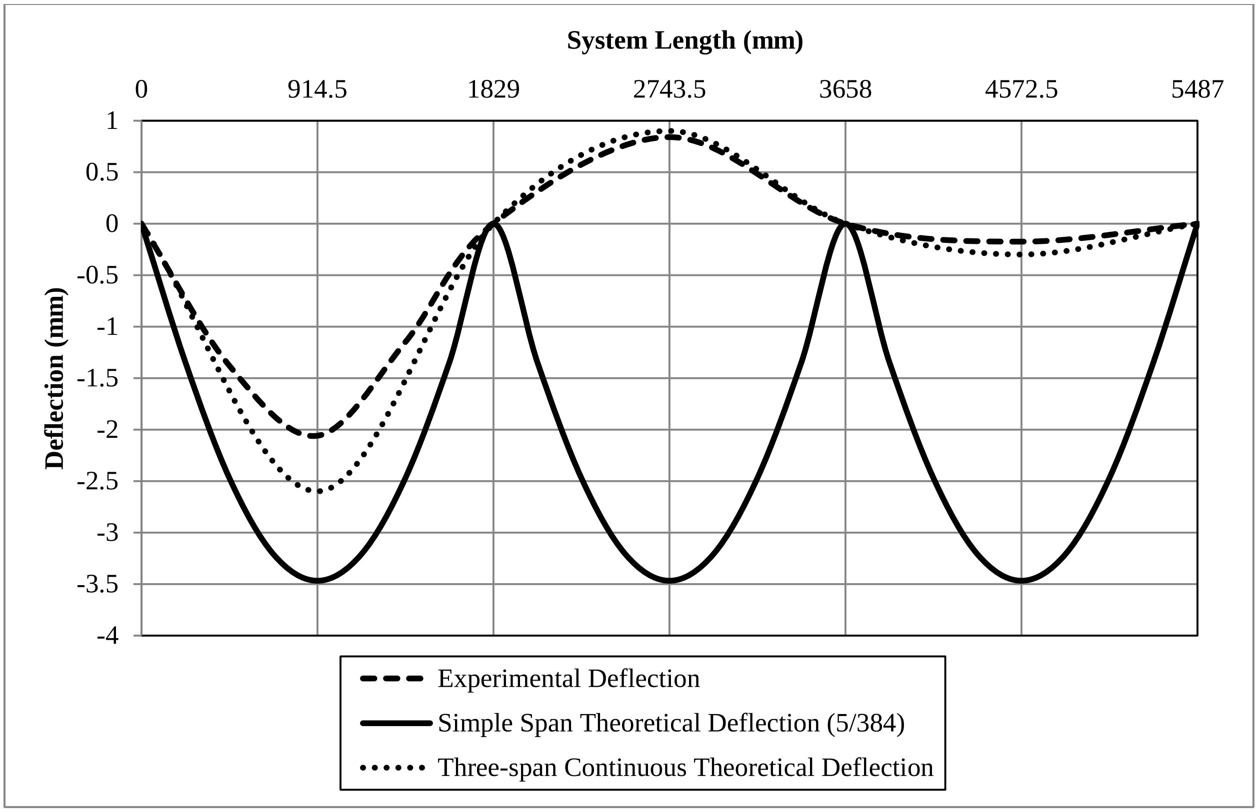


Figure 4.7: Unbalanced UDL Deflection Curve Controlled Random Layup – Screw End-Conditions

The deflection coefficients for controlled random and combination simple span and two-span continuous layup under unbalanced uniform load have been summarized in *Table 4.5*. The average deflection coefficient from the 16 tests presented in the table was found to be 0.49 with a standard deviation of 0.137.

Table 4.5: Controlled Random Unbalanced UDL Deflection Coefficients – Screw End-conditions

Test Name	Deflection Coefficient (γ_{UDL})	Test Name	Deflection Coefficient (γ_{UDL})
ND-CR-1-DFL-S2-8-U1	0.71	**ND-SD-1-DFL-S2-8-U1**	0.54
ND-CR-1-DFL-S2-8-U2	0.43	**ND-SD-1-DFL-S2-8-U2**	0.39
ND-CR-1-AYC-S2-8-U1	0.63	**ND-SD-1-AYC-S2-8-U1**	0.36
ND-CR-1-AYC-S2-8-U2	0.44	**ND-SD-1-AYC-S2-8-U2**	0.23
ND-CR-1-DFL-L2-8-U1	0.56	**ND-SD-1-DFL-L2-8-U1**	0.52
ND-CR-1-DFL-L2-8-U2	0.38	**ND-SD-1-DFL-L2-8-U2**	0.38
ND-CR-1-POP-L2-8-U1	0.75	**ND-SD-1-POP-L2-8-U1**	0.60
ND-CR-1-POP-L2-8-U2	0.47	**ND-SD-1-POP-L2-8-U2**	0.43

4.2.2 Concentrated Load

To the author's knowledge, no prior research study investigated the effect of concentrated load on the stiffness characteristics of decking systems. The load versus mid-span deflection relationship was always linear during the non-destructive testing, as seen in *Figure 4.8*. All non-destructive concentrated load tests results can be found in *Appendix B*.

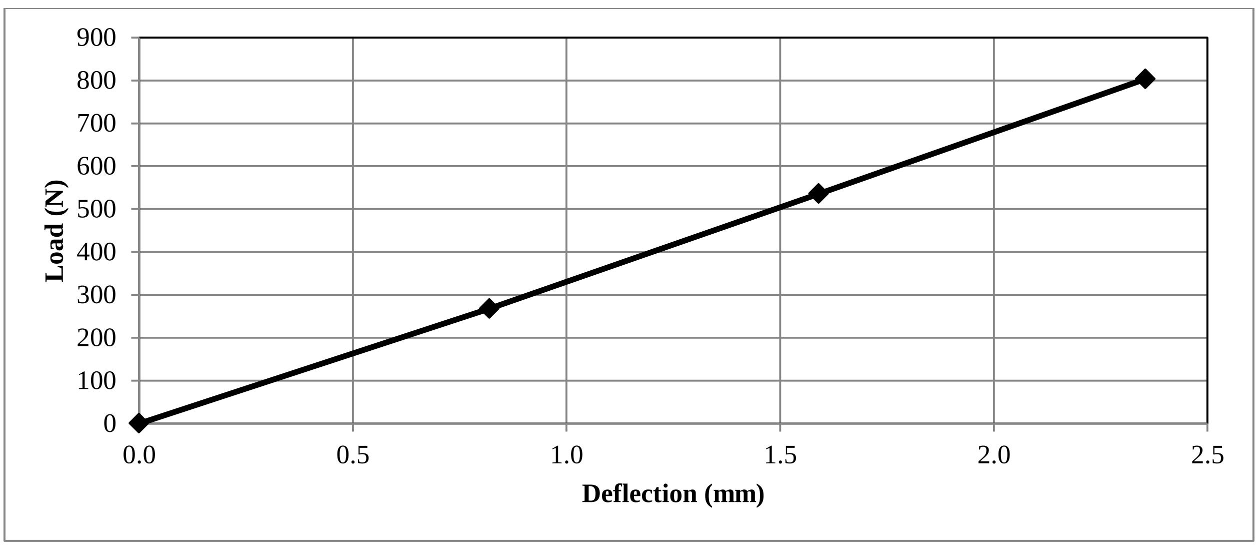


Figure 4.8: Concentrated Load (200x200) vs. Mid-span Deflection Curve – (ND-SS-2-DFL-S2-8)

4.2.2.1 Simple Span Layup

Figure 4.9 shows the (exaggerated) deflected shape of a decking system consisting of 8 boards under a concentrated load of 1.1 kN on an area of 200 x 200 mm^2. The results represent test ND-SS-2-DFL-S2-8. It is obvious from figure that the decking system deflected much less than the expected theoretical deflection for simple span. The calculated deflection coefficient under concentrated load for the test shown in *Figure 4.9* was 0.31.

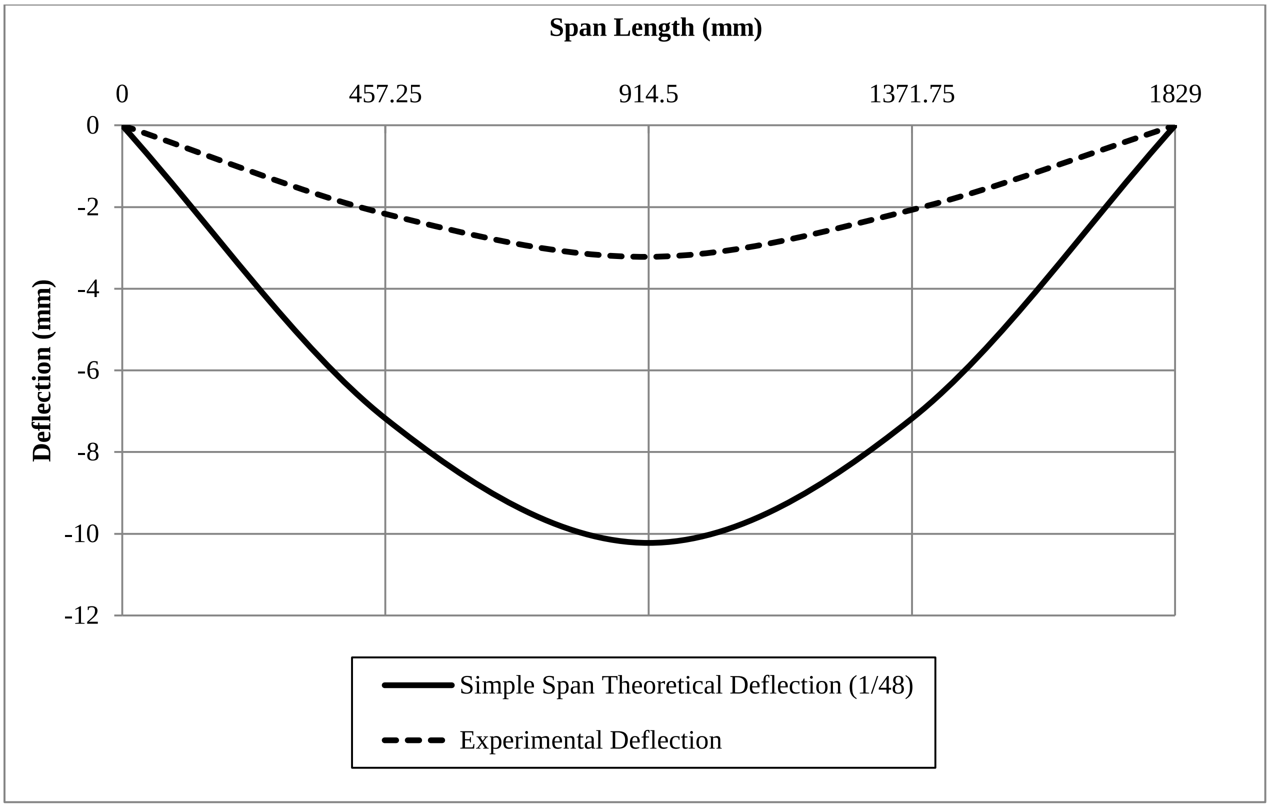


Figure 4.9: CL200 Deflection Curve Simple Span Layup – Screw End-conditions

The simple span concentrated load (200x200) tests were conducted on systems consisting of 2 to 14 boards in width. *Table 4.6* compares the experimental and theoretical deflections when test ND-SS-4-DFL-S2 has been subjected to a 1.1 kN concentrated load. The theoretical deflections were calculated based on a concentrated load at the mid-span of a simply supported beam with pin end-conditions. The average MOE of the boards from the experimental test was used to calculate the theoretical deflection. Similar trends were found for the other non-destructive simple span concentrated load (200x200) tests. In all cases, the experimental deflection was found to be smaller than the theoretical deflection.

Table 4.6: Simple Span CL200 Deflection Coefficients – Screw End-conditions

Number of Boards in Test	Exp. Δ (mm)	Theo. Δ (mm)	Deflection coefficient (γ_{CL})
2	15.5	18.6	0.83
4	8.6	18.9	0.46
6	7.2	18.9	0.38
8	6.1	18.9	0.32
10	6.0	19.1	0.31
12	5.9	19.0	0.31
14	5.7	19.2	0.29

4.2.2.2 Two-Span Continuous Layup

Figure 4.10 shows a typical (exaggerated) deflected shape for a two-span continuous layup consisting of 8 boards and loaded with a 1.1 kN concentrated load (200x200). The resultant curve is from test ND-TS-1-DFL-S2-8. As the 200 mm x 200 mm loading block would rest on top of at least two boards, the theoretical deflection and simple span deflection were determined assuming that two boards were resisting the concentrated load. The theoretical deflection was calculated based on a concentrated load at one mid-span of a two-span continuous beam with pin end-conditions. From the figure it can be observed that the decking system deflected significantly less than the predicted theoretical deflection curve. The calculated deflection coefficient under concentrated load for the test shown in *Figure 4.10* was 0.35.

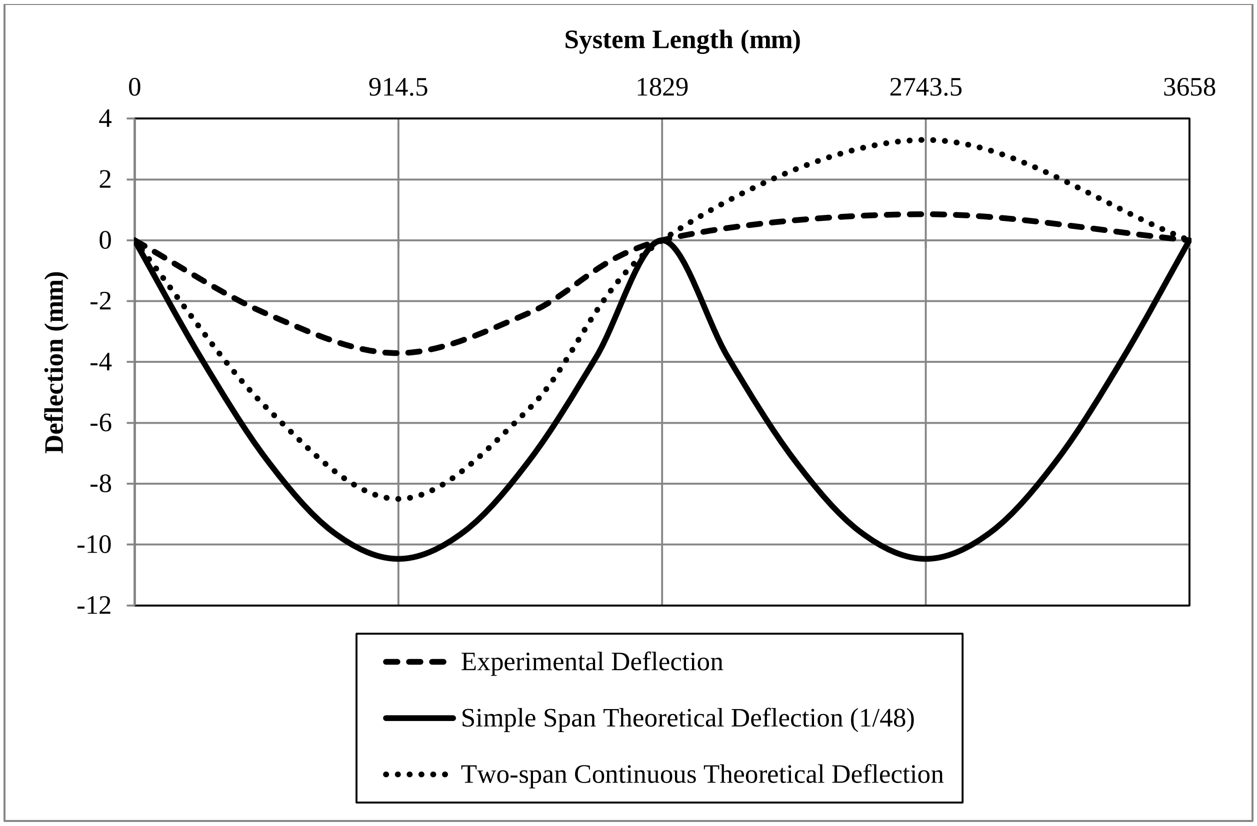


Figure 4.10: CL200 Deflection Curve Two-span Continuous Layup – Screw End-conditions

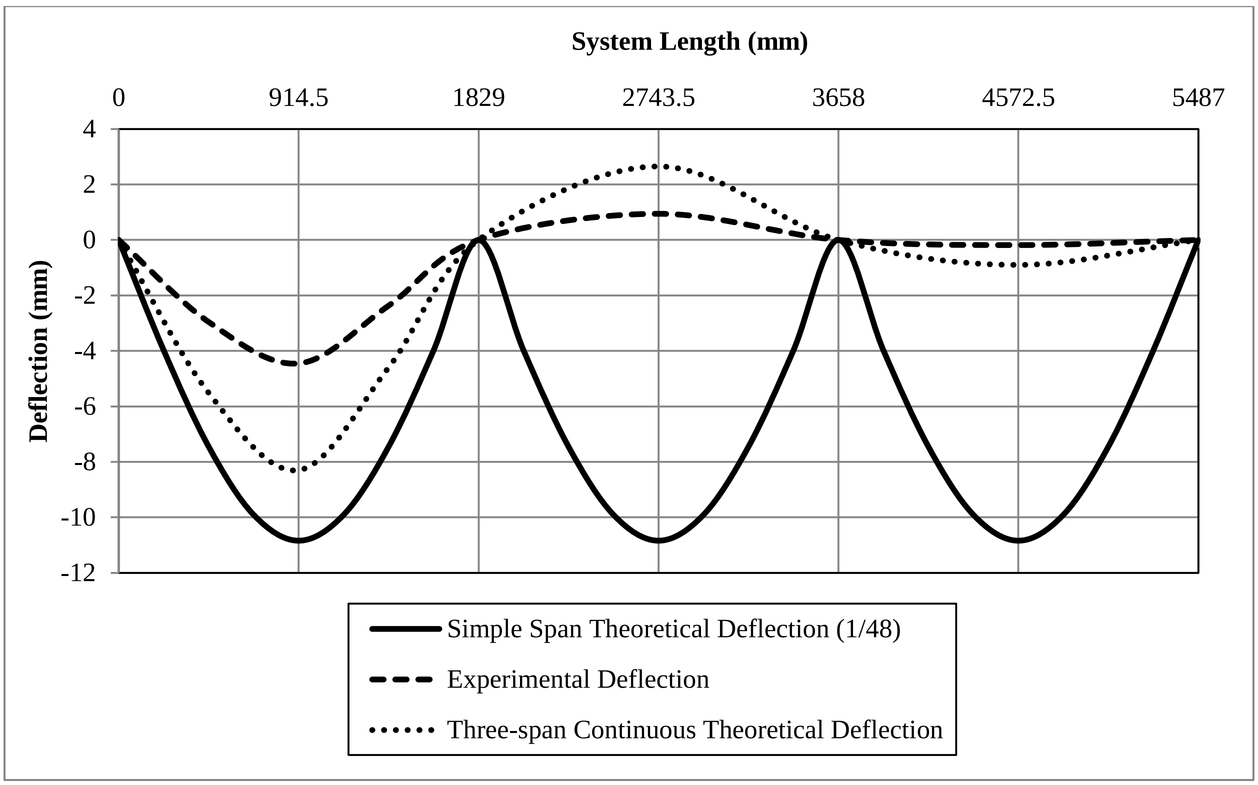
The deflection coefficients for the two-span continuous tests under concentrated load are summarized in *Table 4.7*. The table shows that when a two-span continuous layup is subjected to a concentrated load the calculated deflection coefficient is similar to the simple span layup for eight boards, with an average value of 0.35 and a standard deviation of 0.032.

Table 4.7: Two-Span Continuous CL200 Deflection Coefficients – Screw End-conditions

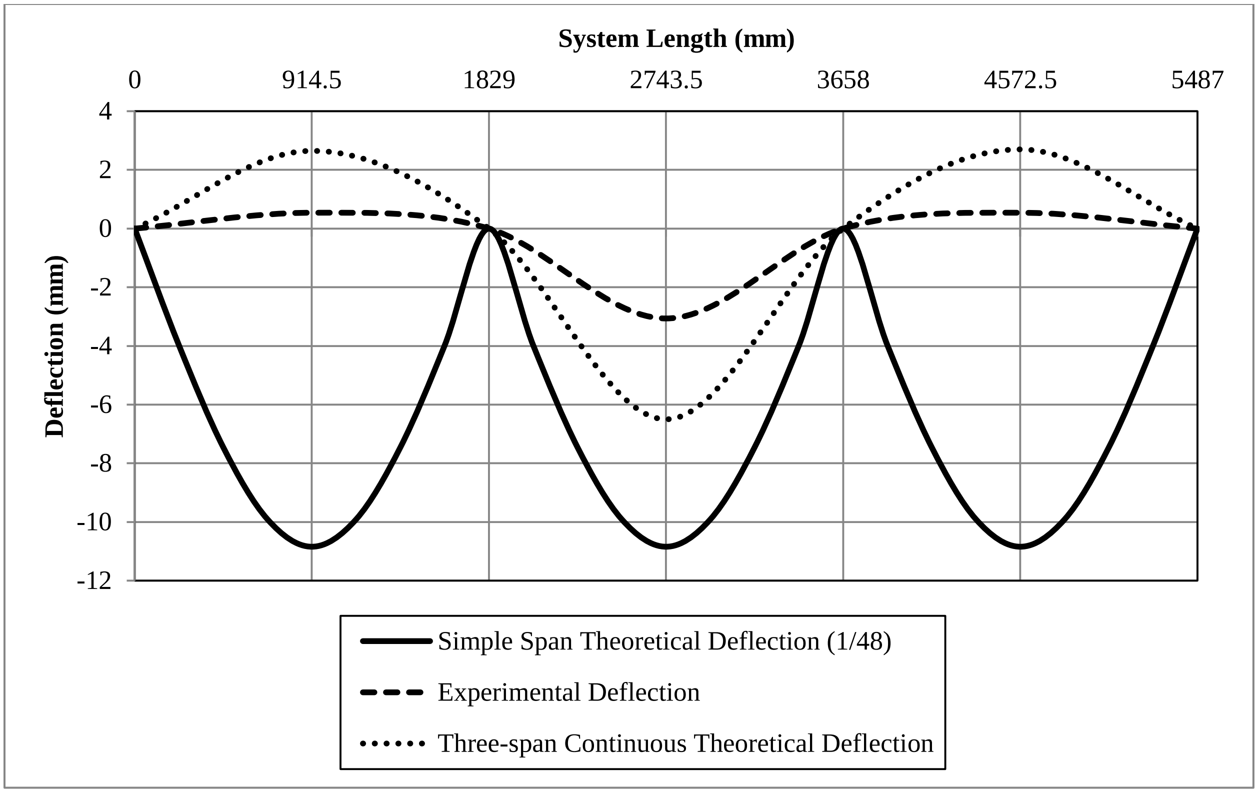
Test Name	**Deflection Coefficient (γ_{CL})**
ND-TS-1-DFL-S2-8	0.35
ND-TS-1-AYC-S2-8	0.30
ND-TS-1-DFL-L2-8	0.33
ND-TS-1-POP-L2-8	0.30
ND-TS-1-SPF-S2-8	0.27
ND-TS-2-DFL-S2-8	0.27

4.2.2.3 Controlled Random Layup

Figure 4.11(a) and *(b)* show the deflected shapes for a three-span continuous decking system consisting of 8 boards constructed with the controlled random layup under a concentrated load, where an exterior and interior span is loaded, respectively. The theoretical deflection was calculated based on a concentrated load at one mid-span of a three-span continuous beam with pin end-conditions. The calculated deflection coefficients under concentrated load for *Figures 4.11(a)* and *(b)* are 0.41, and 0.35, respectively.



(a) Span 1 Loaded – (ND-CR-1-DFL-S2-8-1)



(b) Span 2 Loaded – (ND-CR-1-DFL-S2-8-2)

Figure 4.11: CL200 Deflection Curve Controlled Random – Screw End-conditions

Due to the variability in how the controlled random layup can be constructed, five types of decking were tested on a total of 7 different layup patterns. The results are summarized in *Table 4.8* which includes the results from loading exterior and interior spans for all controlled random layup pattern tests. The average deflection coefficient found for the exterior span was 0.31 with a standard deviation of 0.055, and the average deflection coefficient found for the interior span was 0.27 with a standard deviation of 0.044.

Table 4.8: Controlled Random Layup CL200 Deflection Coefficients – Screw End-conditions

Test Name	Loaded Span	Deflection Coefficient (γ_{CL})
ND-CR-1-DFL-S2-8-1	Exterior	0.41
ND-CR-1-DFL-S2-8-3	Exterior	0.46
ND-CR-1-AYC-S2-8-1	Exterior	0.27
ND-CR-1-AYC-S2-8-3	Exterior	0.34
ND-CR-1-DFL-L2-8-1	Exterior	0.30
ND-CR-1-DFL-L2-8-3	Exterior	0.29
ND-CR-1-POP-L2-8-1	Exterior	0.31
ND-CR-1-POP-L2-8-3	Exterior	0.30
ND-CR-1-SPF-S2-8-1	Exterior	0.25
ND-CR-1-SPF-S2-8-3	Exterior	0.25
ND-CR-2-SPF-S2-8-1	Exterior	0.26
ND-CR-2-DFL-S2-8-1	Exterior	0.31
ND-CR-2-DFL-S2-8-3	Exterior	0.30
ND-CR-3-DFL-S2-8-1	Exterior	0.29
ND-CR-3-DFL-S2-8-3	Exterior	0.27
ND-CR-4-DFL-S2-8-1	Exterior	0.29
ND-CR-4-DFL-S2-8-3	Exterior	0.29
ND-CR-1-DFL-S2-8-2	Interior	0.31
ND-CR-1-AYC-S2-8-2	Interior	0.28
ND-CR-1-DFL-L2-8-2	Interior	0.35
ND-CR-1-POP-L2-8-2	Interior	0.29
ND-CR-1-SPF-S2-8-2	Interior	0.22
ND-CR-2-SPF-S2-8-2	Interior	0.24
ND-CR-2-DFL-S2-8-2	Interior	0.26
ND-CR-3-DFL-S2-8-2	Interior	0.23
ND-CR-4-DFL-S2-8-2	Interior	0.22

A total of 6 different combination simple and two-span continuous layups were tested non-destructively. The results summarized in *Table 4.9* and include the results from loading exterior and interior spans from each layup. The average deflection coefficient found for the exterior span was 0.31 with a standard deviation of 0.047, and the average deflection coefficient found for the interior span was 0.29 with a standard deviation of 0.087.

Table 4.9: Combination Simple and Two-span Continuous Layup CL200 Deflection Coefficients – Screw End-conditions

Test Name	Loaded Span	Deflection Coefficient (γ_{CL})
ND-ST-1-DFL-S2-8-1	Exterior	0.28
ND-ST-1-AYC-S2-8-1	Exterior	0.29
ND-ST-1-DFL-L2-8-1	Exterior	0.37
ND-ST-1-POP-L2-8-1	Exterior	0.34
ND-ST-1-SPF-S2-8-1	Exterior	0.25
ND-ST-2-DFL-S2-8-1	Exterior	0.29
ND-ST-1-DFL-S2-8-2	Interior	0.28
ND-ST-1-AYC-S2-8-2	Interior	0.30
ND-ST-1-DFL-L2-8-2	Interior	0.45
ND-ST-1-POP-L2-8-2	Interior	0.28
ND-ST-1-SPF-S2-8-2	Interior	0.19
ND-ST-2-DFL-S2-8-2	Interior	0.25

4.3 Destructive Test Results

Destructive tests were conducted on simple span and controlled random layups using uniform loading simulated with two line loads at the third point, as well as concentrated loads applied at the mid-span.

4.3.1 Four-Point Bending Tests

A typical load versus mid-span deflection curve for a 7 board wide simple span system under four-point bending can be seen in *Figure 4.12*. It was observed that the decking boards failed in flexure and that the behaviour was brittle and nearly linear almost until ultimate failure. The deviation from the linear behaviour in *Figure 4.12* can be attributed to localized cracks within the system. The results in the figure come from test D-4PB-SS-1-DFL-S2-7.

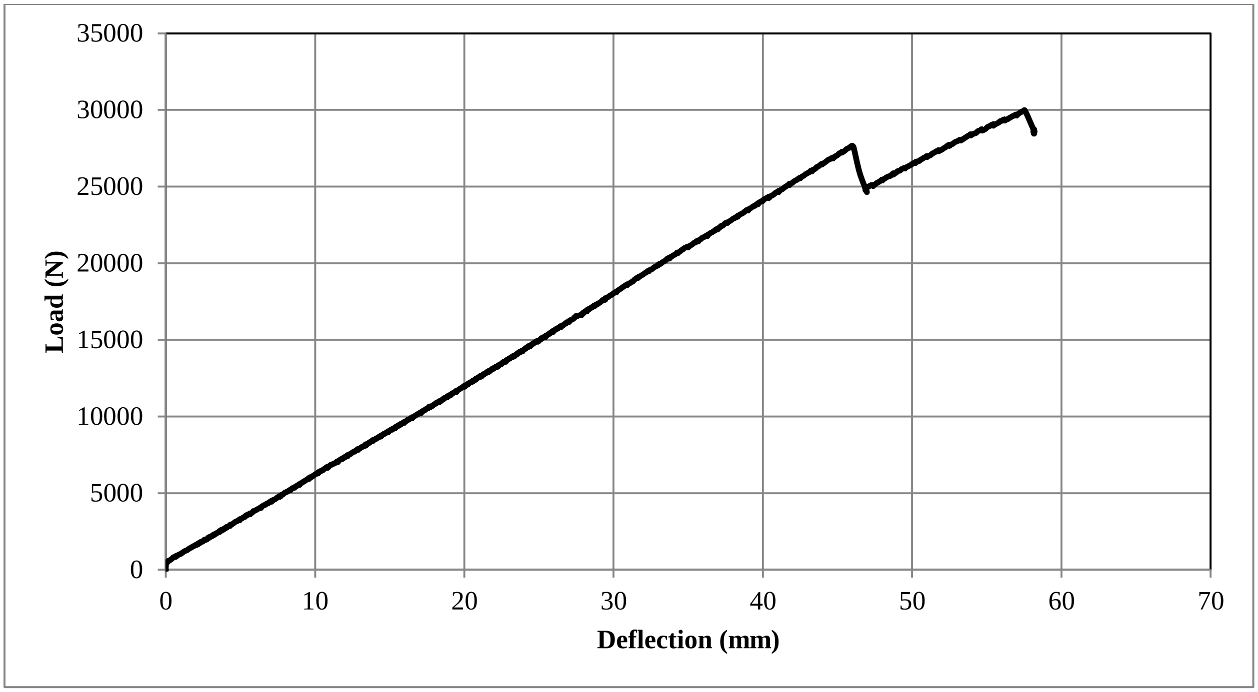


Figure 4.12: Elastic Response of Destructive 4PB Test – Nail End-conditions

It was also observed that if a knot was close to the center of the boards, the failure was typically initiated at the knot. The failure of the laminated decking products was similar to that of the solid sawn boards, and no delamination in the glue lines was observed in any of the tests. *Figures 4.13*(a)-(d) show examples of the failure observed during the simple span tests for decking systems consisting of 1, 3, 5, and 7 boards in width.

With the exception of where failure occurred near a butt joint, failure modes from the controlled random layups were indistinguishable from those observed in the simple span tests, as seen in *Figures 4.13(e)* and *(f)*.

(a) Single Board Failure

(b) 3 Board Failure

(c) 5 Board Failure

(d) 7 Board Failure

(e) Controlled Random Failure (Top View)

(f) Controlled Random Failure (Bottom View)

Figure 4.13: Destructive 4PB Test Failure Mode – Nail End-conditions

The simple span modulus of rupture results, from the four point bending tests, are summarized in *Table 4.10*. A total of 90 simple span four-point bending tests were conducted. The table presents the average modulus of rupture from each type of test, as well as the coefficient of variation (COV). Detailed results from each individual test can be found in *Appendix C*.

Table 4.10: Destructive Simple Span 4PB Test Results Summary

Species	Size (mm)	Number of Boards in Test	Number of Tests Conducted	Average MOR (MPa)	COV (%)
D.Fir-L Solid Sawn	127 x 36	1	11	41	29
		3	7	51	17
		5	4	47	17
		7	2	44	18
Alaskan Yellow Cedar	127 x 36	1	11	46	31
		3	5	47	10
		5	4	44	9
		7	2	42	18
D.Fir-L Laminated	127 x 36	1	12	63	36
		3	5	53	16
		5	4	50	6
		7	2	51	8
D.Fir-L Laminated	131 x 55	1	12	50	26
		3	7	52	14
		5	2	38	13

Four destructive four-point bending tests were conducted on the 3-span controlled random layup systems. This included four different types of decking, and three different layup configurations. The results are summarized in *Table 4.11*.

Table 4.11: Destructive Controlled Random 4PB Test Results Summary

Species	Size (mm)	Number of Boards in Test	Number of Tests Conducted	Average MOR (Mpa)
D.Fir-L Solid Sawn	127 x 36	7	1	32
Alaskan Yellow Cedar	127 x 36	7	1	46
D.Fir-L Laminated	127 x 36	7	1	57
D.Fir-L Laminated	131 x 55	5	1	37

The effect of fastening sheathing on top of the decking boards was also investigated. The boards also failed in flexure and the behaviour was mostly linear until failure. *Table 4.12* summarizes the results from the destructive four-point bending tests that included a sheathing panel. The average modulus of rupture from the two tests was found to be consistent with the tests that did not include any sheathing.

Table 4.12: Destructive Simple Span 4PB with sheathing Test Results Summary

Species	Size (mm)	Number of Boards in Test	Number of Tests Conducted	Average MOR (Mpa)	COV (%)
D.Fir-L Solid Sawn	127 x 36	5	2	41	9

4.3.2 Concentrated Load

A typical load versus mid-span deflection curve for the destructive concentrated load tests can be seen in *Figure 4.14*. The figure comes from test D-CL127-SS-1-DFL-S2-7.

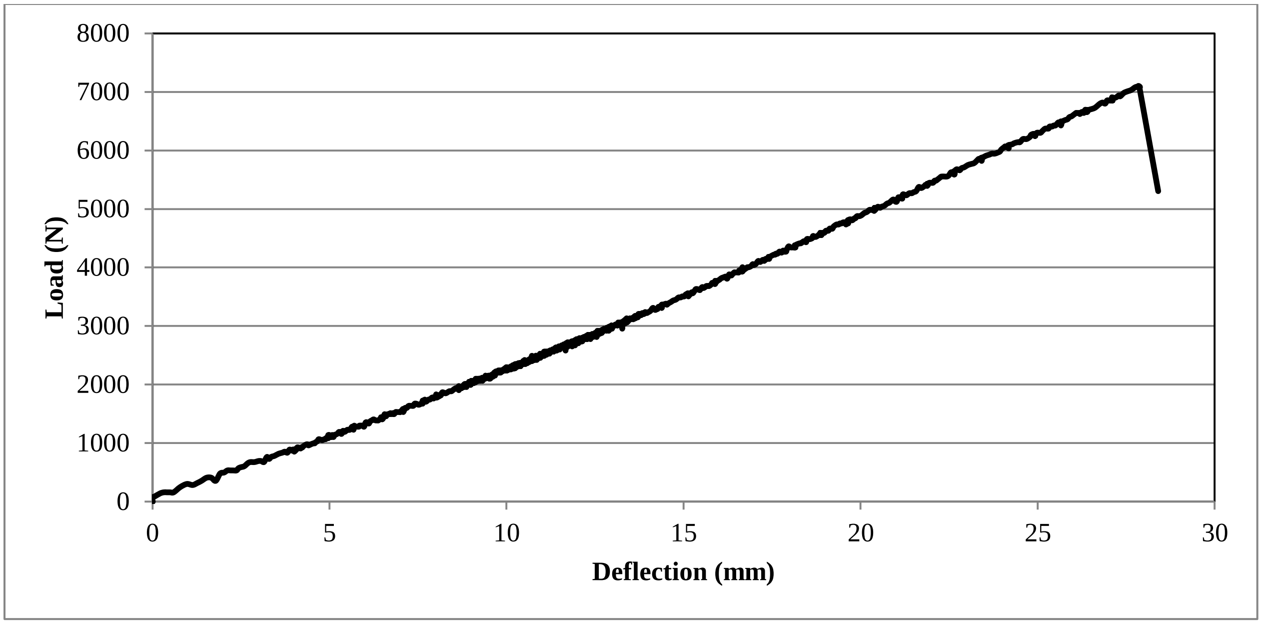
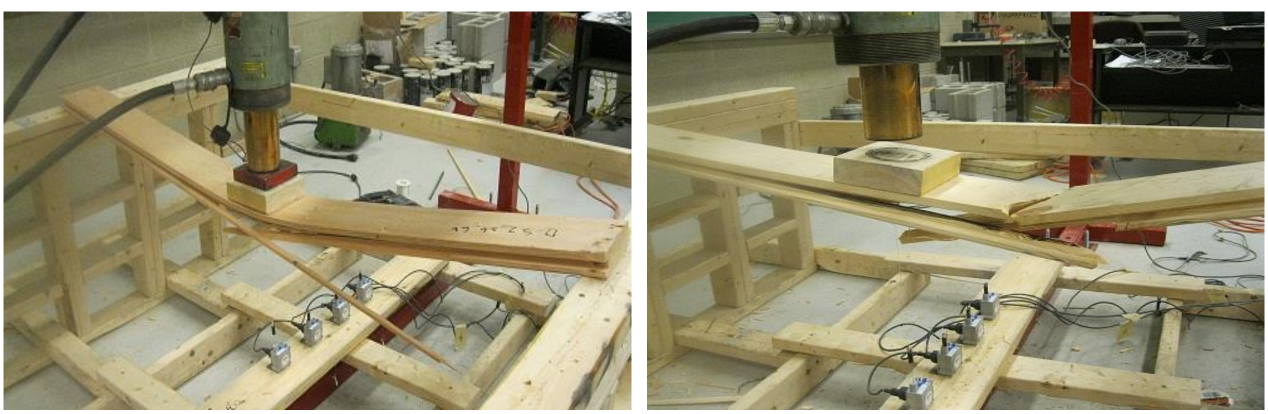


Figure 4.14: Destructive Load versus Deflection CL127 – Nail End-conditions

The figure shows a brittle behaviour and a nearly linear response until failure. This was generally observed for all tests, except for a deviation from linearity that coincided with a localized failure of individual elements within the system. Typical failure modes can be seen in *Figures 4.15(a)* and (*b*).

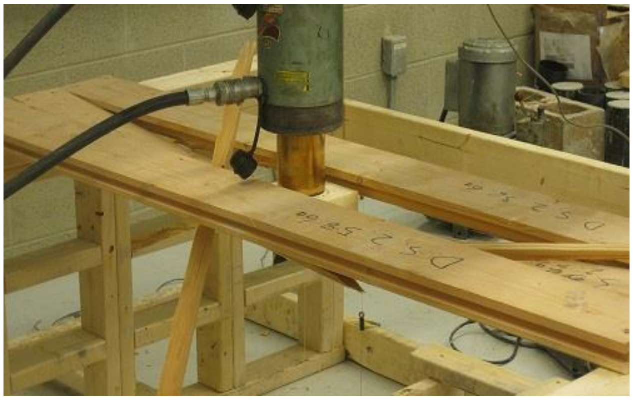


(a) Flexural Failure

(b) Failure at a knot

Figure 4.15: Single Board Failure under Destructive CL127 – Nail End-conditions

When 4 or more boards were tested under concentrated load, the failure mode became more complex and involved failure of the tongue and groove portion of the boards. In all test cases, the system as a whole did not completely fail as the failure was concentrated near the load application point. Boards that did not fail during the test would return to their original shape once the system was unloaded. *Figures 4.16(a)-(c)* show typical failure modes for systems consisting of 3, 5 and 8 boards. The failure mode for the controlled random layup systems under concentrated load was similar to that of the simple span tests. If a butt joint was present close to the loaded area, the failure would also spread to the butt joint, as can be seen in *Figure 4.16(d)*.



(a) 3 Board Failure (CL127)

(b) 5 Board Failure (CL127)

(c) 8 Board Failure (CL200)

(d) Controlled Random Failure (CL200)

Figure 4.16: Destructive Concentrated Load Failure Modes – Nail End-conditions

The MOR values obtained from the simple span layup under concentrated load are summarized in *Table 4.13*. A total of 83 simple span concentrated load tests were conducted with two different loading block sizes. The table presents the average modulus of rupture from each type of test, as well as the coefficient of variance (COV). Detailed results from each individual test can be found in *Appendix C*.

Table 4.13: Destructive Simple Span Concentrated load Test Results Summary

Species	**Size (mm)**	**Loading Block (mm)**	**Number of Boards in Test**	**Number of Tests Done**	**Average MOR (MPa)**	**COV (%)**
D.Fir-L Solid Sawn	127 x 36	127 x 127	1	12	53	20
			3	7	74	21
			5	5	89	23
			7	3	89	13
Ponderosa Pine Laminated	127 x 36	127 x 127	1	11	34	29
			3	7	58	25
			5	7	55	26
			7	5	57	23
D.Fir-L Laminated	131 x 55	127 x 127	1	7	39	36
			3	3	93	20
			5	2	87	5
			7	1	86	-
S-P-F Solid Sawn	127 x 36	200 x 200	2	3	29	22
			4	2	66	15
			6	2	68	14
			8	3	77	13
D.Fir-L Solid Sawn	127 x 36	200 x 200	8	3	76	22

A total of 11 destructive concentrated load tests were conducted on controlled random layups including four different types of decking and 5 layup configurations. The results from the destructive concentrated load controlled random tests are summarized in *Table 4.14*.

Table 4.14: Destructive Controlled Random Concentrated load Test Results Summary

Species	Size (mm)	Loading Block (mm)	Number of Boards in Test	Number of Tests Done	Average MOR (MPa)	COV (%)
D.Fir-L Solid Sawn	127 x 36	127 x 127	7	3	88	31
Ponderosa Pine Laminated	127 x 36	127 x 127	7	1	37	-
D.Fir-L Laminated	131 x 55	127 x 127	7	1	103	-
S-P-F Solid Sawn	127 x 36	200 x 200	8	3	49	26
D.Fir-L Solid Sawn	127 x 36	200 x 200	8	3	78	10

A typical load-displacement curve for decking systems with sheathing on top of the decking boards can be seen in *Figure 4.17*. The figure represents test D-CL127-SSS-3-DFL-S2-7. The relationship was observed to be generally linear-elastic up to around 6-8 kN, where after the stiffness appeared to increase (represented by the steeper slope in *Figure 4.17*). This increase was consistent for all tested specimens and on average the measured stiffness increase was about 14%. In the first portion of the graph (up to 6-8 kN), the behaviour was consistent with that of the combined stiffness from the decking system and sheathing. The additional stiffness increase in the second portion of the curve (past 8 kN) can be attributed to the catenary action where the effect of the concentrated load is localized and the decking system is acting in two-way bending. The number of tests here are limited and general conclusions cannot be drawn. More work is needed to establish and quantify this stiffening action due to the two-way bending.

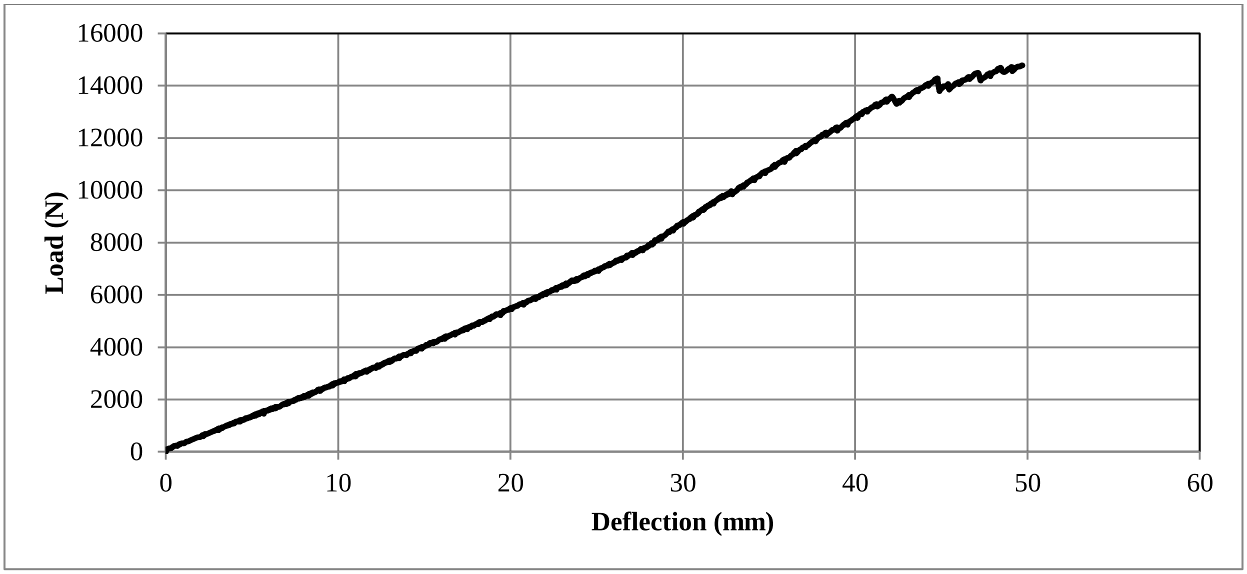


Figure 4.17: CL127 Test with sheathing Load vs. Deflection Curve – Nail End-conditions

A typical failure mode for sheathed decking systems under concentrated loading is a rupture through the sheathing, combined with flexure failure of the boards directly underneath the loading block. The failure would typically occur in the board and the tongue and groove joint between board elements. *Figures 4.18(a)* and *(b)* show a typical failure mode from a concentrated load test for the boards and the sheathing, respectively. No total failure of the decking system was observed as the sheathing helped hold the boards together.

(a) Bending Failure

(b) Sheathing Failure

Figure 4.18: Destructive Simple Span CL127 with Sheathing

Table 4.15 summarizes the results from the destructive concentrated load tests that included a sheathing panel. A total of 6 tests were conducted on two different types of decking.

Table 4.15: Destructive Simple Span CL127 with sheathing Test Results Summary

Species	**Size (mm)**	**Loading Block (mm)**	**Number of Boards in Test**	**Number of Tests Done**	**Average MOR**	**COV (%)**
D.Fir-L Solid Sawn	127 x 36	127 x 127	7	3	207	7
Ponderosa Pine Laminated	127 x 36	127 x 127	7	3	178	11

4.4 Analytical Model

4.4.1 Background

Due to cost and limitations associated with experimental testing, finite element models have successfully been used to represent the behaviour of light frame wood structural systems (e.g. Doudak 2005, Martin 2010, Limkatanyoo 2003, Dung 1999, Pfretzchner 2012). The focus of the modeling work in this project has been limited to the behaviour in the linear elastic region, with emphasis on the interaction between the decking boards through the tongue and groove joint. Commercially available finite element software (SAP 2000 V14, 2013) was used to model the behaviour of the decking systems.

4.4.2 Model Description and Inputs

The decking boards were modelled as thick shell elements, which include the effects of transverse shearing deformation. The shell elements were meshed using 20 mm by 20 mm square elements. The shells were assigned appropriate material and section properties based on the component tests described in *Chapter 3*.

To properly simulate the end conditions of the boards including the additional restraint due to the fasteners, a rotational spring was added at the boundary. The stiffness of the rotational spring was determined using *equation [4.1]*, where E represents of the modulus of elasticity (MPa), I is the moment of inertia (mm^4), L is the length of the board (mm), and r represents the percentage of rotation. A value of r = 0.135 was found to fit the experimental results based on the data from the single board tests. This value was consistently used to modify the stiffness for all of the models.

$$[4.1] \quad Rotational\,Spring\,(N \cdot mm) = r\frac{4EI}{L}$$

The tongue and groove joint was modelled using linear links. The stiffness properties in the linear link were determined using four board tests results, where the middle two boards were loaded (*Figure 4.19*). This test configuration represents the smallest symmetric decking system with only one board on each side of the loaded boards. Based on the testing a stiffness value the linear link in the vertical direction (denoted as U2 in the SAP2000 program) of 3.4 N/mm was found suitable. Due to the complexity in describing the behaviour of the tongue and groove joint, it was deemed appropriate to use the simplest configuration (i.e. one non-loaded board) to derive the stiffness characteristics in the joint and apply it to all other configurations.

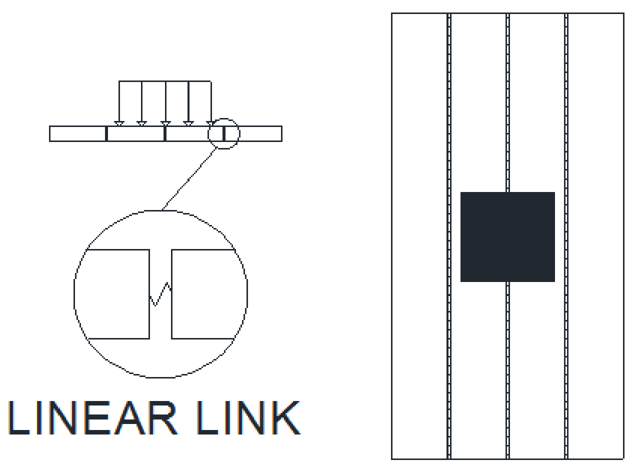


Figure 4.19: Set-up for Establishing Linear Link Properties

Figure 4.20 shows the model stiffness as a function of U2 in the range between 0.1 to 10,000 N/mm. It is obvious from *Figure 4.20* that the chosen stiffness value of 3.4 N/mm lies in a sensitive region of the graph, where a relatively small change in stiffness could affect the results. This was the main motivator to rely on the four-board tests to establish the value rather than small-size component tests. From the graph, it can also be observed that increasing the vertical stiffness to 100 N/mm or more would have little effect on the behaviour of the decking system. Equating this stiffness to a specific connection type (e.g. screws, glue etc.) is outside the scope of this project.

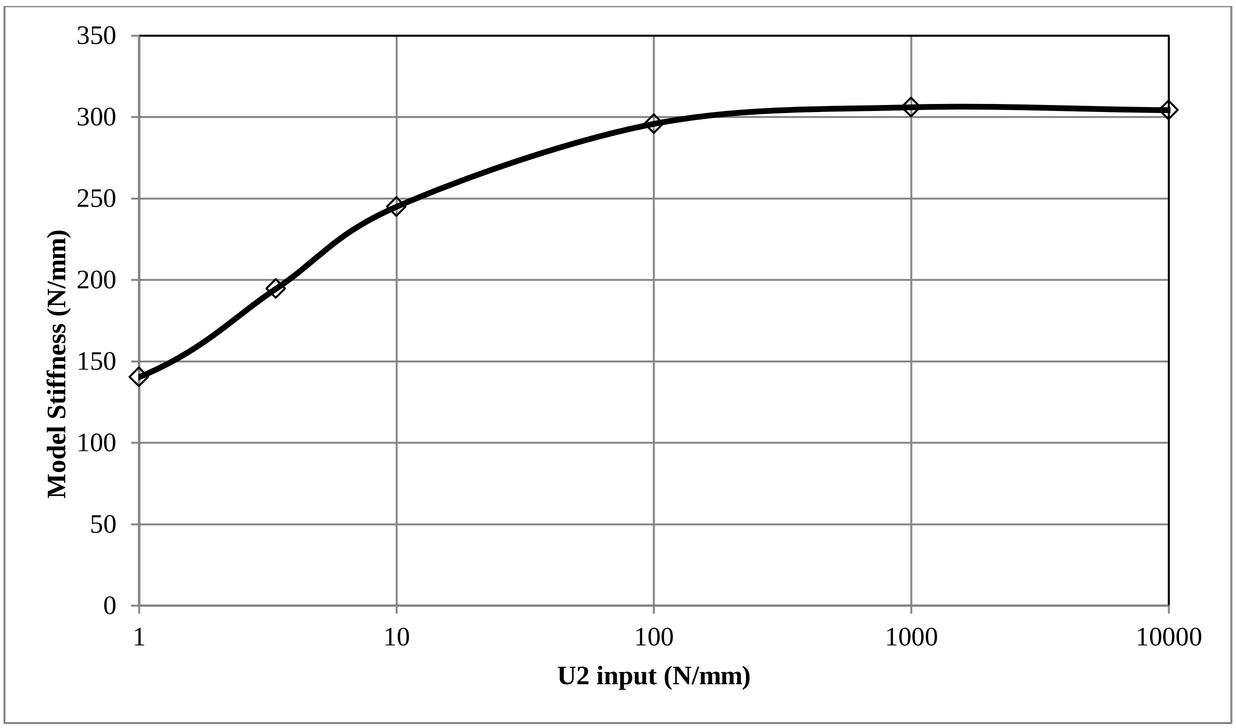


Figure 4.20: Effect of U2 Directional Property on stiffness of a system

Once the behaviour of the tongue and groove joint and the fastened end conditions were determined, it was possible to create and check the accuracy of the model. *Figure 4.21* shows an example of the finite element model with 8 boards on a simple span using D.Fir-L solid sawn decking boards.

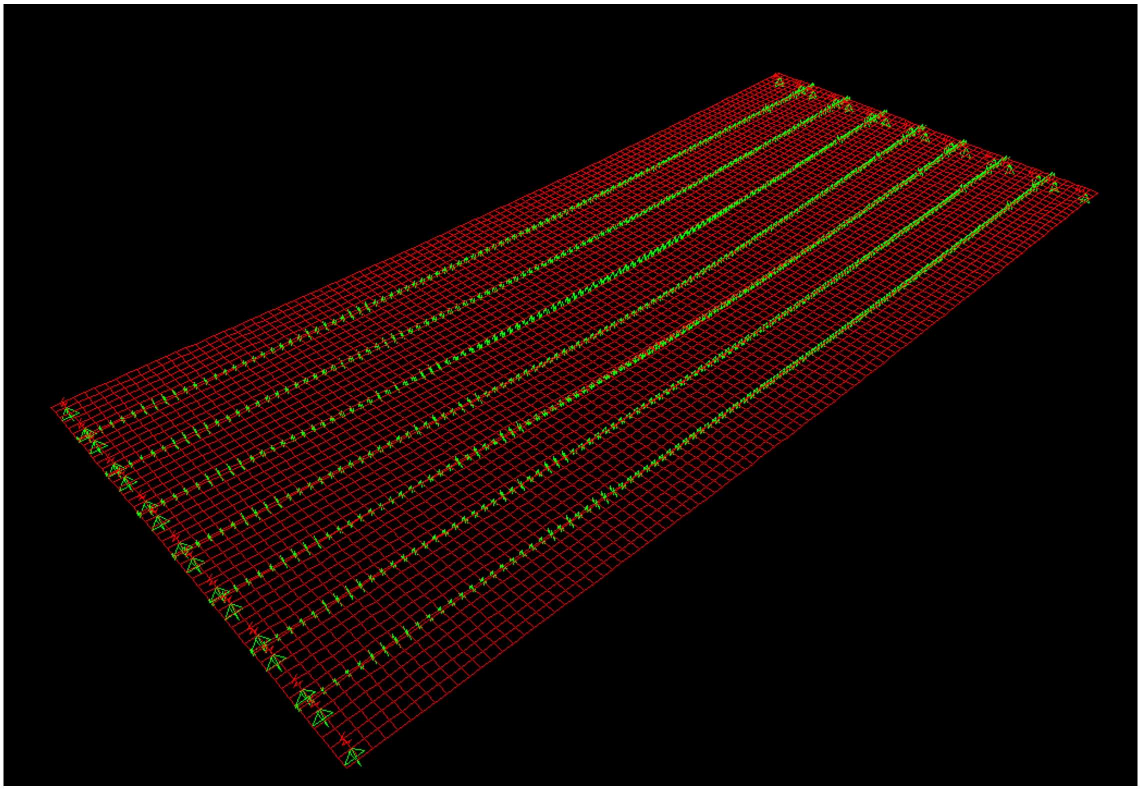


Figure 4.21: 8 Board Simple Span D.Fir-L Solid Sawn 127 mm x 36 mm Model

CHAPTER 5-Discussion

5.1 Deflection Coefficient

As described in Chapter 1, the Canadian design standard (CSA, 2009) provides provisions to calculate the deflection of decking systems of any layup under uniformly distributed loads by multiplying the deflection of a single, simply supported board by a deflection coefficient factor derived from tests similar to those conducted in the current research study. Previous tests have been limited to balanced uniform loading on simple span and controlled random layups. In the following section, the verification of deflection coefficient values currently existing in the design standard and the derivation of values for new layups and loading conditions will be discussed.

5.1.1 Uniform Load Deflection Coefficient (γ_{UDL})

The test series conducted on simple span decking with uniformly distributed load were expected to yield the same deflection as those calculated using established formulae for elastic deflection. *Figure 5.1* shows the average deflection coefficient for the simple span layup pattern as a function of the number of boards of which the decking system consisted. The maximum and minimum spread of each data points are shown by error bars. The number in brackets indicates the number of tests that were used to calculate the average deflection coefficient. It can be seen in *Figure 5.1* that the deflection coefficient is independent of the number of boards in the decking system. On average, the deflection coefficient for the simple span layup under uniformly distributed load was 0.90. This is less than the factor of 1.0 expected and specified in the CSA O86. Previous studies such as the one published by Potlatch Forests Inc. (1959) and Kampe and Slutka (1963) reported similar observations. The results can be attributed to the fact that the ends of the boards were fastened to the supports, whereas the end conditions assumed in the standard are pinned end conditions. As there are no mandatory detailing provisions for the board end fixity in the standard, the use of factor of 1.0 seems, in general, appropriate and slightly conservative.

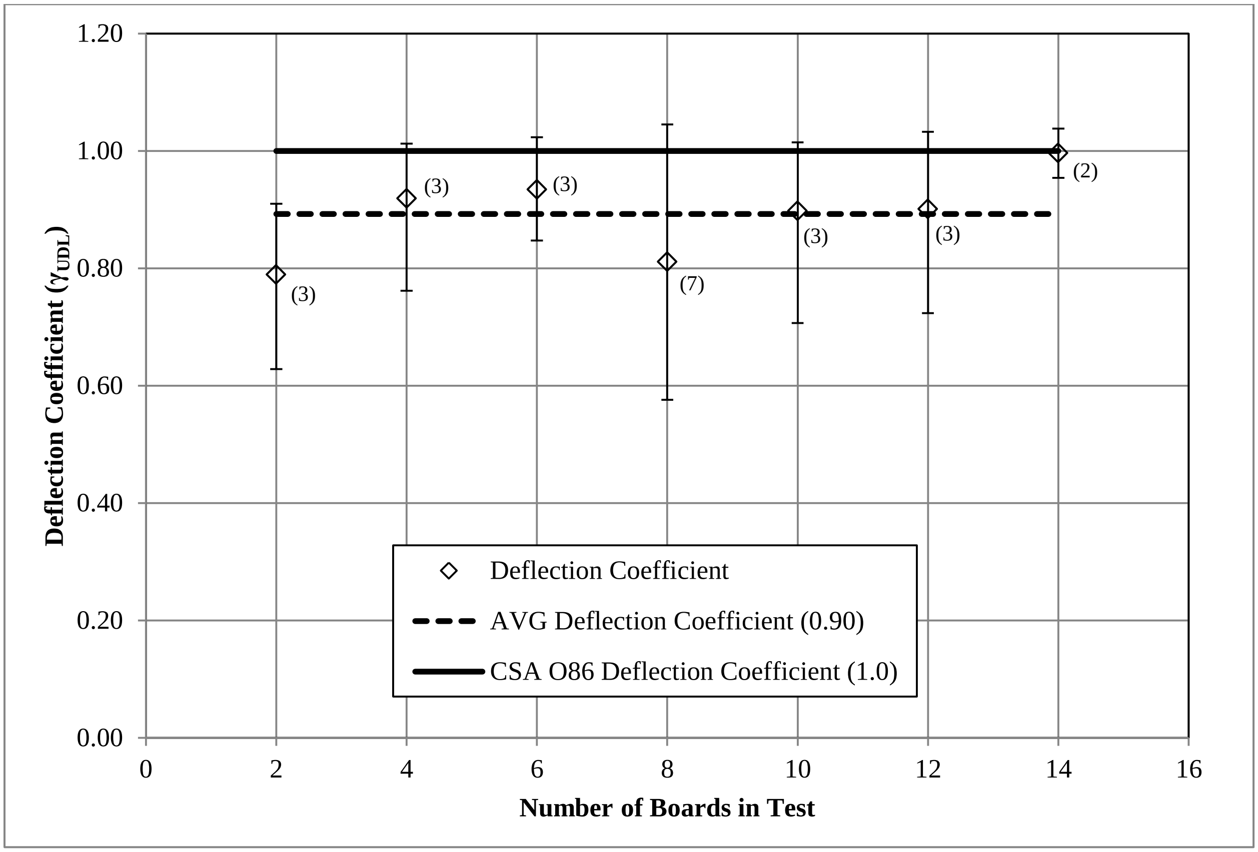


Figure 5.1: UDL Simple Span Layup Deflection Coefficient – Screw End Conditions

For the two-span continuous layup, the deflection coefficient published in the wood standard is 0.42. The National Building Code (NBCC, 2010) requires that unbalanced loading cases be considered on multi-span elements. The design standard does not exclusively address the unbalanced loading cases and a thorough review of the literature did not yield any study on the effect of unbalanced loading on two-span continuous layup. A summary of all the two-span continuous deflection coefficients can be seen in *Figure 5.2*. The current study found that the published deflection coefficient of 0.42 was conservative for boards loaded uniformly under balanced loading. However, under unbalanced loading, the 0.42 deflection coefficient appears to be non-conservative for all cases. Based on the experimental results obtained here, it is recommended that a deflection coefficient of 0.60 be used when designing two-span continuous layup decking systems under unbalanced uniform loading.

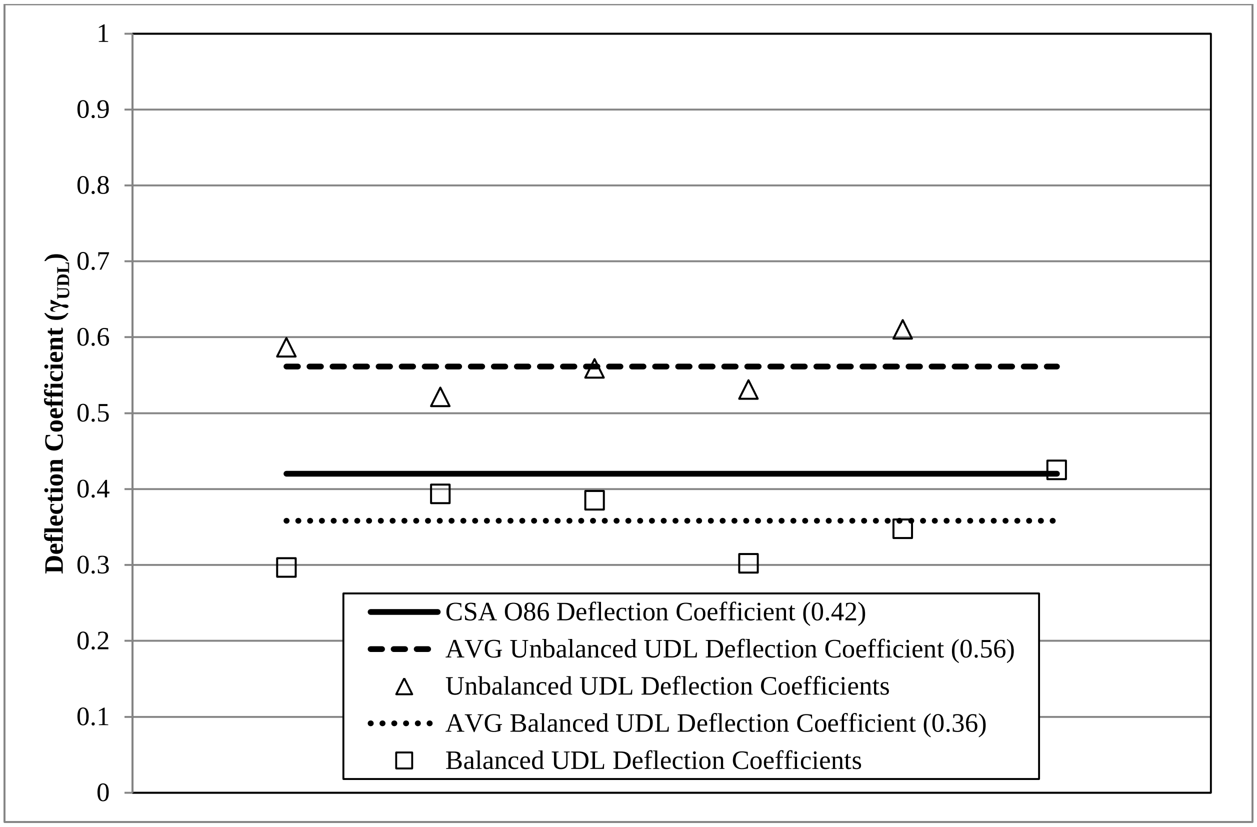


Figure 5.2: UDL Two-Span Continuous Layup Deflection Coefficient – Screw End Conditions

Test results from the controlled random layup under uniform load yielded an average deflection coefficient of 0.58 from all of the test results (*Figure 5.3*). This result is consistent with the study conducted by Kampe and Slutka (1963). This study collected data from all previous studies and found an average deflection coefficient of 0.59. In the current study, it was found that the calculated deflection coefficient was less than that published in the wood design standard (γ=0.77) in all test cases. It can therefore be concluded that the published deflection coefficient for the controlled random layup under uniformly distributed load can be conservatively used for all uniform loading patterns.

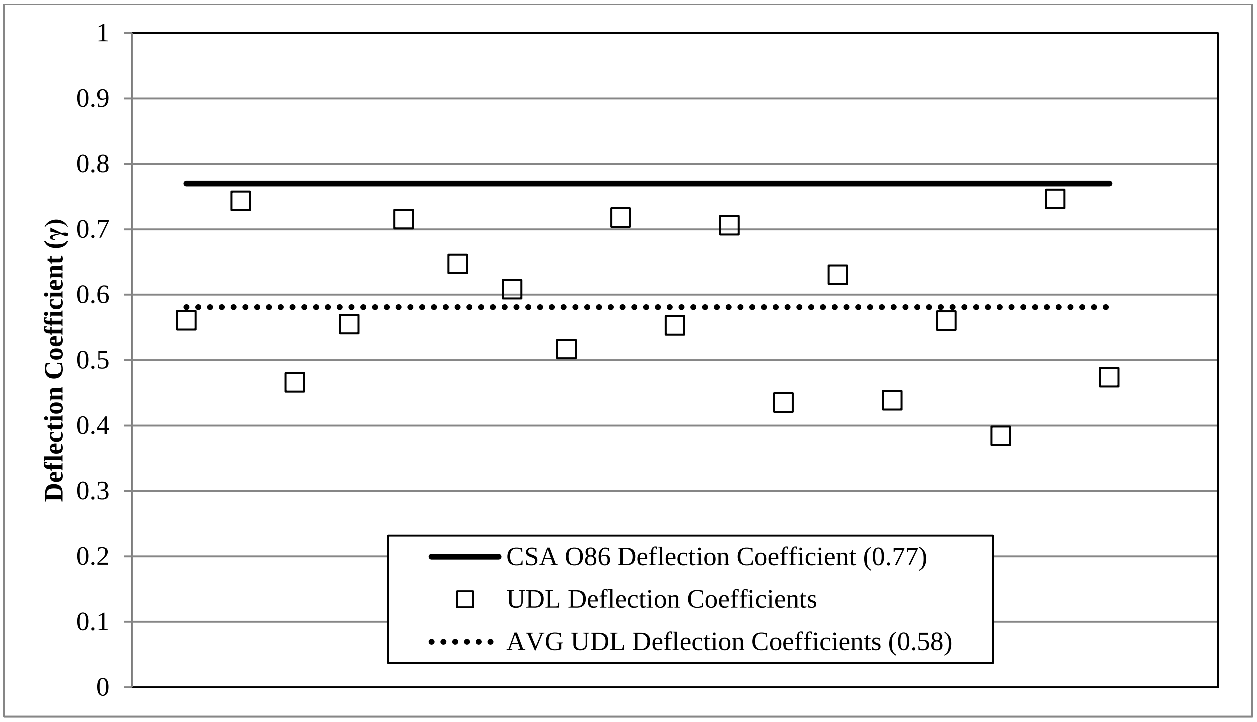


Figure 5.3: UDL Controlled Random Layup Deflection Coefficient Results – Screw End Conditions

The combination simple and two-span continuous layup was also investigated and deflection coefficient determined, as seen in *Figure 5.4*. The figure shows that an average deflection coefficient of 0.46 was obtained from all of the tests. Currently, this layup pattern is assumed by designers to fall under the controlled random layup pattern. The D.Fir Use Book (1958) assigns a deflection coefficient of 0.70 to the combination simple and two-span continuous layup, which according to the experimental results also seems conservative. The maximum deflection coefficient value found in the current testing program was 0.6, which seems appropriate to use for estimating the deflection coefficient for combination simple and two-span continuous layup.

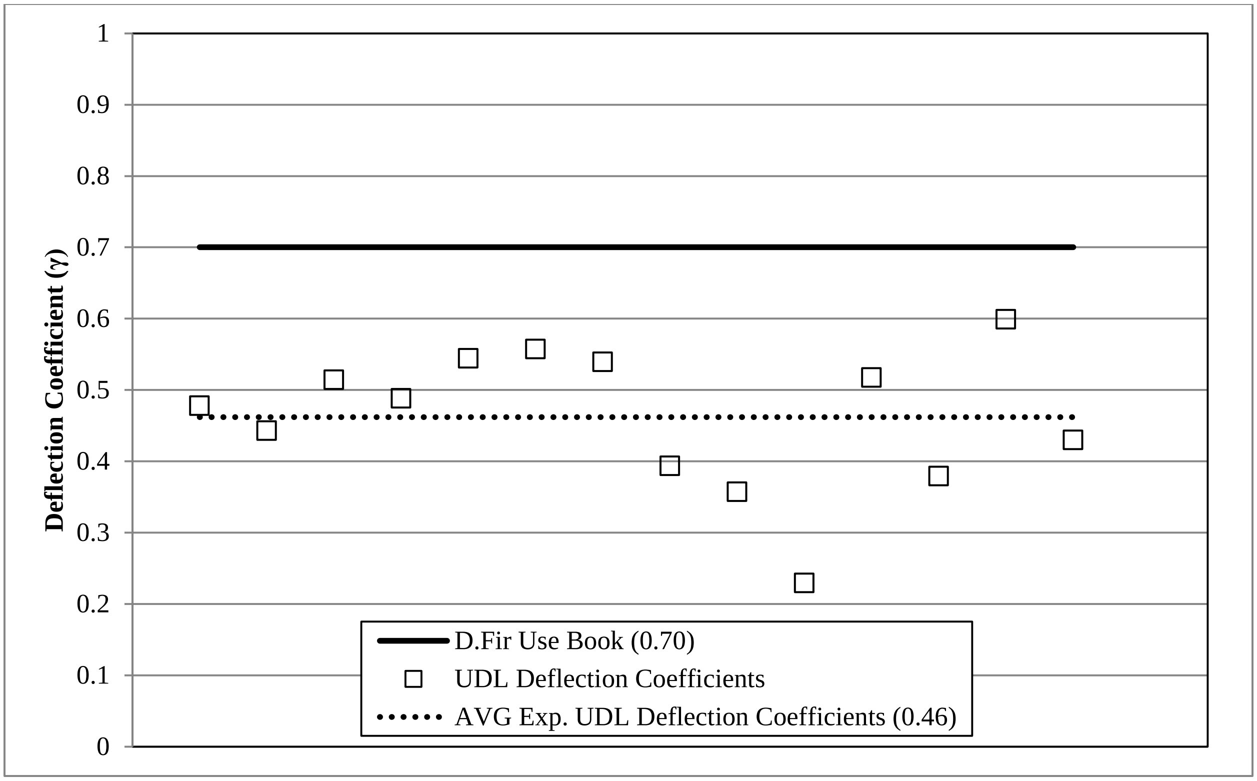


Figure 5.4: UDL Combination Simple and Two-span Continuous Layup Deflection Coefficient Results – Screw End Conditions

5.1.2 Concentrated Load Deflection Coefficient (γ_{CL})

The effect of progressively increasing the number of boards was investigated for the simple span layup pattern under concentrated loads to determine the deflection coefficient and the number of boards that can be considered as representative of the decking system. Tests were conducted on S-P-F in lengths of 1000 mm (3 feet 3-3/8 inches), 2132 mm (7 feet) and 3000 mm (9 feet 10-1/16 inches), and on D.Fir-L in lengths of 1829 mm (6 feet) and 2132 mm (7 feet), where the number of boards in the decking systems varied from 2 to 14. Additionally, tests were conducted on 8 board wide decks consisting of 1829 mm (6 feet) long solid sawn Alaskan Yellow Cedar, laminated D.Fir-L and Ponderosa Pine. *Figure 5.5* summarizes the results from all species and spans and shows the calculated deflection coefficient as a function of the number of boards in a system, normalized to the deflection coefficient of a single decking board. The figure also includes the error bars and the number of tests used to calculate the average deflection coefficient. The results clearly show that adding more boards significantly increases the stiffness and thus reducing the value of the deflection coefficient. This trend continues up to 14 boards; however the relative increase in stiffness seems to diminish, as expected, as more boards are added. The drop in the deflection coefficient (or increase in the stiffness of the system) begins to significantly diminish starting at 6 boards. Based on the observed results, a deflection coefficient of 0.40 seems appropriate for the deflection design of decking systems with a simple span layup under concentrated loads. *Figure 5.5* is representative of all the non-destructive tests that were conducted. Also, no significant difference was found between solid sawn and laminated decking.

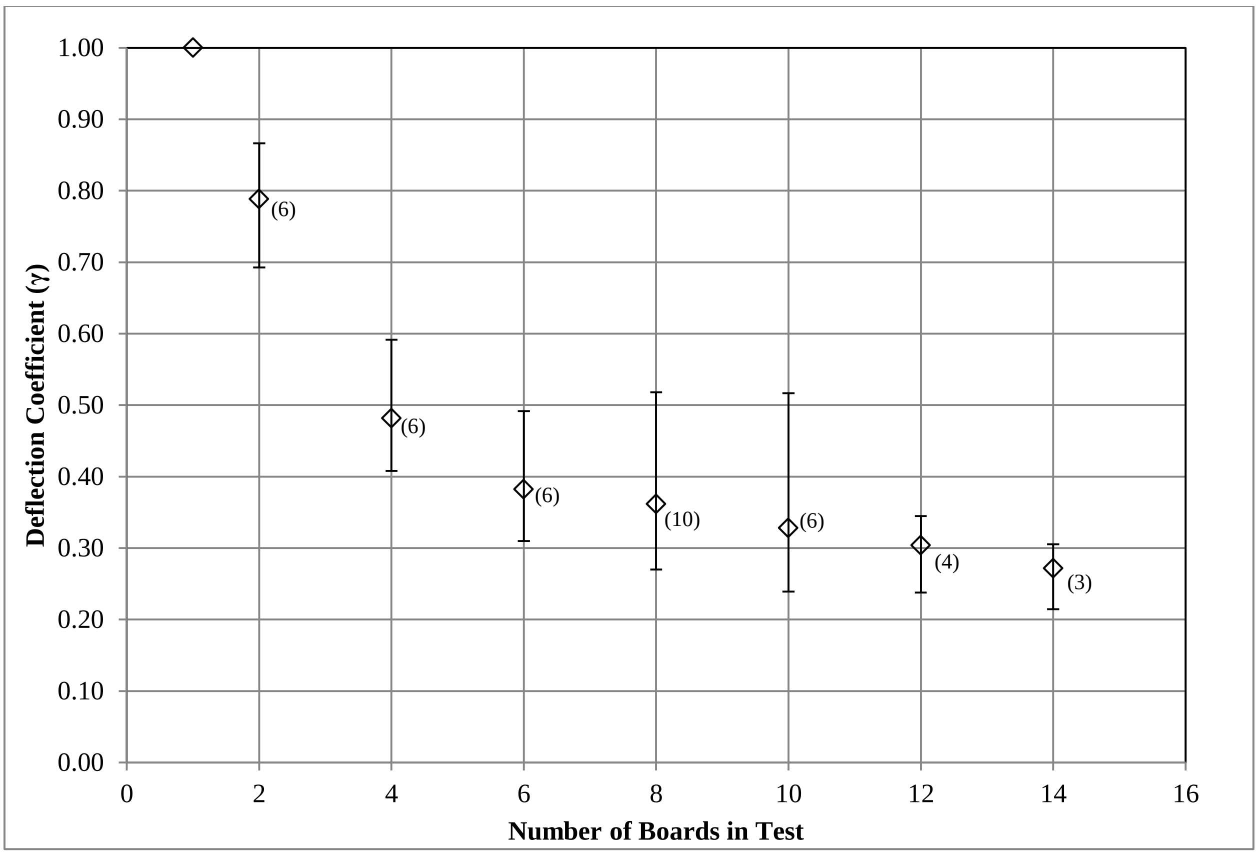


Figure 5.5: Average Simple Span CL200 Deflection Coefficient – Screw end conditions

Based on the results from the simple span testing, 8 boards were considered representative of the behaviour of the decking system, and therefore, all non-destructive testing on the two-span continuous, controlled random and combination simple and two-span continuous layups was done with decking systems consisting of 8 boards. Due to the different ways the controlled-random layup can be laid it was decided to conduct 26 different tests that included 7 different layup configurations.

Table 5.1 summarizes the results for all non-destructive concentrated load tests that were done for the simple span, two-span continuous, controlled random and combination simple and two-span continuous layup patterns. This series of testing confirms the results obtained in *Figure 5.5* for simple span (i.e. γ = 0.36 for 8 boards). It also shows that for the two-span continuous, controlled random layup and combination simple and two-span continuous, similar deflection coefficients are obtained. Based on the experimental results for concentrated load on various layup patterns consisting of 8 boards, one deflection coefficient (γ = 0.40) seems appropriate for all decking layup patterns subjected to a concentrated load at the center. This value may be applied to the theoretical deflection equation for a simply supported beam with a concentrated load at the mid-span.

Table 5.1: CL200 Deflection Coefficients for all Layup Patterns

Test	Number of Boards in Test	Number of Tests Done	Average Deflection Coefficient	Standard Deviation	COV (%)
Single Span	8	10	0.36	0.081	22
Two Span Continuous	8	6	0.30	0.032	11
Controlled Random Exterior Span	8	17	0.31	0.055	18
Controlled Random Interior Span	8	9	0.27	0.044	17
Combination Single and Double Exterior Span	8	6	0.29	0.088	31
Combination Single and Double Interior Span	8	6	0.31	0.042	14

5.2 Load sharing at failure

5.2.1 Four Point Bending

According to the design provisions in the Canadian wood design standard, an increase in capacity of 10% may be accounted for when designing a system of repetitive elements spaced no further apart than 600 mm and supporting the same load. This would hence be applicable to a system of tongue and groove decking. The modulus of rupture was taken as the maximum load capacity measured, divided by the number of boards in the system and compared to the average modulus of rupture obtained from the single board destructive tests. *Figure 5.6* summarizes the results from the simple span destructive four point bending tests results from the tests conducted on D.Fir-L solid sawn 127 mm x 36 mm decking with nailed end conditions. The maximum and minimum spread of the data is shown by the error bars. The number in brackets indicates the number of tests that were used to calculate the average modulus of rupture. As expected, a large spread is observed for the single board data. It was observed that the failure typically occurred at boards with a relatively low stiffness. This was consistent with findings on floor joist systems by Wheat and colleagues (1986). Similar results were found for the other species that were studied.

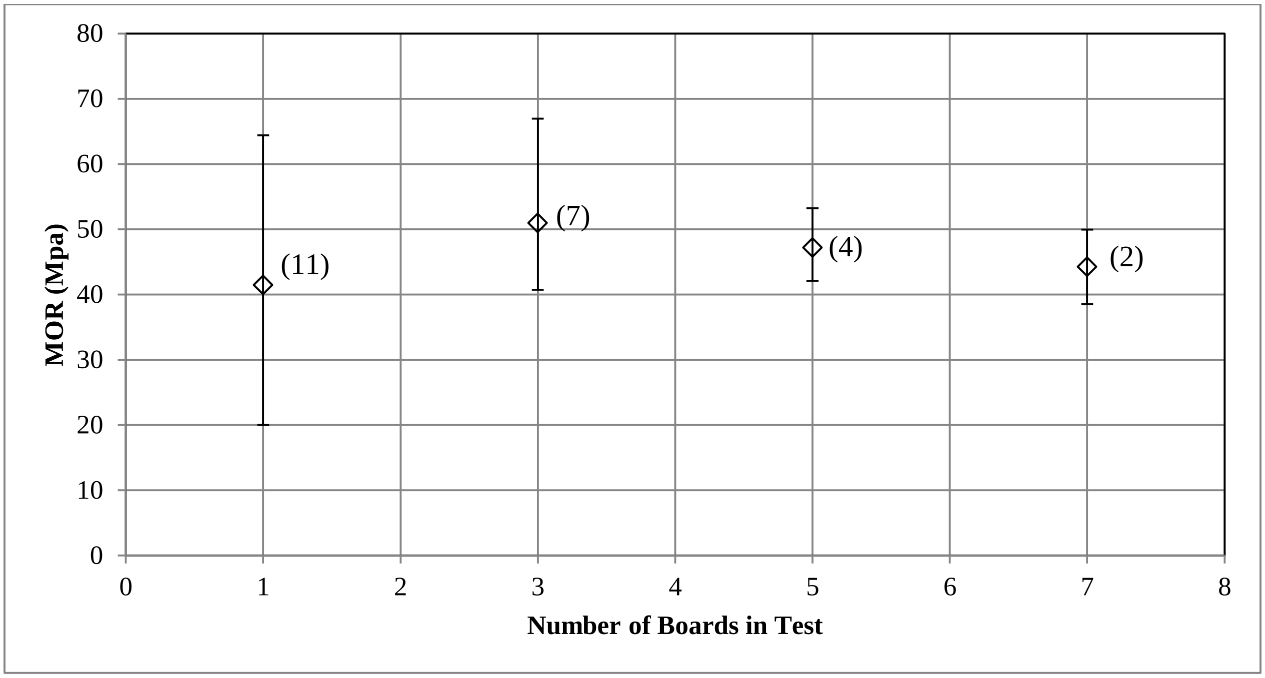


Figure 5.6: 4PB Simple Span Destructive MOR Results (DFL-S2) – Nail End Conditions

The test results of decking subjected to a four point bending test suggest that no increase in rupture strength was found as more boards are added to the system. This could possibly be attributed to the relatively small sample of decking elements obtained from a single manufacturer and contains less variation in stiffness than those the design code was based on (Foschi, 1989). This observation was also consistent with the study conducted by Kampe and Stluka (1963).

5.2.2 Concentrated Load

Figure 5.7 present the simple span destructive concentrated load (127x127) modulus of rupture results for the 127 mm x 36 mm D.Fir-L solid sawn boards with nailed end conditions. The maximum and minimum spread of the data is shown by the error bars. The number in brackets indicates the number of tests that were used to calculate the average modulus of rupture. From the figure it can be observed that the rupture strength increased significantly as more boards were added to the system.

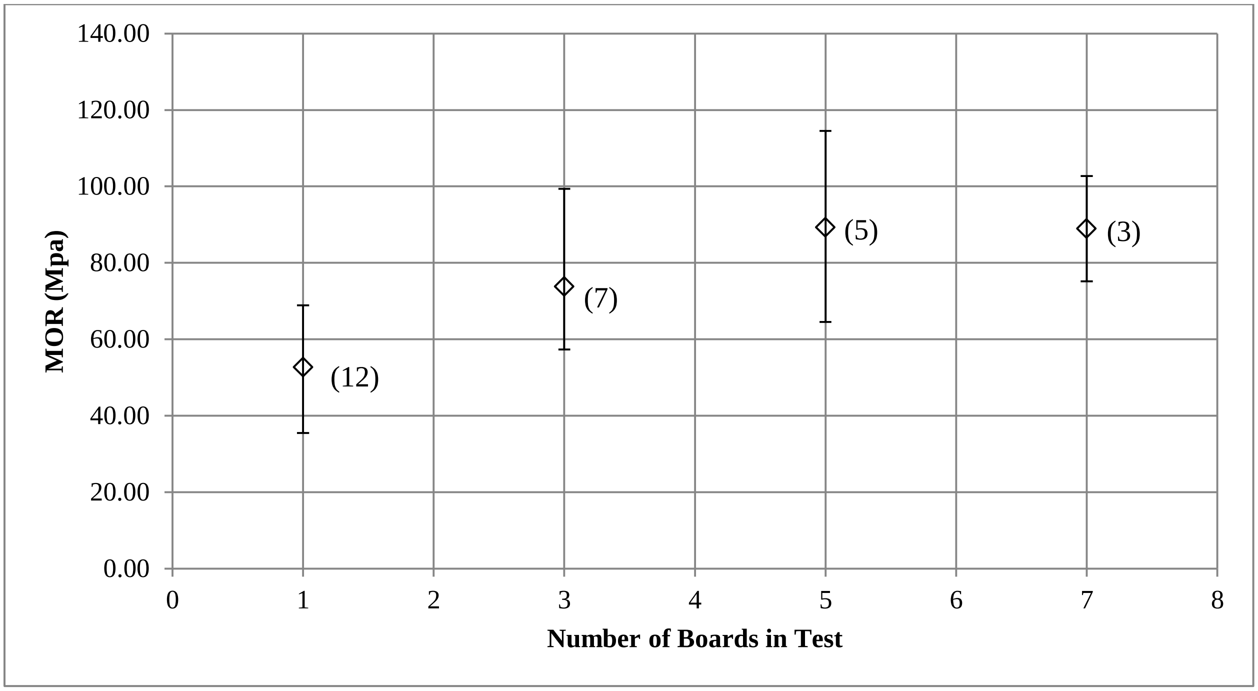


Figure 5.7: CL127 Simple Span Destructive MOR (DFL-S2) – Nailed End Conditions

As mentioned before, the load sharing factor accounts for the variation in stiffness and capacity between the individual board elements, where stiffer elements within the system attract more load and are able to resist higher loading than weaker elements. The scenario considered here is different because the boards in the decking system are not resisting the applied load together but rather the load is transferred from loaded elements to elements not directly under the load through the interlocking mechanism of the tongue and groove. It is obvious in this case that the "system" can only exist as long as the tongue and groove mechanism is intact. If the tongue and groove fails, there will no longer be any transfer of load to the adjacent unloaded elements. The sequence of failure is crucial to determining whether the system failure can be expressed as a function of the failure of a single element. From the non-destructive concentrated load tests, it can be observed that there is significant load sharing occurring between the boards. Destructive concentrated load tests were conducted as to quantify the rupture strength as more boards were added to the system. *Figure 5.8* shows the percentage increase in modulus of rupture as more boards are added to the system. The figure includes the results for both the 200 mm x 200 mm and 127 mm x 127 mm loading blocks. The x-axis represents the number of boards that have been added to the system (i.e. 0 represents no boards being added to the system and 2 represents one board being placed on either side of the loading block). The percent increase for the 200 mm x 200 mm loading block has been normalized to the average modulus of rupture of a two board system, which is the smallest number of boards that can be loaded by this area. Likewise, the percentage increase for the 127 mm x 127 mm loading block has been normalized to the average modulus of rupture of a single board. It is clear from *Figure 5.8* that the highest relative increase in capacity occurs when one board has been added on each side of the loaded boards. The increase in capacity is continuous; however the relative increase diminishes as more board elements, not directly under the load, are added. Even though the failure always occurred at or near the loading block, mostly in the tongue and groove joint, the load was transferred away from the load application point, thereby exerting less stress on the boards and joints in the vicinity of the load application point. From the figure it can be observed that there is an increase in capacity of about 1.5 to 2.5 times the capacity of the loaded boards. It can be concluded, that a significant load sharing is taking place between board elements, and that the assumption of basing the design capacity on that of one board is invalid, especially when the load is assumed to be exerted on an area that covers more than one board (e.g. 200x200 mm area on 127 mm wide boards). This study has been limited to small application areas that is supposed to simulate a concentrated load. The results are applicable to decking systems consisting of boards with 127 mm width. If wider boards are used (or the load is applied on a smaller loading area), it is expected that the conclusions may change. More research is needed to understand the effect of loaded area and decking system sizes on the ultimate capacity of the decking system.

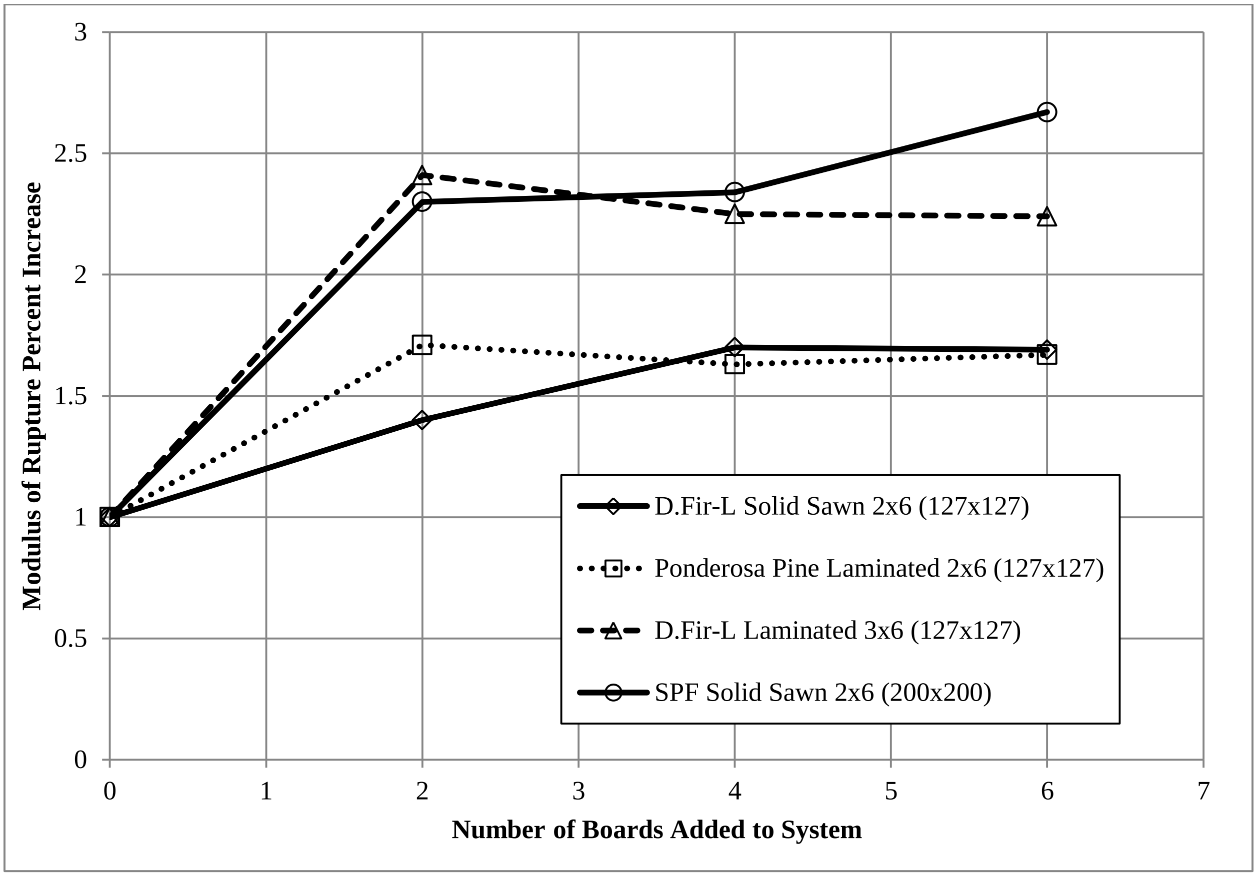


Figure 5.8: Simple Span Destructive Concentrated Load Percent increase in MOR

5.3 Behaviour of Controlled Random Layup

The controlled random layup is the most frequently used decking pattern due to its efficiency and flexibility. Since the code design provisions for stiffness and ultimate capacity are based on the failure and stiffness of the simple span pattern it was of particular interest to investigate the failure modes of the controlled random layup and compare them with those observed in the simple span layup.

5.3.1 Four Point Bending

The test results showed that the failure mode for the controlled random layup was more complex than that for simple span decking involving crack propagation towards the butt joint. *Figures 5.9(a)* and *(b)* show the typical failure of a simple span and controlled random decking system, respectively. From the figures it can be observed that the failure of simple span and controlled random layup under four point bending was almost indistinguishable, except for propagations of failure at the butt joints in the controlled random layup as can be seen in *Figure 5.9(b)*.

(a) Simple Span (b) Controlled Random

Figure 5.9: Destructive Four-Point Bending Failure Modes

As expected, the small difference in the failure mode discussed above does not translate into a significant difference in capacity. Comparing the modulus of rupture between the simple span and controled random layups, *Table 5.2*, yielded a relatively small difference and with no particular tendency to one layup being stronger than the other.

Table 5.2: Destructive Four Point-Bending Controlled Random Layup Results

Species	Number of Boards in Test	Number of Simple Span Tests Conducted	Average Simple Span MOR (MPa)	Number of Controlled Random Tests Conducted	Controlled Random MOR (MPa)	Percent Difference (%)
D.Fir Solid Sawn 127 mm x 36 mm	7	2	44	1	32	29
Alaskan Yellow Cedar Solid Sawn 127 mm x 36 mm	7	2	43	1	46	-8
D.Fir Laminated 127 mm x 36 mm	7	2	52	1	58	-12
D.Fir Laminated 131 mm x 55 mm	5	2	38	1	37	2

5.3.2 Concentrated Load

The failure mode of the controlled random layup pattern under a concentated load was similar to that of the simple span layup pattern especially regarding the transfer of load to board elements not directly under the load. *Figure 5.10(a)* and *(b)* show the typical failure modes of a simple span layup and controlled random layup, respectively. The controlled random failure mostly occurred in the tongue and groove joint, although a more complex failure pattern involving the failure of boards not directly under the loading block was also observed. Those failures typically occurred in layup patterns where the butt joint was in the vicinity of the loaded area, as seen in *Figure 5.10(b)*.

(a) Simple Span (b) Controlled Random

Figure 5.10: Concentrated Load (200x200) Failure Modes

These inconsistencies in failure for the controlled random layup are very difficult to predict or model, as they are highly dependent on the systems layup pattern, the defect distribution, and the location of butt joint. *Table 5.3* shows a comparison between the modulus of rupture obtained for controlled random pattern and those found from the simple span pattern. It was observed that if a butt joint was directly underneath the loading block then the capacity of the system was reduced significantly, as was the case for the S-P-F solid sawn and Ponderosa Pine Laminated tests. These results may be expected for square joints, however, if end-matched joints were used, it can be anticipated that the capacity may be higher. The effect of end-mached joints was outside the scope of the current study.

Table 5.3: Destructive Concentrated Load Controlled Random Layup Results

Species	Loading Block	Number of Boards in Test	Number of Simple Span Tests Conducted	Average Simple Span MOR (MPa)	Number of Controlled Random Tests Conducted	Average Controlled Random MOR (MPa)	Percent Difference (%)
SPF Solid Sawn 127 mm x 36 mm	200x200	8	3	77	2	49	37
D.Fir Solid Sawn 127 mm x 36 mm	200x200	8	3	76	3	78	-3
D.Fir Solid Sawn 127 mm x 36 mm	127x127	7	5	89	3	89	0.5
Pond. Pine Lam. 127 mm x 36 mm	127x127	7	5	55	1	37	32
D.Fir Laminated 131 mm x 55 mm	127x127	5	4	87	1	104	-19

5.4 Effect of Nailing Pattern on Rupture Strength

According to the manufacturers design sheets, additional toe-nails should be driven into the 131 mm x 55 mm decking on 762 mm spacing, as can be seen in *Figure 5.11*.

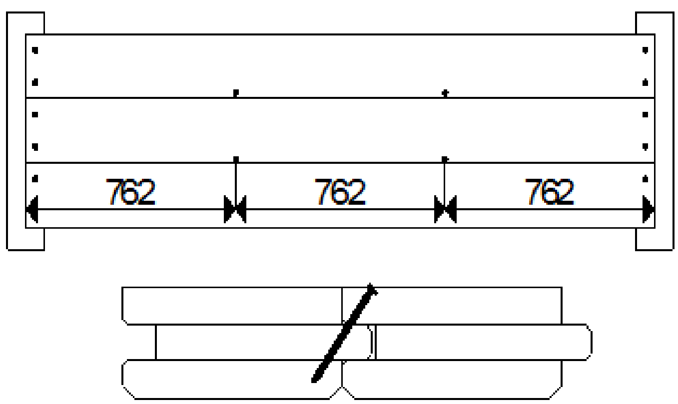


Figure 5.11: Toe-Nail Details

To investigate the effect of additional toe nails on the capacity of a decking system, 16 tests with 131 mm x 55 mm decking were conducted with and without the addition of the face nails. *Table*

5.4 presents the increase in modulus of rupture when additional face nails are used within a simple span decking system.

Table 5.4: Percent Increase in Modulus of Rupture due to Toe Nails

Load Case	Number of Boards in Test	Number of Tests without nails	MOR (Mpa) No Nails	Number of Tests with Nails	MOR (MPa) Nails @ 760 mm	Percent Increase in MOR
Concentrated Load (127x127)	3	2	74	3	91	1.23
Concentrated Load (127x127)	5	2	68	2	87	1.27
Four-Point Bending	3	1	38	6	54	1.41

The results clearly show an increase in the capacity with the additional face nails at the mid-span. The effect is less pronounced for the concentrated load tests possibly due to the concentration of the failure in the tongue and groove joint. Adding a single toe nail at mid span is likely not sufficient to shift the failure to a bending failure of multiple boards. Even though it was outside the scope of this project, it is speculated that if more nails or other fasteners (e.g. screws, glue) were added, the capacity could have been increased significantly more than was observed in Table 5.4. The 20% increase in capacity was consistent for the two series of tests with 3 and 5 boards in the system. The increase in capacity was higher for the four point bending tests with an average increase of 40%, however the limited number of tests makes it difficult to draw a general conclusion.

5.5 Effect of Sheathing

5.5.1 Uniform Load

Due to the inadequacy of the decking boards to transfer forces in plane of the floor or roof systems, sheathing is typically added to provide diaphragm action. However, the contribution of the sheathing to the stiffness and strength of the decking system is assumed negligible. *Table 5.5* summarizes the effect of adding sheathing on the stiffness of the decking system. A relatively small percent increase in stiffness of 4-6% was found, which can be attributed to the relatively small bending stiffness of the sheathing panel and the slight increase in the section modulus. No increase in capacity was observed when the sheathing panel was added. It should be noted that the number of tests here was limited and did now allow for general conclusions to be drawn.

Table 5.5: Increase in Stiffness due to Sheathing on Four-Point Bending Test

Test	**Species**	**Size (mm)**	**Stiffness before sheathing (N/mm)**	**Stiffness After Sheathing (N/mm)**	**Percent increase in stiffness (%)**
1	D.Fir Solid Sawn	127 x 36	447	474	6.2
2	D.Fir Solid Sawn	127 x 36	429	449	4.8

Figures 5.12(a) and *(b)* show the failure of the decking system without and with sheathing, respectively. Even though the sheathing did not contribute significantly to the strength and stiffness of the decking system under the four point bending tests, it helped contain the spread of the failure.

(a) No sheathing

(b) with sheathing

Figure 5.12: Destructive Simple Span Four-Point Bending Sheathing Comparison

5.5.2 Concentrated Load

It has already been shown in *Section 5.1.2* that there exists significant load sharing between loaded and non-loaded board elements when a concentrated load is applied on a decking system. Adding the sheathing panel on top of the decking boards was thought to produce two positive effects on the capacity: (1) it would distribute the load even further away from the load application point and engage more boards in the load carrying mechanism; and (2) it would prevent (or reduce the possibility of) the tongue a groove failure that was consistently observed under the concentrated load tests. *Tables 5.6(a)* and *(b)* presents the results from the simple span concentrated load (127x127) tests that were done with the addition of sheathing for stiffness and capacity, respectively. From *Table 5.6(a)*, it can be observed that the average increase in initial stiffness was 48%. *Table 5.6(b)* shows a significant increase in ultimate capacity when sheathing was nailed on top of a decking system. For D.Fir-L solid sawn, the percent increase in modulus of rupture was a 133%, and for the laminated Ponderosa Pine, the percent increase in modulus of rupture was 224%. Clearly, the addition of the sheathing helps to spread the concentrated load amongst the other boards within the system, and also aids against the failure of the tongue and groove mechanism.

Table 5.6: Effect of Sheathing on Concentrated Load (127x127) Test

(a) Increase in Stiffness due to Sheathing

Species	Stiffness without sheathing (N/mm)	Initial Stiffness with Sheathing (N/mm)	Percent increase in Initial Stiffness (%)
D.Fir Solid Sawn	188	273	46
D.Fir Solid Sawn	201	274	37
D.Fir Solid Sawn	173	274	58
Ponderosa Pine Laminated	136	205	51
Ponderosa Pine Laminated	144	202	40
Ponderosa Pine Laminated	130	203	57
Average			48

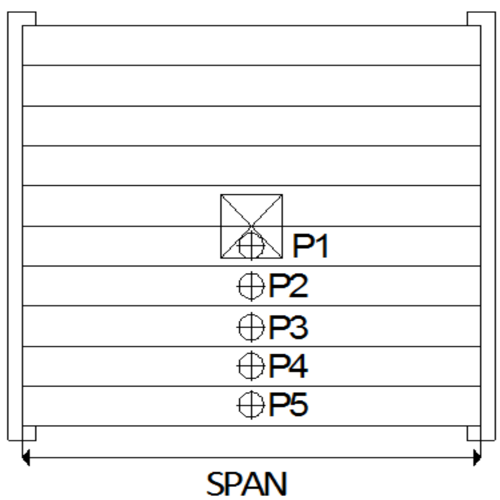
(b) Average Percent Difference in MOR with Addition of Sheathing

Species	Number of Boards in Test	Number of Simple Span Tests Conducted	Average Simple Span MOR (Mpa)	Number of Simple Span + Sheathing Tests Conducted	Average Simple Span + Sheathing MOR (Mpa)	Percent Increase in MOR (%)
D.Fir Solid Sawn 127 mm x 36 mm	7	5	89	3	207	133
Ponderosa Pine Laminated 127 mm x 36 mm	7	5	55	3	178	224

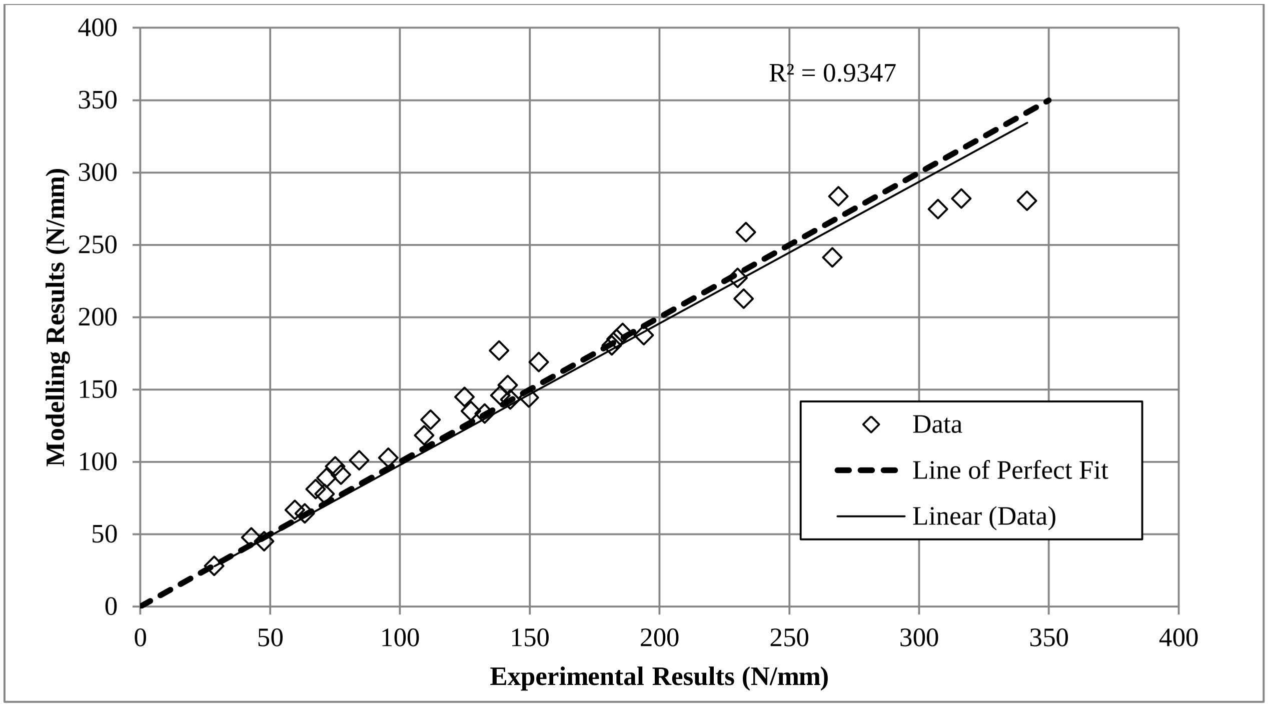
5.6 Modelling Results

5.6.1.1 Simple Span

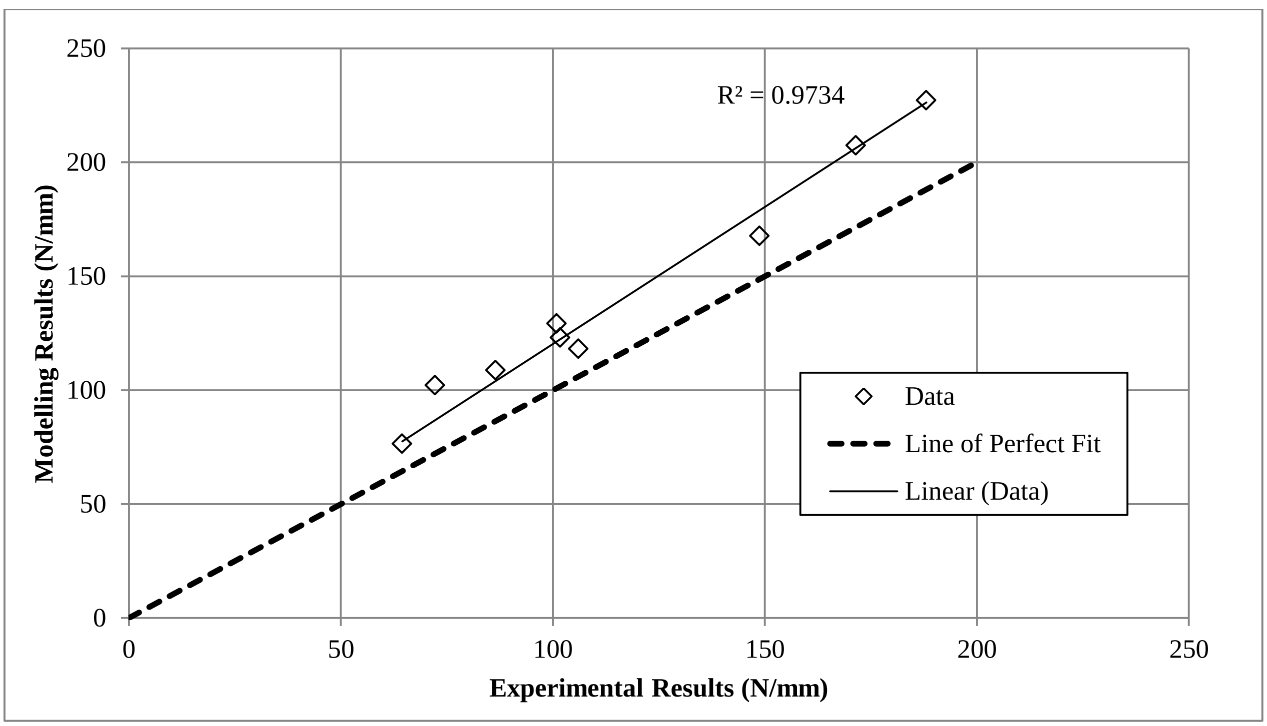
A total of 36 simple span models were created, including 5 different species and 3 span lengths for both solid sawn and laminated species. Since no glue line delamination was observed for the laminated boards, the model was based on equivalent solid dimensions with the appropriate material properties for the laminated decks. A comparison between the experimental stiffness and those obtained using the FE model for concentrated load with an area of 200 mm x 200 mm was made. *Figure 5.13(a)* shows the location of the measurement points. Figures *5.13(b)-(f*) present the comparison between the experimental and model stiffness at the five locations shown in *Figure 5.13(a)*. The results show that the model was clearly capable of predicting not only the deflection of the board under loading in isolation and as part of a system (Figure 5.13b) but also those non-loaded boards within the system with high level of accuracy.



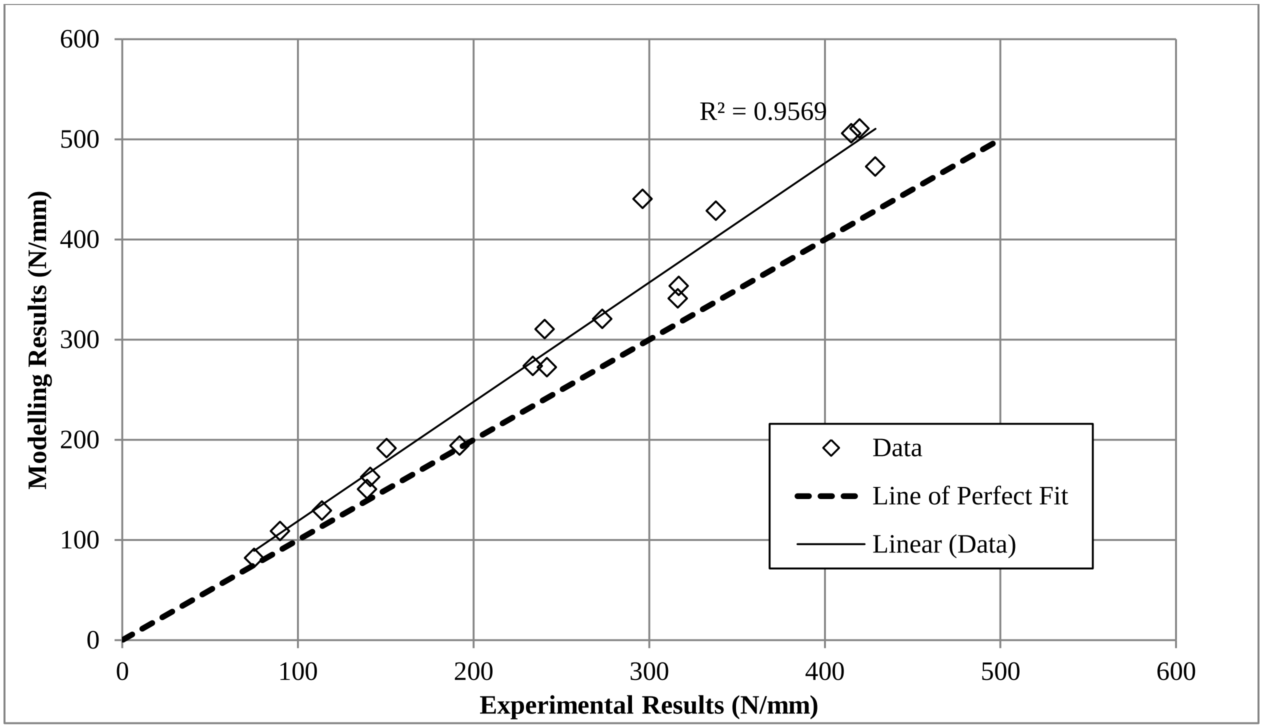
(a) Simple Span Model Stiffness vs. Experimental Stiffness



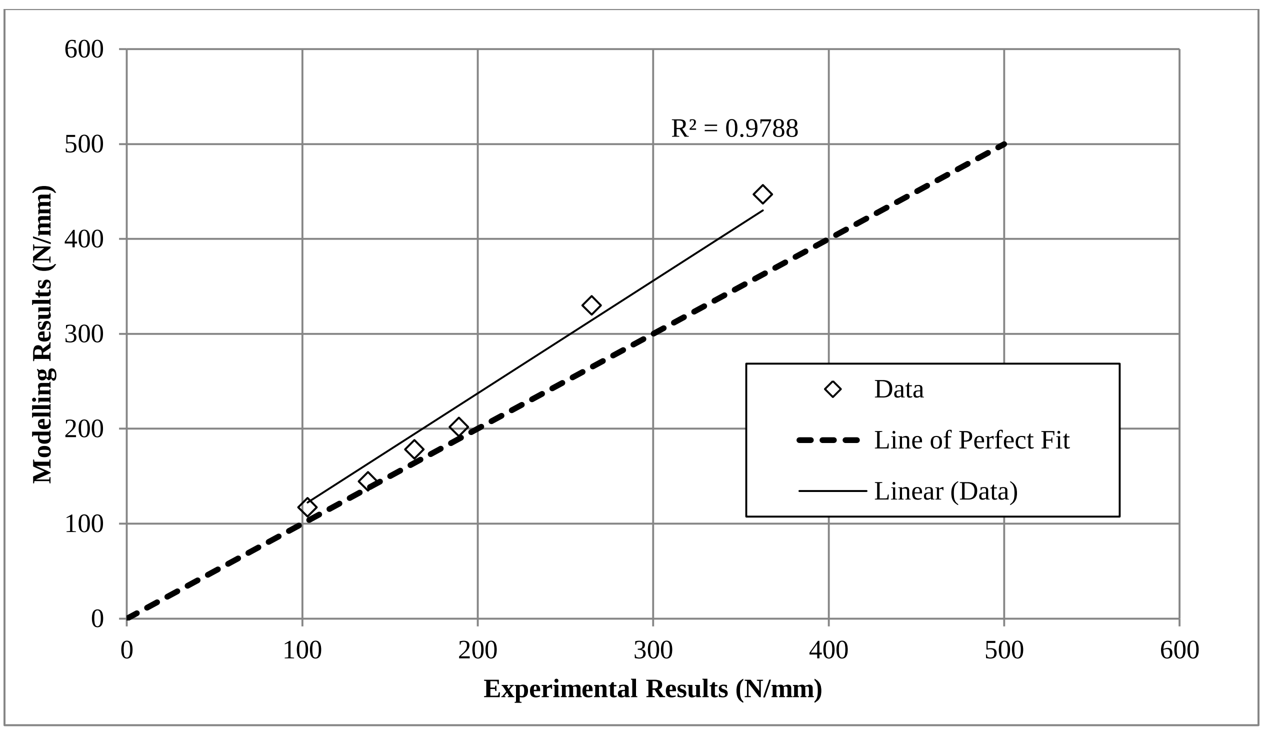
(b) Stiffness Comparison at Point 1 (P1)



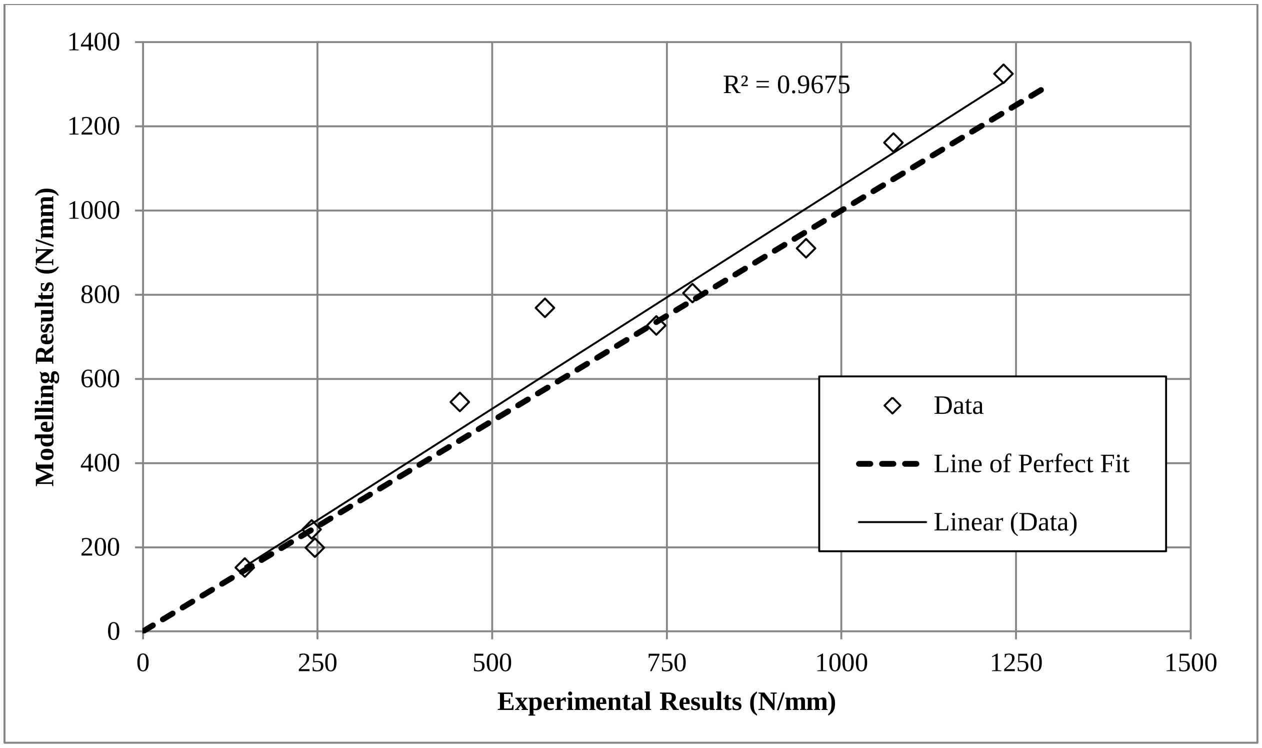
(c) Stiffness Comparison at Point 2 (P2)



(d) Stiffness Comparison at Point 3 (P3)



(e) Stiffness Comparison at Point 4 (P4)



(f) Stiffness Comparison at Point 5 (P5)

Figure 5.13: Simple Span Experimental vs. Model Results

Figure 5.14 shows the measured and predicted deflection shape for a 3000 mm long, D.Fir-L, solid sawn, 127 mm x 36 mm boards, where the decking system consisted of 2, 6 and 14 boards. As expected, the model was able to mimic the two-board system deflection with higher level of accuracy. The maximum error at mid-span for the 6 and 14 board systems was about 14%.

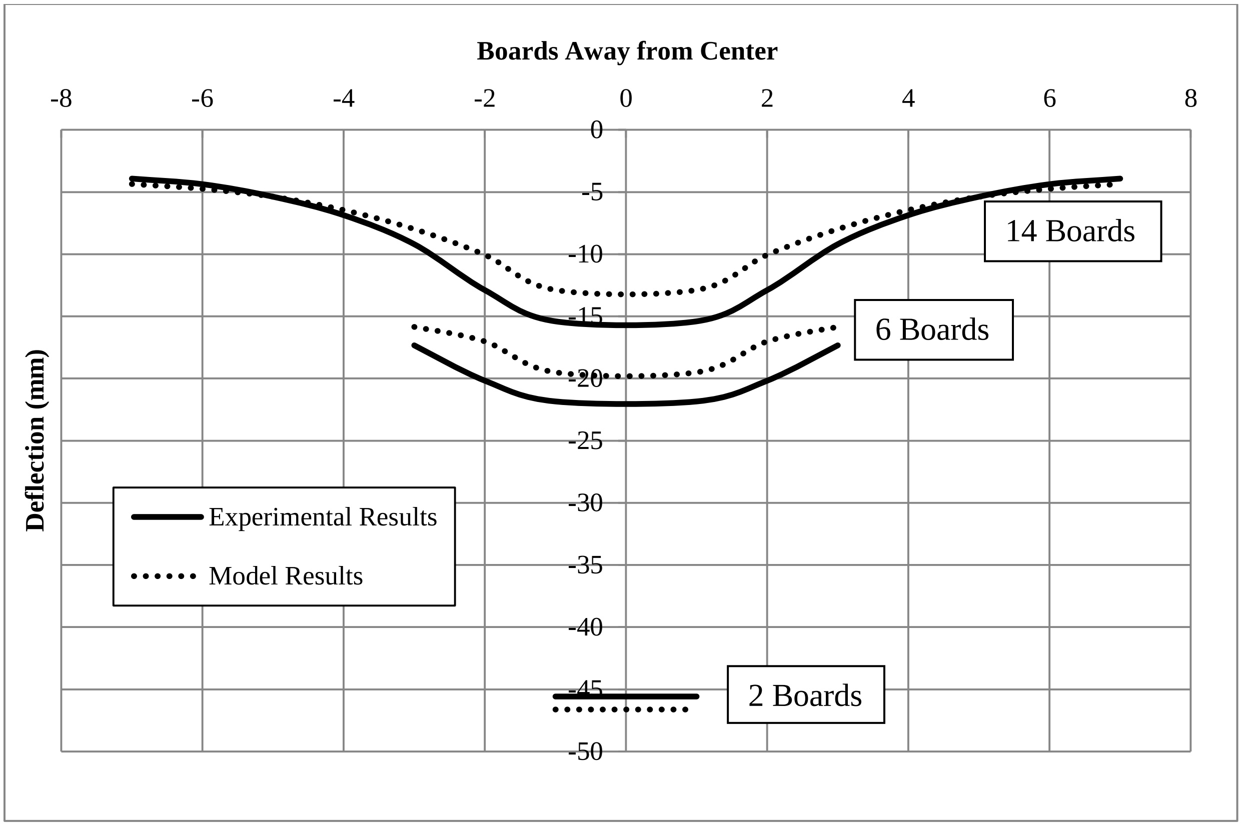


Figure 5.14: Experimental versus Model Concentrated Load Mid-span Deflection

5.6.1.2 Two-span Continuous and Controlled Random Modelling Results

The decking systems with two-span continuous and control random layup were modelled using the same principles that were used for the simple span models. Compared to the simple span data, the number of tests here were limited and the system more complex. The meshing process for the controlled random layup was more erroneous, and included finer meshing near the location of the linear links. The model also accounted for butt joints by allowing a 1 mm gap between boards with such end detail. The model results and comparison with the test data can be seen in *Tables 5.7* and *5.8*, for the two-span continuous and controlled random layups, respectively. As was anticipated, the model fit with the experiment results are not as good as those obtained for the simple span case, however, the model was still able of capturing the behaviour with reasonable accuracy.

Table 5.7: Two-Span Continuous Model Stiffness vs. Experimental Stiffness

Test Name	Exp. Stiffness (N/mm)	Model Stiffness (N/mm)	Percent Difference (%)
ND-TS-1-DFL-S2-8	321	308	4
ND-TS-1-AYC-S2-8	239	254	-6
ND-TS-1-DFL-L2-8	314	266	15
ND-TS-1-POP-L2-8	264	241	9
ND-TS-1-SPF-S2-8	195	238	-23
ND-TS-2-DFL-S2-8	213	237	-11

Table 5.8: Controlled Random Model Stiffness vs. Experimental Stiffness

Test Name	Exp. Stiffness (N/mm)	Model Stiffness (N/mm)	Percent Difference (%)
ND-CR-1-DFL-L2-8-1	266	296	-11
ND-CR-1-DFL-L2-8-3	237	286	-21
ND-CR-1-POP-L2-8-1	240	241	-1
ND-CR-1-POP-L2-8-3	250	219	13
ND-CR-4-DFL-S2-8-3	355	279	21
ND-CR-1-DFL-S2-8-2	258	230	11
ND-CR-1-DFL-S2-8-2	392	385	2
ND-CR-1-AYC-S2-8-2	262	320	-22
ND-SD-1-DFL-S2-8-2	232	335	-44
ND-SD-1-AYC-S2-8-2	290	310	-7
ND-SD-1-DFL-S2-8-1	306	357	-17
ND-SD-1-POP-L2-8-2	227	313	-38
ND-SD-1-SPF-S2-8-2	310	341	-10
ND-SD-2-DFL-S2-8-2	247	298	-21

The average error found between the model results and those obtained from the experimental tests was 11% and 17% for the two-span continuous and controlled random layups respectively. This is not considered too high given the variability of the material. The maximum error found was 44% for the controlled random layup. The lack of accuracy is mainly due to the complexity of the system, including the effects of butt joints.

5.6.2 Modelling Deflection Coefficient Results

The deflection coefficients for a concentrated load on a simple span for different number of boards were determined using the results from the model and compared with those found in the experimental study (*Figure 5.15*). From the figure, it can be observed that the deflection coefficients found from the modelling were very close to those found in the experimental testing. This clearly shows that the model was capable of recreating the increase in stiffness as more boards were added to the system for the simple span layup pattern.

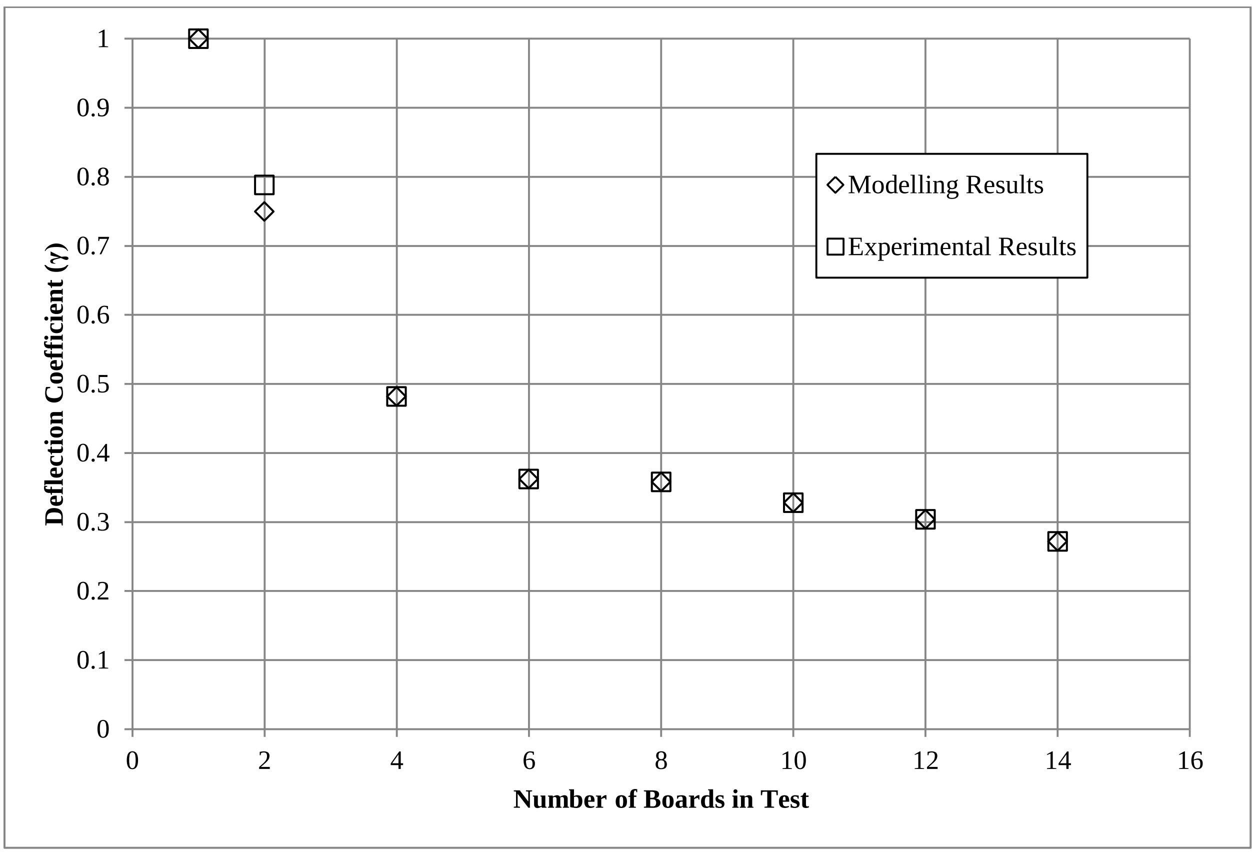


Figure 5.15: Average Simple Span CL200 Deflection Coefficient (Model vs. Exp.)

Using the stiffness obtained from the model, the deflection coefficients were calculated for both the two-span continuous and controlled random layup pattern, as shown in *Table 5.9*. From the table it is apparent that the complexity described earlier regarding the force transfer especially in the controlled random layup made is more difficult for the model to predict the behaviour. A maximum difference of about 30% is deemed acceptable given the variability of the material and layup pattern, however, more work is needed to refine the model.

Table 5.9: Deflection Coefficient for Multi-span layups Under Concentrated Load

Test	**Number of Models**	**Average Model Deflection Coefficient**	**Average Experimental Deflection Coefficient**	**Percent Error (%)**
Simple Span	9	0.36	0.36	0
Two-Span Continuous	6	0.23	0.30	-30
Controlled Random Exterior Span	4	0.35	0.31	11
Controlled Random Interior Span	2	0.36	0.27	25
Combination Single and Double Exterior Span	4	0.34	0.29	15
Combination Single and Double Interior Span	4	0.27	0.31	-15

The model was able to mimic the behaviour of the simple span decking system for loaded and non-loaded boards when a 200 mm x 200 mm loading block was applied. Now, the model can, for example, be used to investigate the behaviour of decking systems within the elastic region for a number of different loading blocks. The purpose of this investigation is to determine how many boards participate in resisting the applied concentrated load. For this analysis, all boards were assigned the same length (2134 mm) and modulus of elasticity based on the average MOE for the D.Fir-L Select Structural boards (12500 MPa). Models consisting of 2 to 20 boards were created, and the stiffness was recorded based on the deflection of the board immediately under the loading block. The resulting stiffness as function of the number of boards within the system has been plotted in *Figure 5.16*. From the figure, it can be observed that the stiffness levels out for each loading block once 8 to 10 boards have been added to the system, which is consistent with the experimental test results.

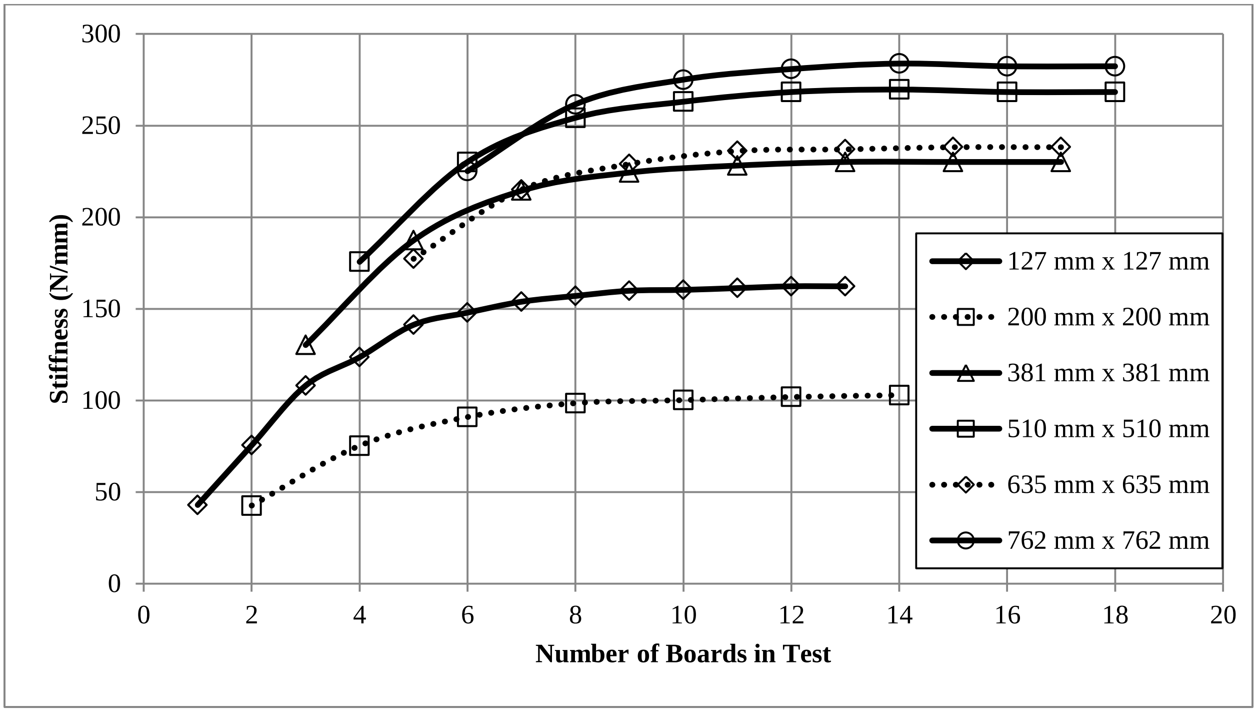


Figure 5.16: Comparison of Stiffness between different Loading Blocks

5.7 Implications on Decking Design Tables

As mentioned in Chapter 1, this project was motivated by the code change that stipulated that the application area of a live load of 1.3 kN be applied on an area of 200 mm x 200 mm instead of 750 mm x 750 mm (NBCC, 2010).

This section investigates the impact of the current study's results on the design of plank decking systems. A review of the current design provisions and selection tables is presented and a proposal is made for changes based on the project findings. The decking tables in the Canadian Wood Design Manual (WDM, 2010) include values for 36, 64 and 89 mm Select grade and

Commercial grade decking. For simplicity, this investigation here only looks at select grade species.

5.7.1 Impact of Code Change based on Existing Practice

The following assumptions were used in the calculation of the decking tables, based on existing design practices:

- Dead Load of 0.5 kPa.
- Deflection Limit of L/240 (Typical for Roofs).
- For uniform load, the controlled random layup was assumed in the calculation of the deflection (0.77 factor applies to UDL). Moment resistance was calculated based on a uniform load on a simple span.
- The point load of 1.3 kN is assumed to have an area of 0.2 m by 0.2 m as required by the 2010 edition of the NBCC.

The decking selection tables based on a uniformly distributed load on a controlled random layup that are currently published in the Canadian Wood Design Manual (WDM, 2010) have been recreated to show which spans are governed by the 1.3 kN concentrated load check. The values at the bottom of the table represent the span length in meters that would govern the design under a 1.3 kN concentrated load. The span length at the bottom of the table indicates the span at which the 1.3 kN concentrated load would govern. Based on that span length, the highlighted cells within the table are those that would no longer meet the design check. *Table 5.10(a)* and (*b)* present the results for the maximum factored uniform load and maximum specified uniform load, respectively.

Table 5.10: Existing Practice Design Tables

(a) Maximum Factored Uniform Load W_{fr} (kPa) – Select Grade

Span	D.fir-L			Hem-Fir			S-P-F			Northern		
m	Thickness mm			Thickness mm			Thickness mm			Thickness mm		
	36	64	89	36	64	89	36	64	89	36	64	89
1.0	39.5			38.3			39.5			25.4		
1.2	27.4			26.6			27.4			17.6		
1.4	20.2			19.6			20.2			13.0		
1.6	15.4			15.0			15.4			9.92	31.3	
1.8	12.2			11.8			12.2	38.5		7.84	24.8	
2.0	9.88	31.2		9.58	30.3		9.88	31.2		6.35	20.1	
2.2	8.16	25.8		7.92	25.0		8.16	25.8		5.25	16.6	
2.4	6.86	21.7		6.65	21.0		6.86	21.7		4.41	13.9	28.9
2.6	5.85	18.5		5.67	17.9		5.85	18.5	38.3		11.9	24.6
2.8	5.04	15.9	33.0	4.89	15.4	32.0	5.04	15.9	33.0		10.2	21.2
3.0	4.39	13.9	28.8		13.5	27.9		13.9	28.8		8.92	18.5
3.2		12.2	25.3		11.8	24.5		12.2	25.3		7.84	16.2
3.4		10.8	22.4		10.5	21.7		10.8	22.4		6.94	14.4
3.6		9.64	20.0		9.34	19.4		9.64	20.0		6.19	12.8
3.8		8.65	17.9		8.39	17.4		8.65	17.9		5.56	11.5
4.0		7.81	16.2		7.57	15.7			16.2			10.4
4.2			14.7			14.2			14.7			9.42
4.4			13.4			13.0			13.4			8.59
4.6			12.2			11.9			12.2			7.86
4.8			11.2			10.9			11.2			7.22
5.0			10.4			10.0			10.4			6.65
5.2			9.57			9.28			9.57			6.15
5.4			8.87			8.61			8.87			5.70
5.6			8.25			8.00			8.25			5.30
5.8			7.69			7.46			7.69			4.94
Span due to CL (m)	2.00	5.53	10.10	1.94	5.38	9.86	2.00	5.53	10.10	1.34	3.76	7.04

(b) Maximum Specified Uniform Load for L/240 Deflection $W_{\Delta R}$ (kPa) – Select Grade

Span	D.fir-L			Hem-Fir			S-P-F			Northern		
m	Thickness mm			Thickness mm			Thickness mm			Thickness mm		
	36	64	89	36	64	89	36	64	89	36	64	89
1.0	20.20			19.39			16.97			12.12		
1.2	11.69			11.22			9.82			7.01		
1.4	7.36			7.07			6.18			4.42		
1.6	4.93			4.73			4.14			2.96	16.62	
1.8	3.46			3.32			2.91	16.35		2.08	11.68	
2.0	2.52	14.19		2.42	13.62		2.12	11.92		1.51	8.51	
2.2	1.90	10.66		1.82	10.23		1.59	8.95		1.14	6.39	
2.4	1.46	8.21		1.40	7.88		1.23	6.90		0.88	4.93	13.25
2.6	1.15	6.46		1.10	6.20		0.97	5.42	14.59		3.87	10.42
2.8	0.92	5.17	13.90	0.88	4.96	13.35	0.77	4.34	11.68		3.10	8.34
3.0	0.75	4.20	11.30		4.03	10.85		3.53	9.49		2.52	6.78
3.2		3.46	9.31		3.32	8.94		2.91	7.82		2.08	5.59
3.4		2.89	7.76		2.77	7.45		2.43	6.52		1.73	4.66
3.6		2.43	6.54		2.34	6.28		2.04	5.49		1.46	3.92
3.8		2.07	5.56		1.99	5.34		1.74	4.67		1.24	3.34
4.0		1.77	4.77		1.70	4.58			4.01			2.86
4.2			4.12			3.95			3.46			2.47
4.4			3.58			3.44			3.01			2.15
4.6			3.14			3.01			2.63			1.88
4.8			2.76			2.65			2.32			1.66
5.0			2.44			2.34			2.05			1.46
5.2			2.17			2.08			1.82			1.30
5.4			1.94			1.86			1.63			1.16
5.6			1.74			1.67			1.46			1.04
5.8			1.56			1.50			1.31			0.94
Span due to CL (m)	1.22	2.90	4.75	1.20	2.84	4.66	1.12	2.66	4.36	0.95	2.25	3.68

The results show that the change has a significant impact on decking design for strength and stiffness, particularly for the 36 mm thick decking.

5.7.2 Impact of Results of Current Study

The deflection under concentrated load was determined using a deflection coefficient 0.40, as was determined from the non-destructive concentrated load (200x200) tests. For the strength calculation, the load is assumed to be resisted by 3 boards as significant load sharing was observed in the destructive concentrated load tests. The decking selection tables were recreated based on these assumptions as shown in *Table 5.11(a)* and (*b*).

Table 5.11: Impact of Current Study on Design Tables

(a) Maximum Factored Uniform Load W_{fr} (kPa) – Select Grade

Span	D.fir-L			Hem-Fir			S-P-F			Northern		
m	Thickness mm			Thickness mm			Thickness mm			Thickness mm		
	36	64	89	36	64	89	36	64	89	36	64	89
1.0	39.5			38.3			39.5			25.4		
1.2	27.4			26.6			27.4			17.6		
1.4	20.2			19.6			20.2			13.0		
1.6	15.4			15.0			15.4			9.92	31.3	
1.8	12.2			11.8			12.2	38.5		7.84	24.8	
2.0	9.88	31.2		9.58	30.3		9.88	31.2		6.35	20.1	
2.2	8.16	25.8		7.92	25.0		8.16	25.8		5.25	16.6	
2.4	6.86	21.7		6.65	21.0		6.86	21.7		4.41	13.9	28.9
2.6	5.85	18.5		5.67	17.9		5.85	18.5	38.3		11.9	24.6
2.8	5.04	15.9	33.0	4.89	15.4	32.0	5.04	15.9	33.0		10.2	21.2
3.0	4.39	13.9	28.8		13.5	27.9		13.9	28.8		8.92	18.5
3.2		12.2	25.3		11.8	24.5		12.2	25.3		7.84	16.2
3.4		10.8	22.4		10.5	21.7		10.8	22.4		6.94	14.4
3.6		9.64	20.0		9.34	19.4		9.64	20.0		6.19	12.8
3.8		8.65	17.9		8.39	17.4		8.65	17.9		5.56	11.5
4.0		7.81	16.2		7.57	15.7			16.2			10.4
4.2			14.7			14.2			14.7			9.42
4.4			13.4			13.0			13.4			8.59
4.6			12.2			11.9			12.2			7.86
4.8			11.2			10.9			11.2			7.22
5.0			10.4			10.0			10.4			6.65
5.2			9.57			9.28			9.57			6.15
5.4			8.87			8.61			8.87			5.70
5.6			8.25			8.00			8.25			5.30
5.8			7.69			7.46			7.69			4.94
Span due to CL (m)	5.28	13.49	22.98	5.15	13.17	22.49	5.28	13.49	22.98	3.59	9.53	16.72

(b) Maximum Specified Uniform Load for L/240 Deflection $W_{\Delta R}$ (kPa) – Select Grade

Span	D-fir			Hem-Fir			S-P-F			Northern		
m	Thickness mm			Thickness mm			Thickness mm			Thickness mm		
	36	64	89	36	64	89	36	64	89	36	64	89
1.0	20.20			19.39			16.97			12.12		
1.2	11.69			11.22			9.82			7.01		
1.4	7.36			7.07			6.18			4.42		
1.6	4.93			4.73			4.14			2.96	16.62	
1.8	3.46			3.32			2.91	16.35		2.08	11.68	
2.0	2.52	14.19		2.42	13.62		2.12	11.92		1.51	8.51	
2.2	1.90	10.66		1.82	10.23		1.59	8.95		1.14	6.39	
2.4	1.46	8.21		1.40	7.88		1.23	6.90		0.88	4.93	13.25
2.6	1.15	6.46		1.10	6.20		0.97	5.42	14.59		3.87	10.42
2.8	0.92	5.17	13.90	0.88	4.96	13.35	0.77	4.34	11.68		3.10	8.34
3.0	0.75	4.20	11.30		4.03	10.85		3.53	9.49		2.52	6.78
3.2		3.46	9.31		3.32	8.94		2.91	7.82		2.08	5.59
3.4		2.89	7.76		2.77	7.45		2.43	6.52		1.73	4.66
3.6		2.43	6.54		2.34	6.28		2.04	5.49		1.46	3.92
3.8		2.07	5.56		1.99	5.34		1.74	4.67		1.24	3.34
4.0		1.77	4.77		1.70	4.58			4.01			2.86
4.2			4.12			3.95			3.46			2.47
4.4			3.58			3.44			3.01			2.15
4.6			3.14			3.01			2.63			1.88
4.8			2.76			2.65			2.32			1.66
5.0			2.44			2.34			2.05			1.46
5.2			2.17			2.08			1.82			1.30
5.4			1.94			1.86			1.63			1.16
5.6			1.74			1.67			1.46			1.04
5.8			1.56			1.50			1.31			0.94
Span due to CL (m)	1.93	4.58	7.52	1.89	4.49	7.36	1.77	4.20	6.89	1.50	3.55	5.82

It can be observed that the code change would have no impact on the strength calculation when the design assumptions have been modified based on the study findings. This is consistent with the observed behaviour of decking systems where no failure have been documented based on the prescribed loading condition of 1.3 kN on an area of 200 mm by 200 mm. Clearly the loading magnitude and the size of the area in the code provisions are realistic but the assumptions of load sharing amongst tongue and groove decking boards were not adequate. When it comes to deflection, there are still a number of span lengths that are affected by the code provision. When comparing *Tables 5.9(b)* and *5.10(b),* it can be observed that the number of cells within the tables that are affected by the design provision has been reduced from 91 to 24. From *Table 5.10(b),* it can be observed that the 2010 code provision mainly effects the 36 mm thick decking for every species, and two span lengths for the 64 mm thick Northern Species decking.

CHAPTER 6-Conclusions

Non-destructive and destructive uniformly distributed and concentrated load tests were conducted on plank (tongue and groove) wood decking systems to investigate the system behaviour. Based on the test results and observed failure modes, the following conclusions can be drawn:

- The established deflection coefficients used to check the deflection of plank decking under balanced uniformly distributed loads can accurately predict the behaviour of the three types of decking layup patterns specified in the Canadian Design Standard (CSA O86, 2009).
- When unbalanced uniformly distributed loads are applied to plank decking, it was found that the deflection coefficient of 0.42 for two-span continuous layup is non-conservative and that a more appropriate value to use in this case would be 0.60.
- It was found that under concentrated loads, the stiffness of the decking system increased significantly as more boards were added. The number of boards found to be representative of a “system” was 8. Adding additional boards did not have significant effect on the stiffness of the system. This information would be useful for deciding the number to construct the decking system for testing purposes.
- It was found that a deflection coefficient of γ = 0.40 is appropriate to calculate the deflection for the three types of decking layup patterns specified in the Canadian Design Standard (CSA O86, 2009) under concentrated load on an area of 200 mm by 200 mm.
- The failure mode of a controlled random layup decking system under a uniformly distributed load was found to be consistent with the failure observed for simple span. The assumption of basing the capacity of the controlled random layup on the capacity of

simple span layup is appropriate.

- The failure mode of a decking system under a concentrated load was found to be consistent with a combination of failure in the decking boards and the tongue and groove joints. For the controlled random layup, the failure mode was more complex involving, in some cases, several decking elements.
- Significant load sharing was observed for plank decking under concentrated loads. An increase in capacity of about 1.5 to 2.5 times the capacity of the loaded boards was found. A significant load sharing takes place between board elements, and the assumption of basing the design capacity on that of one board was found to be invalid.
- Placing sheathing on top of a decking system did not significantly increase the stiffness or rupture strength when decking was under a uniformly distributed load. However in the case concentrated load there was an increase of over 50% in stiffness and an increase of over 100% in ultimate capacity. The increase in stiffness and capacity can be attributed to the sheathing aiding in distributing the concentrated load to the unloaded decking elements, and preventing the failure of the tongue and groove joints.
- A detailed finite element model, limited to the linear elastic region of the behaviour was created and compared to the experimental results. The model was found to predict the behaviour of simple span plank decking systems with reasonable accuracy. For the two-span continuous and controlled random plank decking systems the model was not as accurate due to the complexity of the systems.
- It was found that the decking selection tables in the Canadian Wood Design Manual for strength check would not be affected by the NBCC code change once proper analysis and design assumptions were included based on the results from the current study. The impact

of the change is still significant for the serviceability check, especially for the 36 mm thick decking boards.

6.1 Recommendations for Future Work

Based on the current study, the following areas have been identified for future work:

- The study focussed on the behaviour of 127 mm x 36 mm and 131 mm x 55 mm decking sizes. It would be beneficial to investigate whether the findings in this study are applicable to larger decking sizes.
- The effect of unbalanced loading needs to be further investigated, including the effect of full and partial loading on different spans.
- The modelling work in this study was limited to the linear elastic region. Expanding the model to capture the load sharing and failure mechanism would be desirable.

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APPENDIX A-Modulus of Elasticity Results

Species	b (mm)	d (mm)	Grade	Finish
S-P-F	127	36	No.1/No.2	Solid Sawn

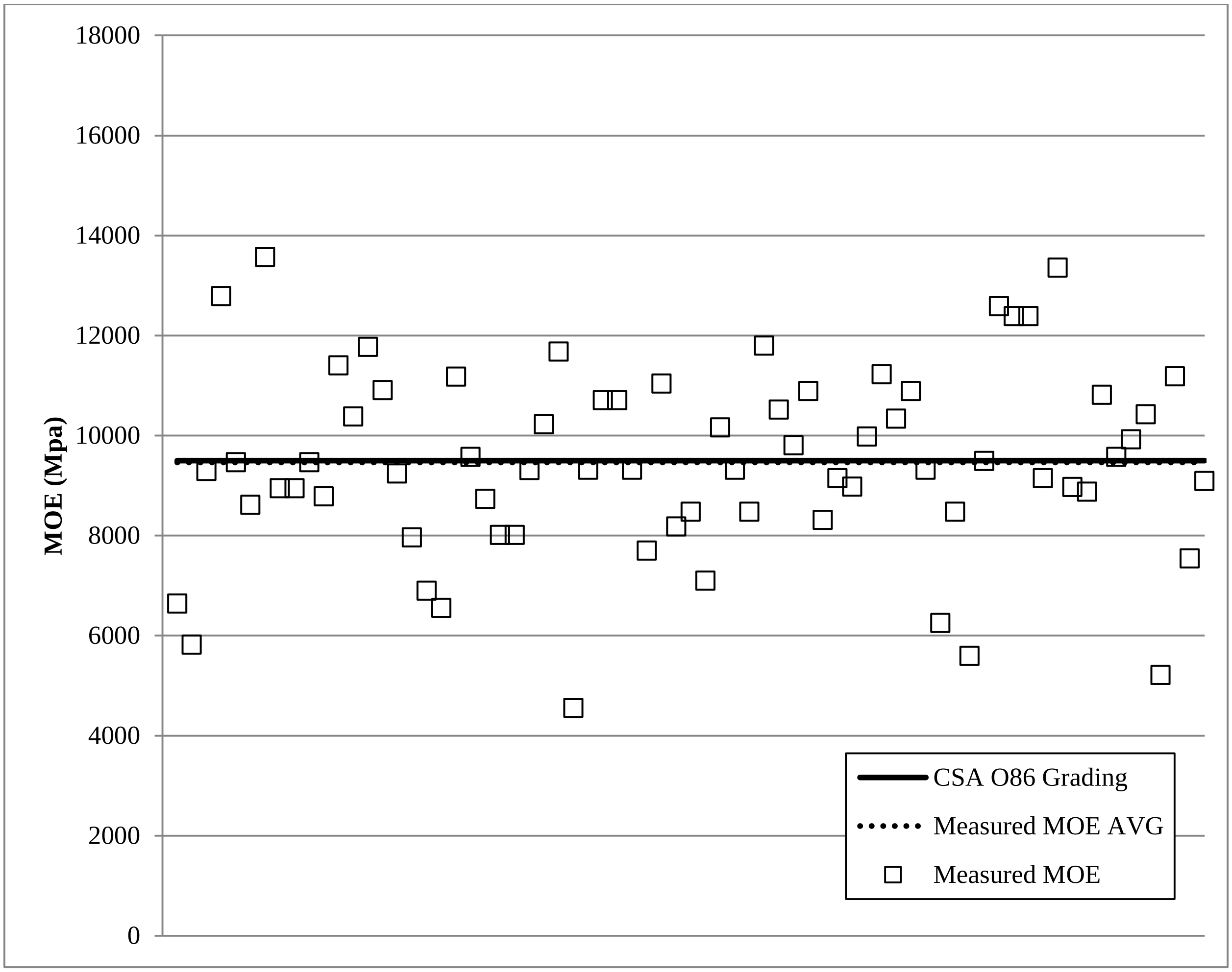


Figure 6.1: A.1 – S-P-F Solid Sawn 127 mm x 36 mm MOE Results

CSA O86 Grading (MPa)	Measured MOE AVG (MPa)	Measured MOE Standard Deviation (MPa)	Measured MOE Coefficient of Variation (%)
9500	9459	1888	20

Species	b (mm)	d (mm)	Grade	Finish
D.Fir-L	127	36	No.1/No.2	Solid Sawn

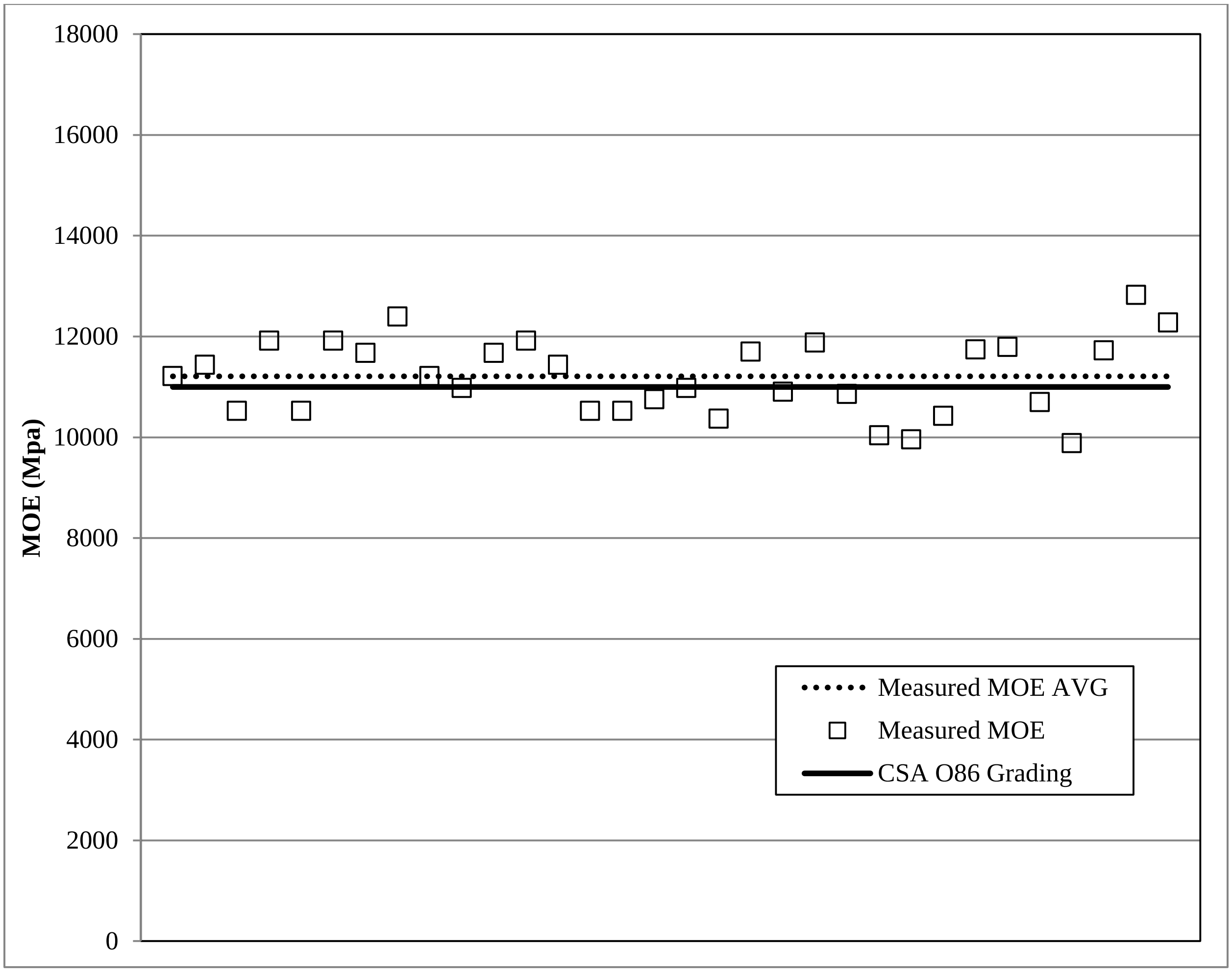


Figure 6.2: A.2 – D.Fir-L Solid Sawn 127 mm x 36 mm MOE Results (Timber Systems Limited)

CSA O86 Grading (MPa)	Measured MOE AVG (MPa)	Measured MOE Standard Deviation (MPa)	Measured MOE Coefficient of Variation (%)
11000	11209	751	7

Species	b (mm)	d (mm)	Grade	Finish
D.Fir-L	127	36	Select Structural	Solid Sawn

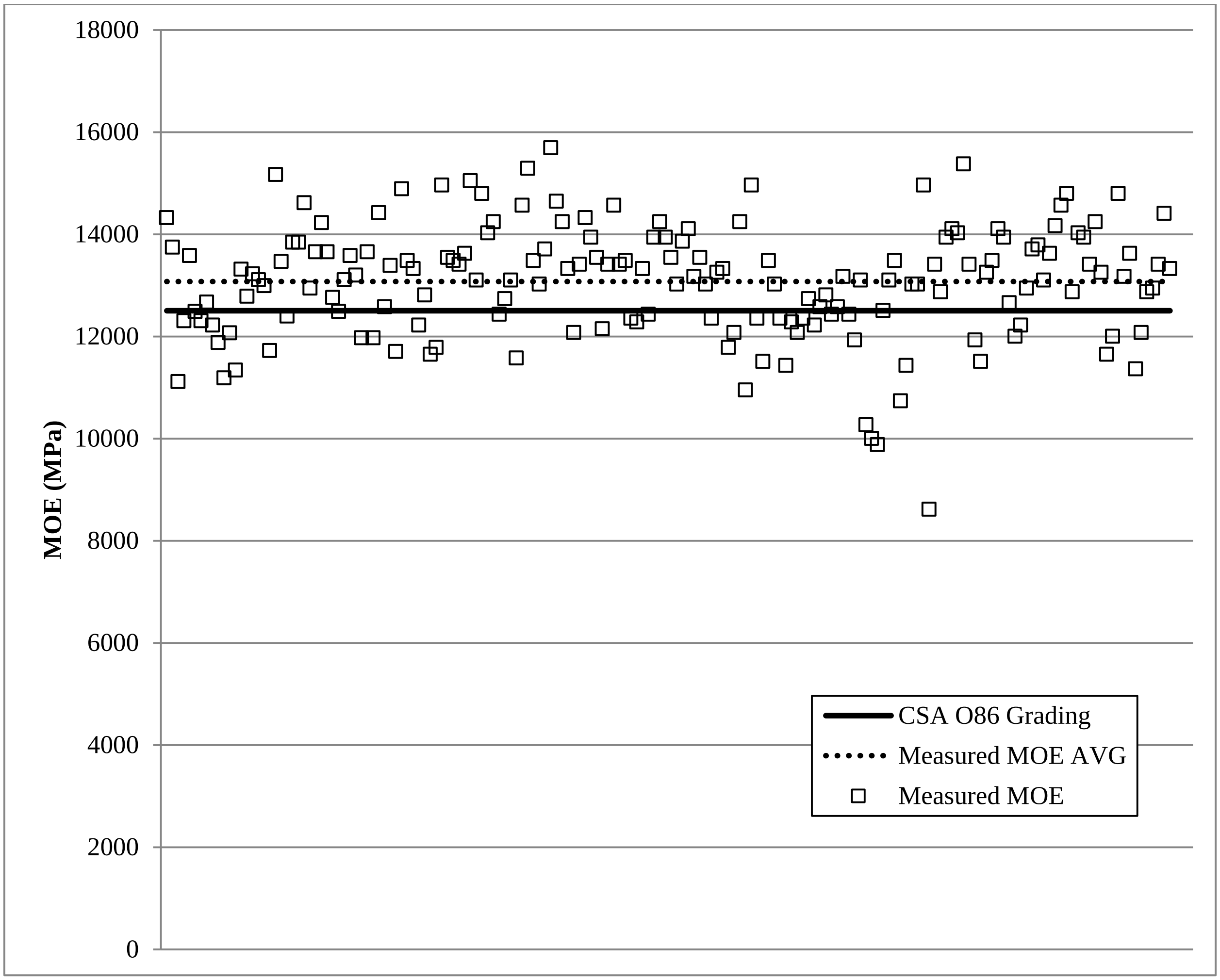


Figure 6.3: A.3 – D.Fir-L Solid Sawn 127 mm x 36 mm MOE Results (Filler King)

CSA O86 Grading (MPa)	Measured MOE AVG (MPa)	Measured MOE Standard Deviation (MPa)	Measured MOE Coefficient of Variation (%)
12500	13077	1116	9

Species	b (mm)	d (mm)	Grade	Finish
Alaskan Yellow Cedar	127	36	Select Structural	Solid Sawn

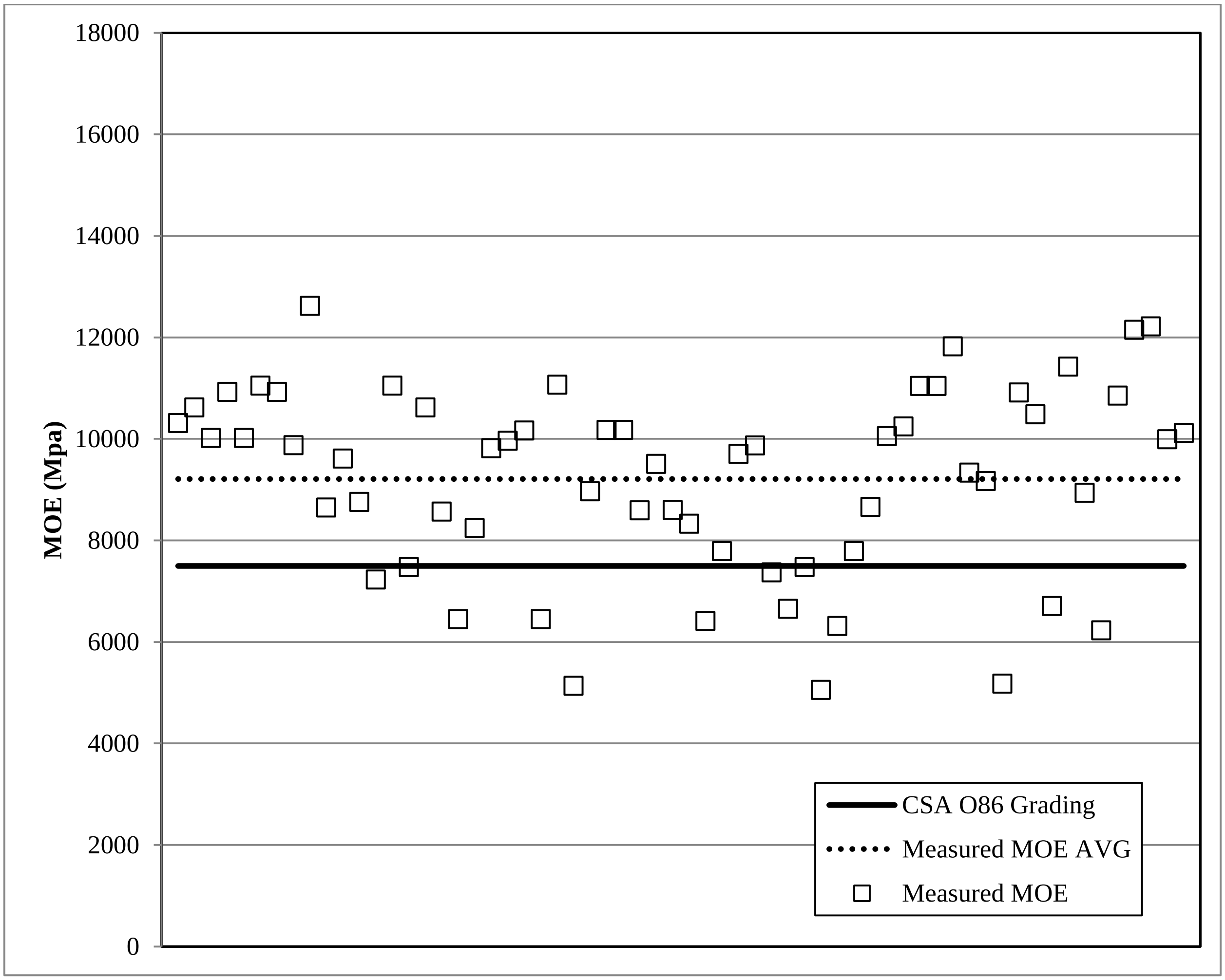


Figure 6.4: A.4 – Alaskan Yellow Cedar Solid Sawn 127 mm x 36 mm MOE Results (Filler King)

CSA O86 Grading (MPa)	Measured MOE AVG (MPa)	Measured MOE Standard Deviation (MPa)	Measured MOE Coefficient of Variation (%)
7500	9210	1857	20

Species	b (mm)	d (mm)	Grade	Finish
D.Fir-L	127	36	Select Structural	Laminated

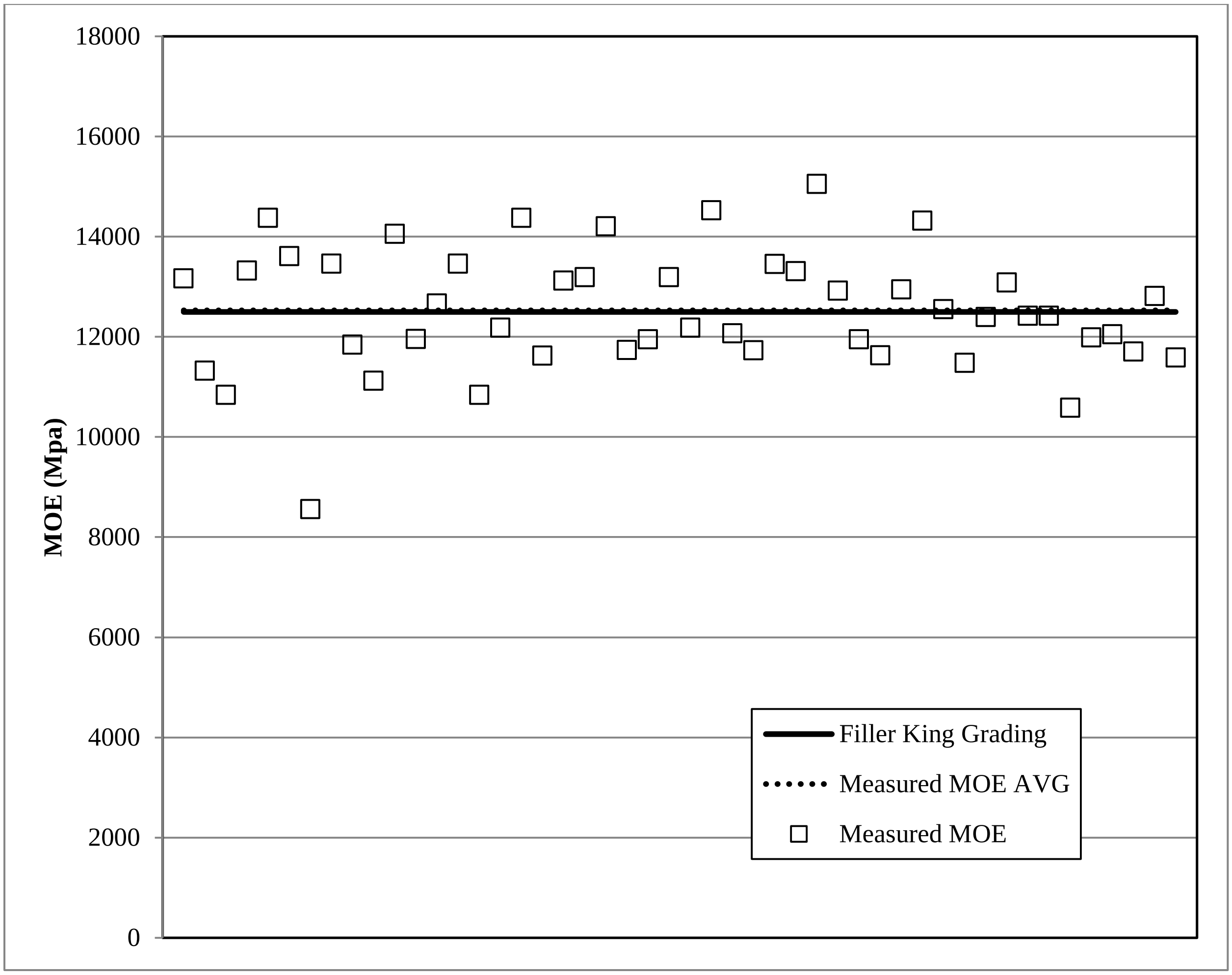


Figure 6.5: A.5 – D.Fir-L Laminated 127 mm x 36 mm MOE Results (Filler King)

Filler King Grading (MPa)	Measured MOE AVG (MPa)	Measured MOE Standard Deviation (MPa)	Measured MOE Coefficient of Variation (%)
12500	12527	1217	10

Species	b (mm)	d (mm)	Grade	Finish
Ponderosa Pine	127	36	Select Structural	Laminated

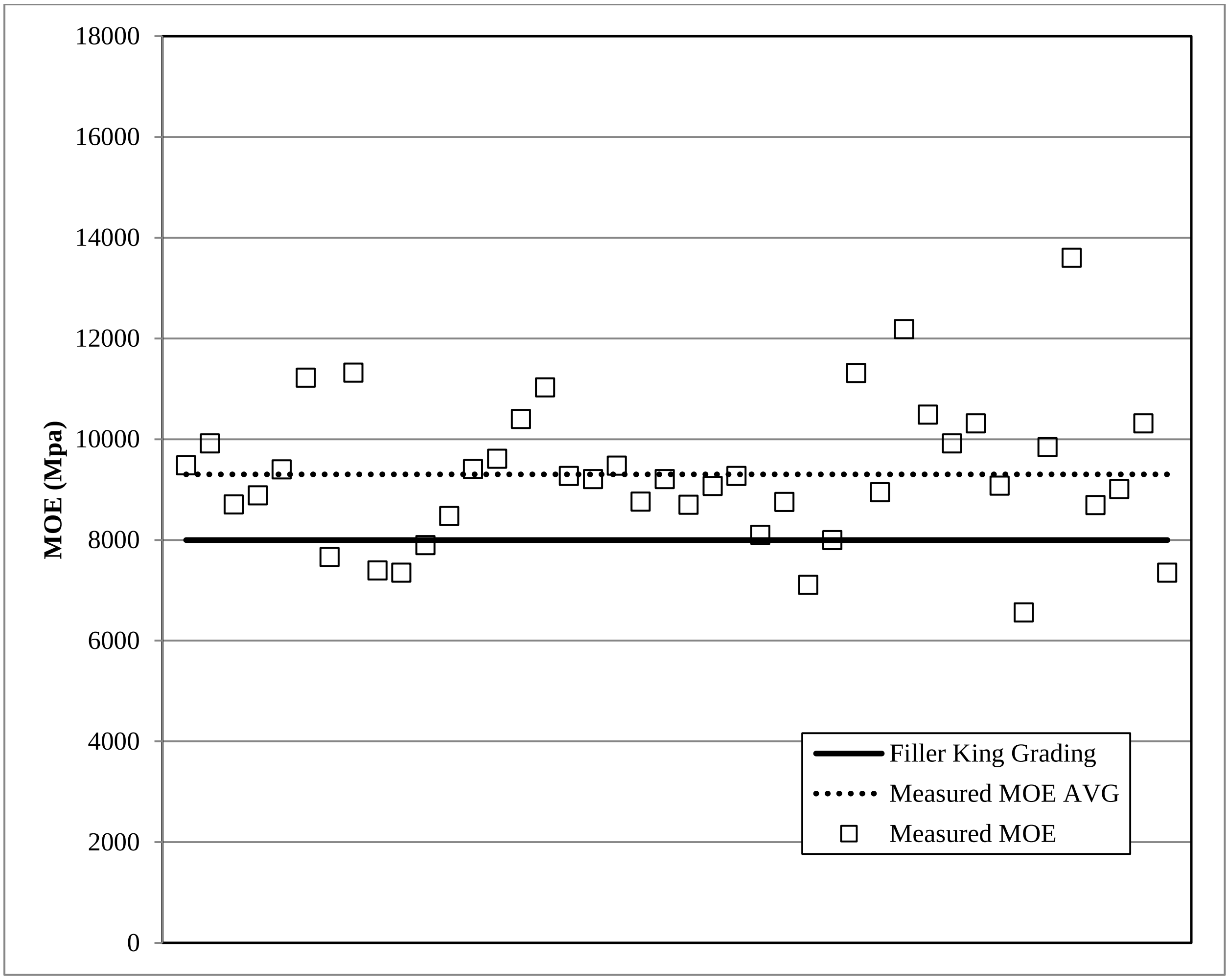


Figure 6.6: A.6 – Ponderosa Pine Laminated 127 mm x 36 mm MOE Results (Filler King)

Filler King Grading (MPa)	Measured MOE AVG (MPa)	Measured MOE Standard Deviation (MPa)	Measured MOE Coefficient of Variation (%)
8000	9300	1412	15

Species	b (mm)	d (mm)	Grade	Finish
D.Fir-L	131	55	Select Structural	Laminated

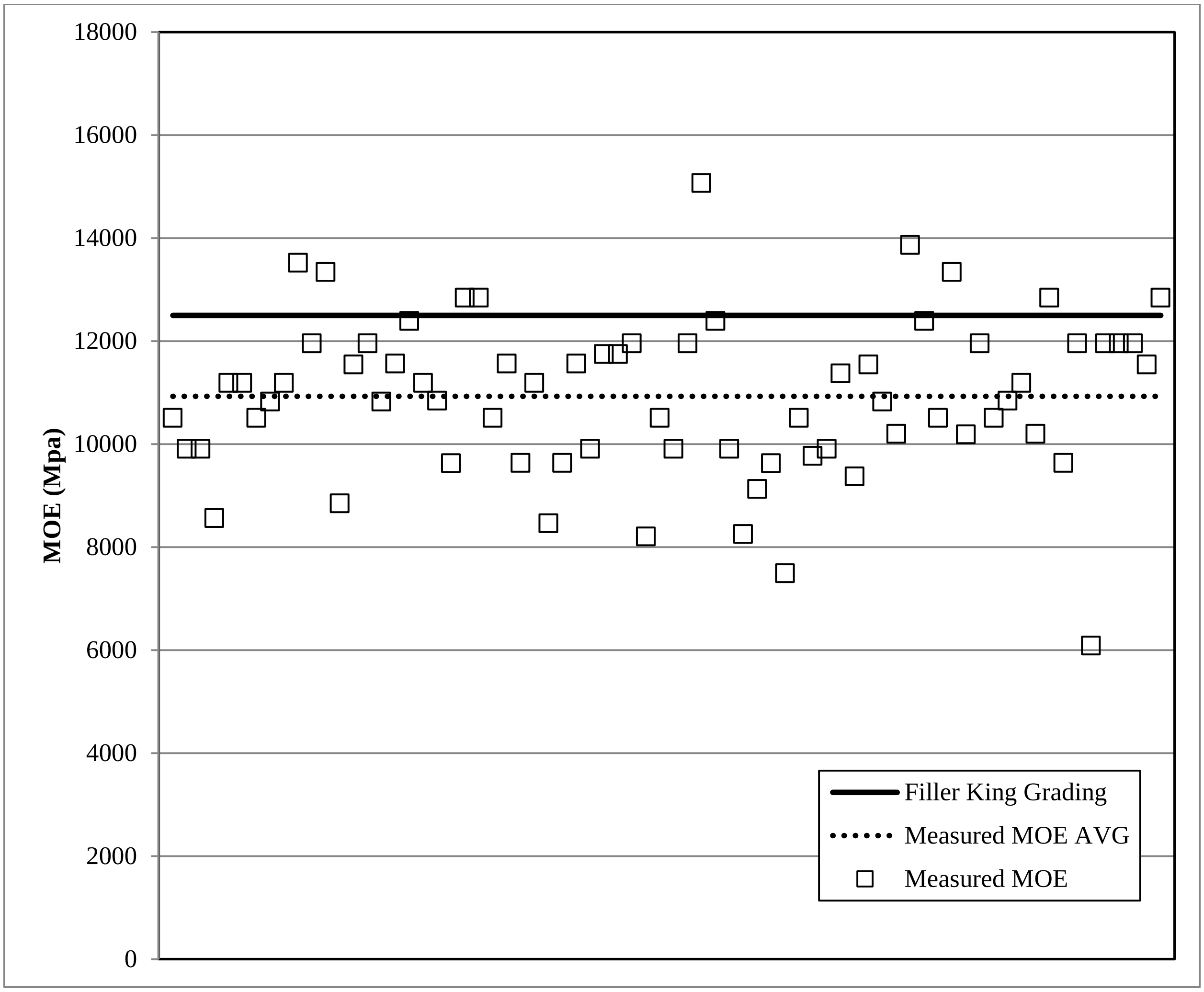


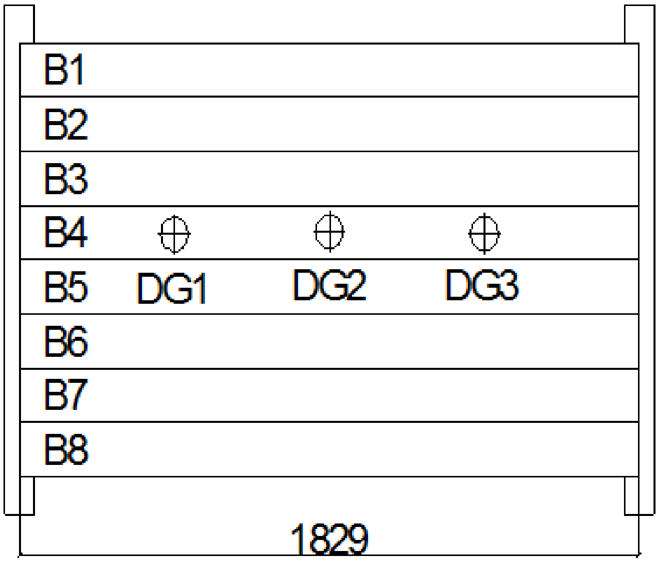
Figure 6.7: A.7 – D.Fir-L Laminated 131 mm x 55 mm MOE Results (Filler King)

Filler King Grading (MPa)	Measured MOE AVG (MPa)	Measured MOE Standard Deviation (MPa)	Measured MOE Coefficient of Variation (%)
12500	10924	1544	14

APPENDIX B-Non Destructive Test Results

Figure 6.8: B.1 – ND-SS-1-DFL-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
D.Fir-L	1	127	36	1829	Simple Span	Solid Sawn



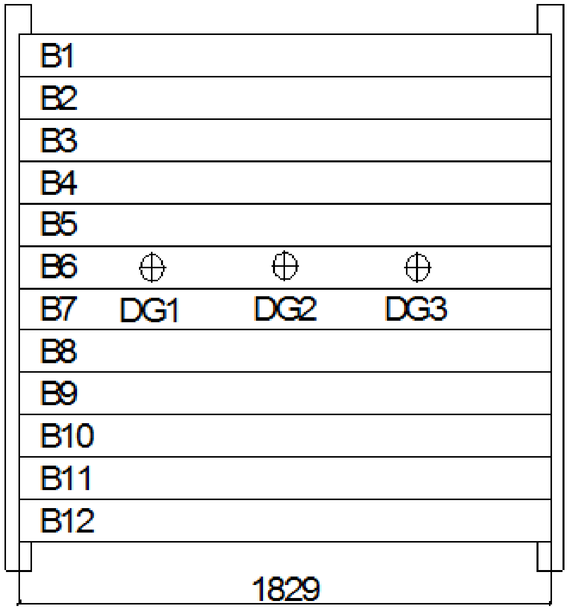
Board	MOE (Mpa)
B1	12668
B2	13580
B3	12219
B4	14322
B5	13746
B6	12307
B7	12307
B8	12489
Average	12955

	Deflection (mm) at 1.3 kN Concentrated Load		
CL200 Test Results	DG1	DG2	DG3
Span 1 Loaded	3.16	4.83	3.00

	Deflection (mm) at UDL (0.231 N/mm)		
UDL Test Results	DG1	DG2	DG3
Span 1 Loaded	2.36	2.96	2.25

Figure 6.9: B.2 –ND-SS-2-DFL-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
D.Fir-L	2	127	36	1829	Simple Span	Solid Sawn



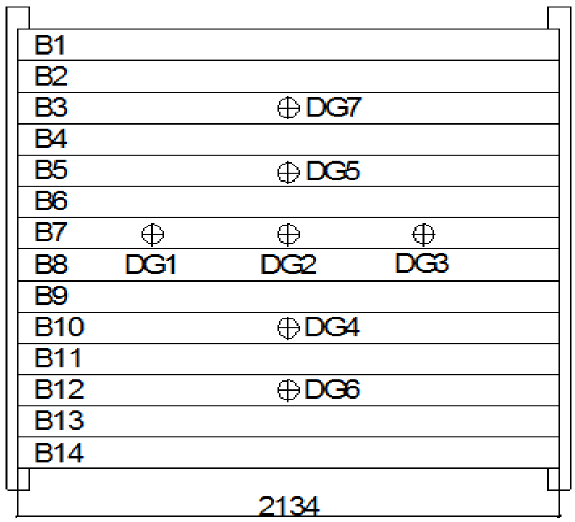
Board	MOE (Mpa)
B1	12489
B2	13110
B3	13201
B4	13580
B5	14418
B6	12579
B7	13390
B8	11971
B9	11971
B10	11971
B11	13390
B12	14889

CL200 Test Results			Deflection (mm) at 1.3 kN Concentrated Load		
Number of Boards in Test	Average MOE	Boards in Test	DG1	DG2	DG3
2	12985	B6-B7	6.76	10.40	6.71
4	13090	B5-B8	3.29	4.87	3.10
6	12985	B4-B9	2.80	4.23	2.68
8	12885	B3-B10	2.56	3.81	2.44
10	12958	B2-B11	2.14	3.21	2.19
12	13080	B1-B12	2.76	4.11	2.58

UDL Test Results			Deflection (mm) at UDL (0.231 N/mm)		
Number of Boards in Test	Average MOE	Boards in Test	DG1	DG2	DG3
2	12985	B6-B7	3.04	4.34	3.06
4	13090	B5-B8	2.41	3.60	2.43
6	12985	B4-B9	2.66	4.04	2.83
8	12885	B3-B10	2.54	3.66	2.51
10	12958	B2-B11	2.22	3.38	2.39
12	13080	B1-B12	2.32	3.42	2.31

Figure 6.10: B.3 – ND-SS-3-DFL-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish	Board	MOE (Mpa)
D.Fir-L	3	127	36	2134	Simple Span	Solid Sawn	B1	10054
							B2	11615
							B3	9503
							B4	11246
							B5	11282
							B6	10340
							B7	11076
							B8	11660
							B9	11660
							B10	11005
							B11	11175
							B12	11559
							B13	11716
							B14	10213

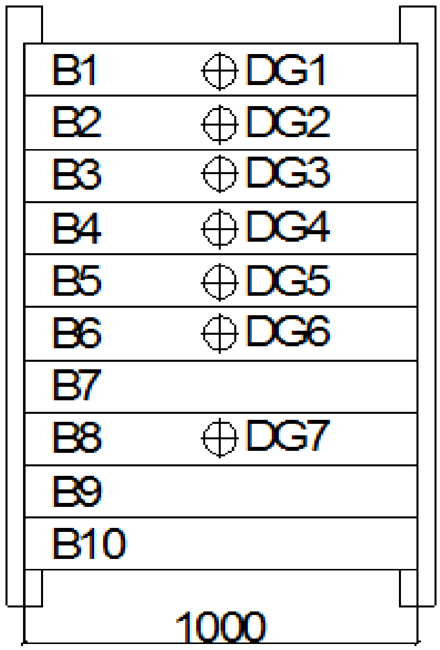


CL200 Test Results			Deflection (mm) at 1.3 kN Concentrated Load					
Number of Boards in Test	Average MOE	Boards in Test	DG1	DG2	DG3	DG4	DG5	DG6	DG7
2	11368	B7-B8	11.33	16.67	11.07				
4	11184	B6-B9	7.03	10.20	6.64				
6	11171	B5-B10	5.45	8.46	5.41	5.08	5.08		
8	11181	B4-B11	4.75	7.16	4.54	3.85	4.48		
10	11051	B3-B12	4.69	7.08	4.82	3.03	4.34	1.34	1.73
12	11153	B2-B13	4.73	9.04	4.57	3.10	3.83	1.21	1.40
14	11007	B1-B14	4.54	6.70	4.39	3.13	3.90	1.22	1.32

UDL Test Results			Deflection (mm) at UDL (0.231 N/mm)						
Number of Boards in Test	Average MOE	Boards in Test	DG1	DG2	DG3	DG4	DG5	DG6	DG7
2	11368	B7-B8	6.16	8.49	6.04				
4	11184	B6-B9	7.35	10.23	6.95				
6	11171	B5-B10	6.51	11.15	6.19	10.52	10.32		
8	11181	B4-B11	7.13	9.99	6.71	10.29	10.88		
10	11051	B3-B12	7.66	10.69	7.64	10.04	10.33	10.04	10.20
12	11153	B2-B13	7.76	10.78	7.63	9.78	10.29	9.32	10.57
14	11007	B1-B14	7.88	10.98	7.71	10.33	10.41	9.94	10.30

Figure 6.11: B.4 – ND-SS-1-SPF-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
S-P-F	1	127	36	1000	Simple Span	Solid Sawn

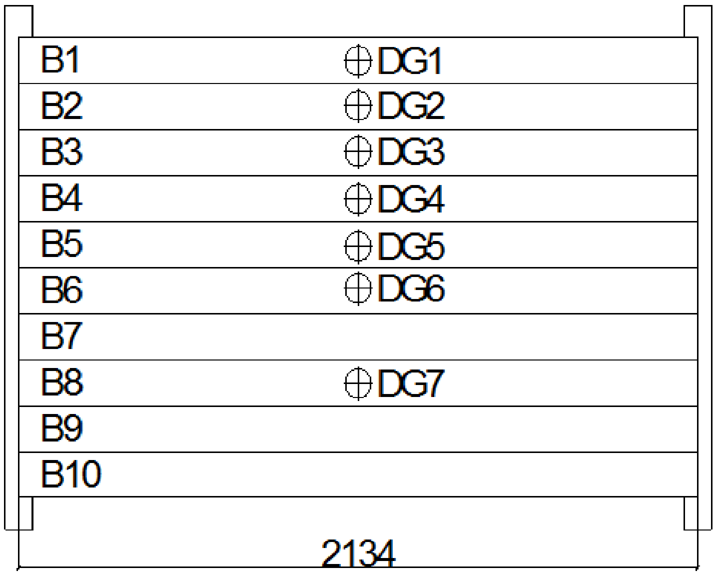


Board	MOE (Mpa)
B1	8182
B2	5595
B3	9314
B4	8475
B5	8182
B6	8182
B7	8475
B8	8475
B9	8182
B10	8475
Average	8154

CL200 Test Results			Deflection (mm) at 1.3 kN Concentrated Load						
Number of Boards in Test	Average MOE	Boards in Test	DG1	DG2	DG3	DG4	DG5	DG6	DG7
2	8182	B5-B6					2.40	2.81	
4	8329	B4-B7				0.93	1.70	1.56	
6	8517	B3-B8			0.36	0.64	1.49	1.38	0.35
8	8110	B2-B9		0.11	0.31	0.66	1.53	1.41	0.26
10	8154	B1-B10	0.07	0.06	0.25	0.49	1.42	1.52	0.32

Figure 6.12: B.5 – ND-SS-2-SPF-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
S-P-F	2	127	36	2134	Simple Span	Solid Sawn

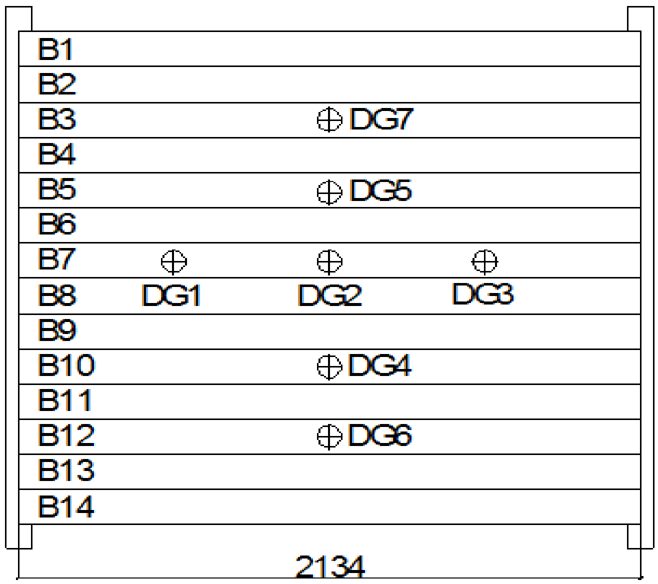


Board	MOE (Mpa)
B1	9571
B2	9310
B3	6550
B4	5820
B5	8011
B6	11173
B7	8011
B8	8732
B9	6898
B10	9242
Average	8332

CL200 Test Results			Deflection (mm) at 1.3 kN Concentrated Load						
Number of Boards in Test	Average MOE	Boards in Test	DG1	DG2	DG3	DG4	DG5	DG6	DG7
2	9592	B5-B6					20.49	21.92	
4	8254	B4-B7				12.27	13.61	14.73	
6	8050	B3-B8			6.77	8.74	10.62	11.62	9.26
8	8063	B2-B9		4.90	5.58	7.58	9.37	10.07	5.56
10	8332	B1-B10	2.86	3.59	4.76	6.91	8.86	9.18	5.23

Figure 6.13: B.6 – ND-SS-3-SPF-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
S-P-F	3	127	36	2134	Simple Span	Solid Sawn



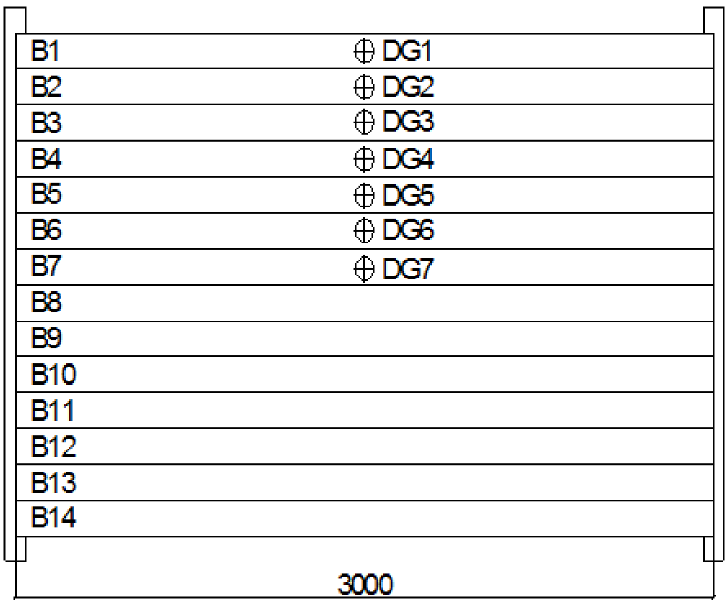
Board	MOE (Mpa)
B1	11040
B2	9571
B3	11674
B4	10222
B5	8011
B6	11173
B7	6898
B8	5820
B9	6898
B10	8011
B11	8732
B12	9310
B13	9242
B14	6550

CL200 Test Results			Deflection (mm) at 1.3 kN Concentrated Load						
Number of Boards in Test	Average MOE	Boards in Test	DG1	DG2	DG3	DG4	DG5	DG6	DG7
2	6359	B7-B8	13.24	18.82	12.94				
4	7697	B6-B9	9.37	14.09	8.55				
6	7802	B5-B10	6.73	10.54	6.63	8.55	8.15		
8	8221	B4-B11	6.21	9.80	6.32	5.80	5.35		
10	8675	B3-B12	5.97	9.40	5.95	4.69	4.39	2.39	2.26
12	8797	B2-B13	5.74	9.12	5.49	4.47	4.11	1.84	1.77
14	8797	B1-B14	5.70	8.69	6.26	4.41	4.10	1.57	1.65

UDL Test Results			Deflection (mm) at UDL (0.231 N/mm)						
Number of Boards in Test	Average MOE	Boards in Test	DG1	DG2	DG3	DG4	DG5	DG6	DG7
2	6359	B7-B8	8.40	11.50	8.35				
4	7697	B6-B9	10.58	15.31	11.64				
6	7802	B5-B10	9.64	13.91	9.56	14.65	8.98		
8	8221	B4-B11	9.60	13.93	10.52	14.62	12.91		
10	8675	B3-B12	8.79	13.04	9.12	12.43	11.86	10.75	11.17
12	8797	B2-B13	9.34	12.50	9.35	12.53	11.44	10.78	10.29
14	8797	B1-B14	9.20	12.63	9.31	12.42	11.24	9.60	10.56

Figure 6.14: B.7 – ND-SS-4-SPF-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
S-P-F	4	127	36	3000	Simple Span	Solid Sawn

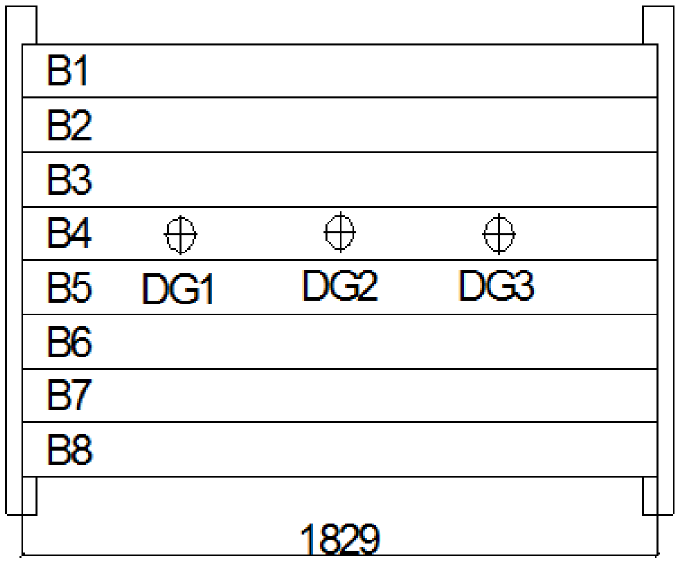


Board	MOE (Mpa)
B1	8103
B2	11603
B3	4805
B4	9240
B5	9726
B6	9481
B7	11470
B8	11204
B9	7792
B10	10580
B11	10073
B12	9120
B13	11470
B14	13502

CL200 Test Results			Deflection (mm) at 1.3 kN Concentrated Load						
Number of Boards in Test	Average MOE	Boards in Test	DG1	DG2	DG3	DG4	DG5	DG6	DG7
2	11337	B7-B8							45.58
4	9987	B6-B9						29.26	30.41
6	10042	B5-B10					17.33	20.17	21.84
8	9946	B4-B11				12.62	14.47	18.00	19.22
10	9349	B3-B12			8.90	9.45	11.44	15.03	18.11
12	9714	B2-B13		5.37	5.89	7.26	9.44	12.92	17.17
14	9869	B1-B14	3.92	4.37	5.38	6.86	9.20	12.89	15.40

Figure 6.15: B.8 – ND-SS-1-AYC-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
Alaskan Yellow Cedar	1	127	36	1829	Simple Span	Solid Sawn



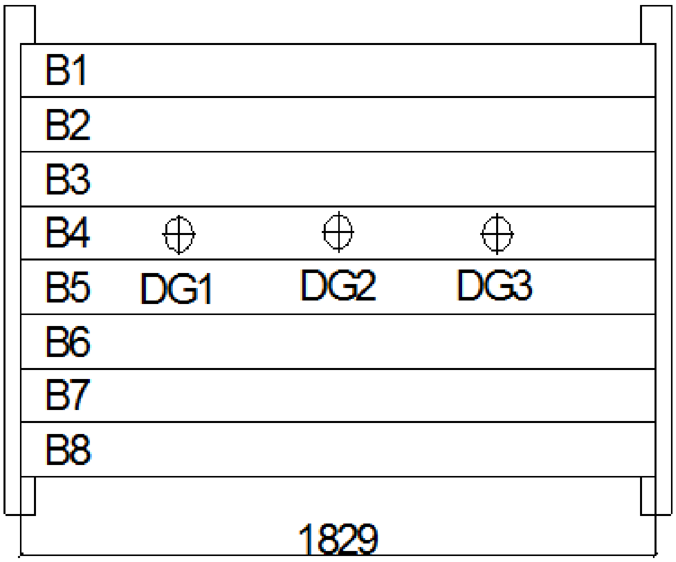
Board	MOE (Mpa)
B1	10168
B2	9962
B3	9813
B4	7474
B5	10621
B6	8568
B7	6451
B8	8243
Average	8913

	Deflection (mm) at 1.3 kN Concentrated Load		
CL200Test Results	DG1	DG2	DG3
Span 1 Loaded	3.49	5.44	3.48

	Deflection (mm) at UDL (0.231 N/mm)		
UDL Test Results	DG1	DG2	DG3
Span 1 Loaded	2.76	4.00	2.62

Figure 6.16: B.9 – ND-SS-1-DFL-L2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
D.Fir-L	1	127	36	1829	Simple Span	Laminated



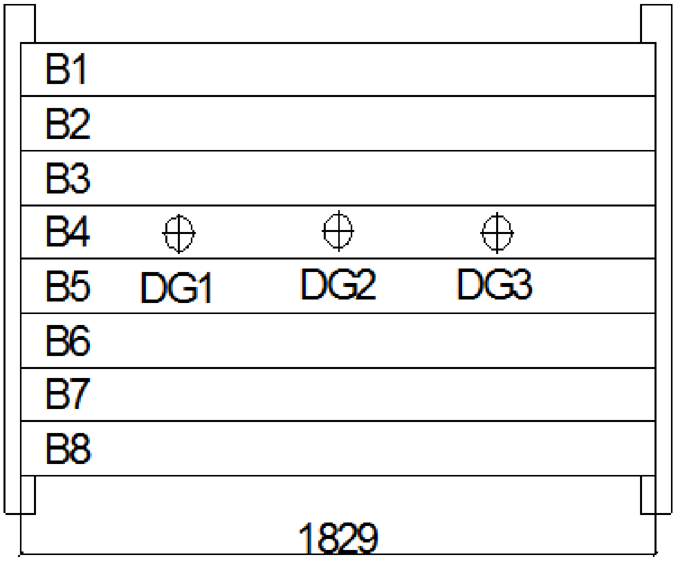
Board	MOE (Mpa)
B1	11947
B2	11728
B3	13188
B4	10837
B5	11736
B6	13120
B7	13188
B8	12181
Average	12241

	Deflection (mm) at 1.3 kN Concentrated Load		
CL200 Test Results	DG1	DG2	DG3
Span 1 Loaded	3.84	6.14	3.86

	Deflection (mm) at UDL (0.231 N/mm)		
UDL Test Results	DG1	DG2	DG3
Span 1 Loaded	2.53	4.51	2.51

Figure 6.17: B.10 – ND-SS-1-POP-L2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
Ponderosa Pine	1	127	36	1829	Simple Span	Laminated



Board	MOE (Mpa)
B1	9472
B2	8760
B3	11217
B4	9270
B5	9396
B6	11028
B7	9203
B8	9406
Average	9719

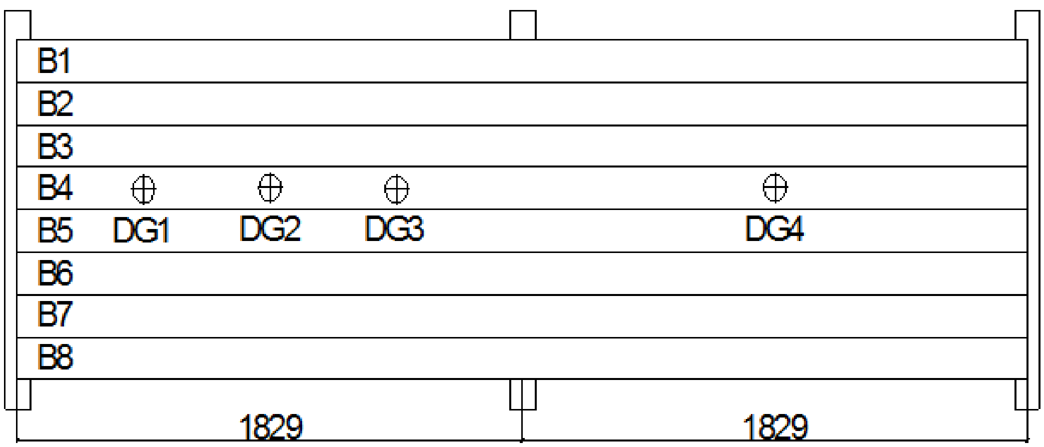
	Deflection (mm) at 1.3 kN Concentrated Load		
CL200 Test Results	DG1	DG2	DG3
Span 1 Loaded	3.58	5.65	3.42

	Deflection (mm) at UDL (0.231 N/mm)		
UDL Test Results	DG1	DG2	DG3
Span 1 Loaded	3.46	5.09	3.37

Figure 6.18: B.11 – ND-TS-1-DFL-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
D.Fir-L	1	127	36	3658	Two-Span Continuous	Solid Sawn

Board	MOE (Mpa)
B1	11720
B2	15166
B3	13467
B4	14227
B5	13844
B6	13653
B7	12763
B8	13653
Average	13562



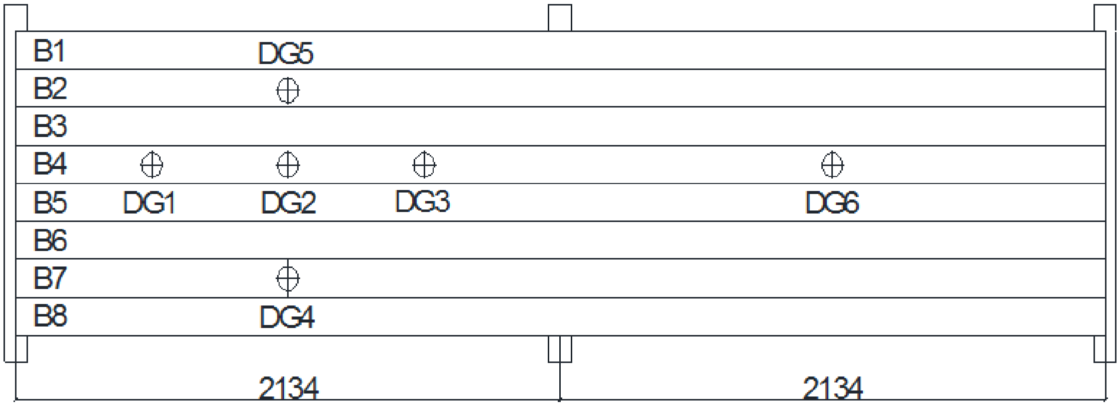
	Deflection (mm) at 1.3 kN Concentrated Load			
CL200 Test Results	DG1	DG2	DG3	DG4
Span 1 Loaded	2.98	4.05	2.22	-1.00

	Deflection (mm) at UDL (0.231 N/mm)			
UDL Test Results	DG1	DG2	DG3	DG4
Span 1 Loaded	2.00	2.68	1.62	-1.04
Span 1 and 2 Loaded	1.11	1.35	0.62	1.59

Figure 6.19: B.12 – ND-TS-2-DFL-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
D.Fir-L	2	127	36	4268	Two-span Continuous	Solid Sawn

Board	MOE (Mpa)
B1	10980
B2	10980
B3	10751
B4	11440
B5	10525
B6	11676
B7	11914
B8	10525
Average	11099



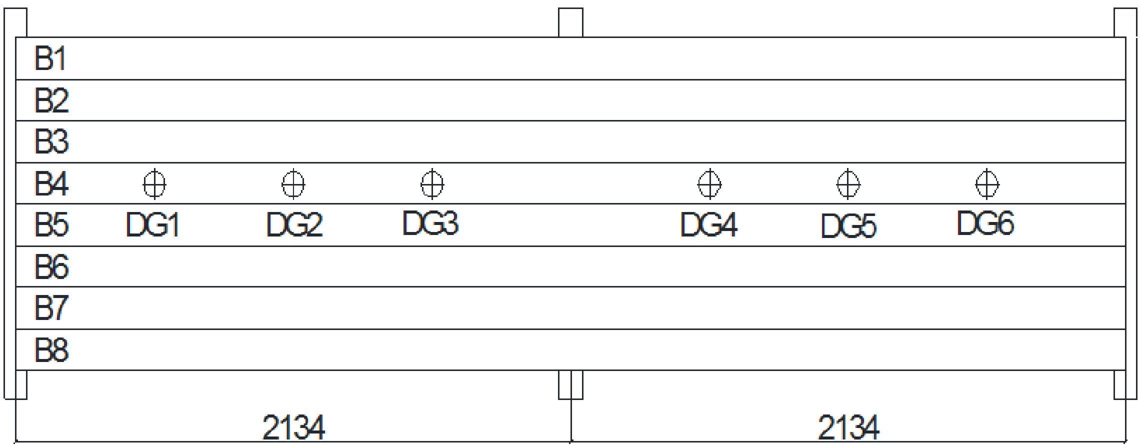
	Deflection (mm) at 1.3 kN Concentrated Load					
CL200 Test Results	DG1	DG2	DG3	DG4	DG5	DG6
Span 1 Loaded	4.13	6.10	3.59	2.44	3.10	-1.39

	Deflection at UDL (0.231 N/mm)					
UDL Test Results	DG1	DG2	DG3	DG4	DG5	DG6
Span 1 and 2 Loaded	3.24	4.18	2.30	2.23	2.35	3.62

Figure 6.20: B.13 – ND-TS-1-SPF-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
S-P-F	1	127	36	4268	Two-span Continuous	Solid Sawn

Board	MOE (Mpa)
B1	8946
B2	8611
B3	9466
B4	9291
B5	9466
B6	12788
B7	13570
B8	8779
Average	10115



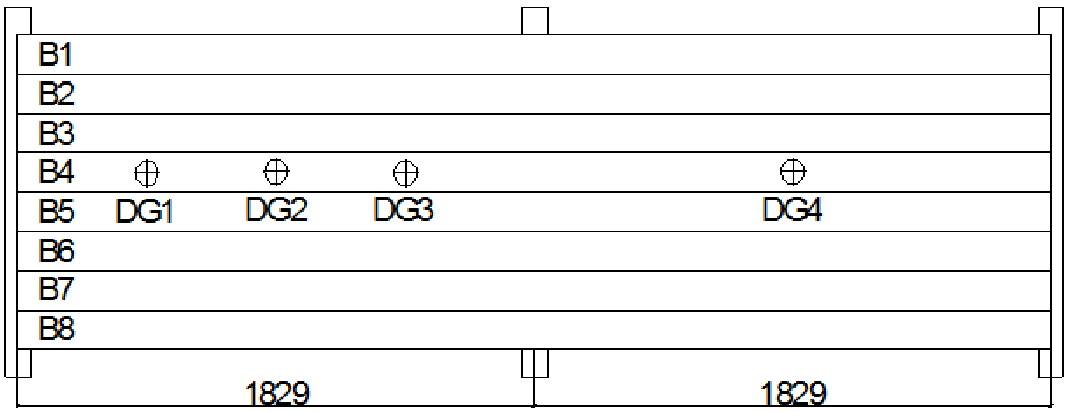
	Deflection (mm) at 1.3 kN Concentrated Load					
CL200 Test	DG1	DG2	DG3	DG4	DG5	DG6
Span 1 Loaded	4.13	6.10	3.59		-1.39	

	Deflection (mm) at UDL (0.231 N/mm)					
UDL Test Results	DG1	DG2	DG3	DG4	DG5	DG6
Span 1 Loaded	-1.10	-1.86	-1.70	4.16	7.02	4.90
Span 1 and 2 Loaded	2.94	4.00	1.70	2.39	6.95	3.66

Figure 6.21: B.14 – ND-TS-1-AYC-S2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
Alaskan Yellow Cedar	1	127	36	3658	Two-Span Continuous	Solid Sawn

Board	MOE (Mpa)
B1	8651
B2	12621
B3	9874
B4	10927
B5	9611
B6	8760
B7	7231
B8	11050
Average	9841



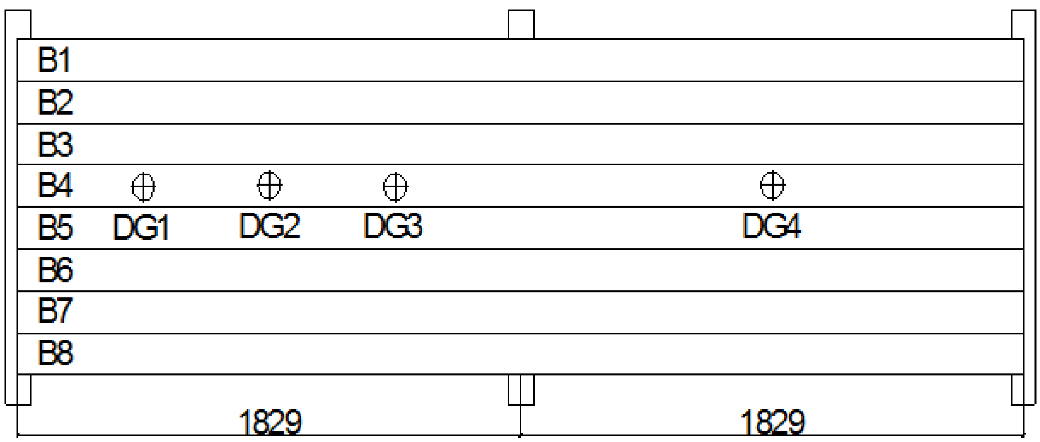
	Deflection (mm) at 1.3 kN Concentrated Load			
CL200 Test Results	DG1	DG2	DG3	DG4
Span 1 Loaded	2.77	4.74	2.88	-1.46

	Deflection (mm) at UDL (0.231 N/mm)			
UDL Test Results	DG1	DG2	DG3	DG4
Span 1 Loaded	2.35	3.28	2.13	-1.29
Span 1 and 2 Loaded	1.52	1.83	0.83	2.47

Figure 6.22: B.15 – ND-TS-1-DFL-L2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
D.Fir-L	1	127	36	3658	Two-Span Continuous	Laminated

Board	MOE (Mpa)
B1	14058
B2	13462
B3	8559
B4	11204
B5	10841
B6	13324
B7	14374
B8	13608
Average	12429



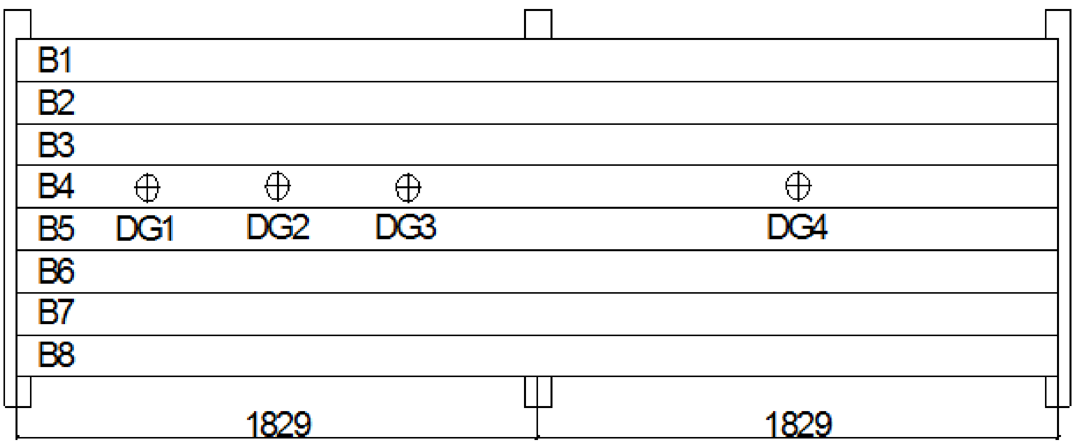
	Deflection (mm) at 1.3 kN Concentrated Load			
CL200 Test Results	DG1	DG2	DG3	DG4
Span 1 Loaded	2.75	4.14	2.40	-1.37

	Deflection (mm) at UDL (0.231 N/mm)			
UDL Test Results	DG1	DG2	DG3	DG4
Span 1 Loaded	1.97	2.78	1.80	-1.17
Span 1 and 2 Loaded	1.48	1.92	0.92	1.90

Figure 6.23: B.16 – ND-TS-1-POP-L2

Species	Test #	b (mm)	d (mm)	L (mm)	Layup Type	Finish
Ponderosa Pine	1	127	36	3658	Two-Span Continuous	Laminated

Board	MOE (Mpa)
B1	7347
B2	9073
B3	9009
B4	10309
B5	8692
B6	13601
B7	9840
B8	7178
Average	9381



	Deflection (mm) at 1.3 kN Concentrated Load			
CL200 Test Results	DG1	DG2	DG3	DG4
Span 1 Loaded	3.21	4.92	2.54	-1.40

	Deflection (mm) at UDL (0.231 N/mm)			
UDL Test Results	DG1	DG2	DG3	DG4
Span 1 Loaded	2.59	3.50	2.10	-1.50
Span 1 and 2 Loaded	1.89	2.36	1.08	1.99

Figure 6.24: B.17 – ND-CR-1-DFL-S2

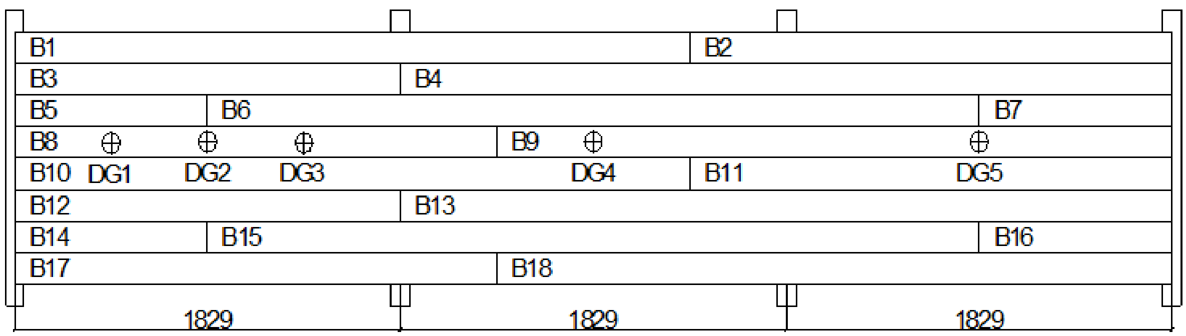
Species	Test #	b (mm)	d (mm)	Layup Type	Finish
D.Fir-L	1	127	36	Controlled Random	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3200	2286	1829	3658	914	3658	914	2286
MOE (Mpa)	11336	13110	14322	12396	13844	13844	13653	13222

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	3200	3200	2286	1829	3658	914	3658	914
MOE (Mpa)	13313	11185	12994	11115	13653	14227	14615	14034

Board	B17	B18
L (mm)	2286	3200
MOE (Mpa)	12783	12068

Average MOE (Mpa)	13095



CL200 Test Results	Deflection (mm) at 1.3 kN Concentrated Load				
	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	3.27	4.89	2.58	-1.09	0.21
Span 2 Loaded		0.52		3.66	-0.63
Span 3 Loaded		0.12		-0.79	5.49

UDL Test Results	Deflection (mm) at UDL (0.231 N/mm)				
	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	2.26	3.37	2.06	-1.70	0.22
Span 1 and 2 Loaded	1.47	2.07	1.09	1.18	-0.51
All Spans Loaded	1.90	2.68	1.29	0.32	2.22

Figure 6.25: B.18 – ND-CR-2-DFL-S2

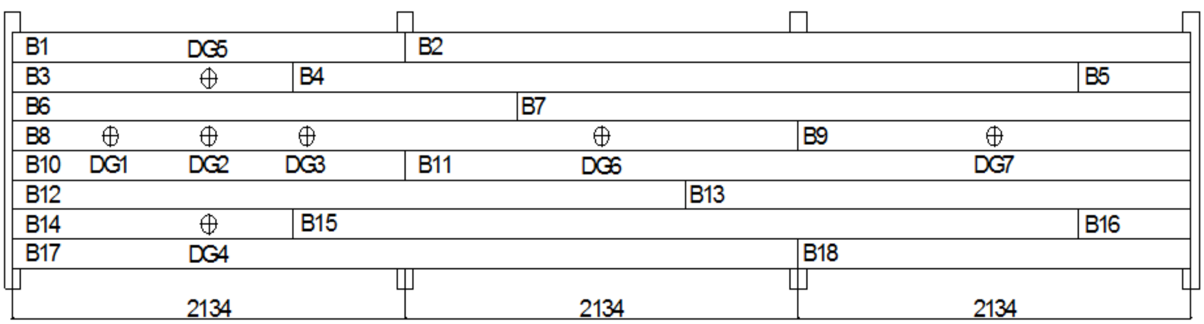
Species	Test #	b (mm)	d (mm)	Layup Type	Finish
D.Fir-L	2	127	36	Controlled Random	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	2134	4267	1524	4267	610	2743	3658	4267
MOE (Mpa)	11440	10980	10902	11440	11701	10902	10369	11914

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	2134	2134	4267	3658	2743	1524	4267	610
MOE (Mpa)	10525	11440	9957	11701	11879	11879	10980	10369

Board	B17	B18
L (mm)	4267	2134
MOE (Mpa)	10751	10525

Average MOE (Mpa)	11092



	Deflection (mm) at 1.3 kN Concentrated Load						
CL200 Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Span 1 Loaded	4.72	6.96	3.99	2.92	3.59	-1.00	0.22
Span 2 Loaded	-0.79	-1.31	-1.22			5.97	-1.19
Span 3 Loaded		0.33				-1.28	6.79

	Deflection (mm) at UDL (0.231 N/mm)						
UDL Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Balanced	4.61	5.81	3.63	6.38	5.86	2.12	5.85

Figure 6.26: B.19 – ND-CR-3-DFL-S2

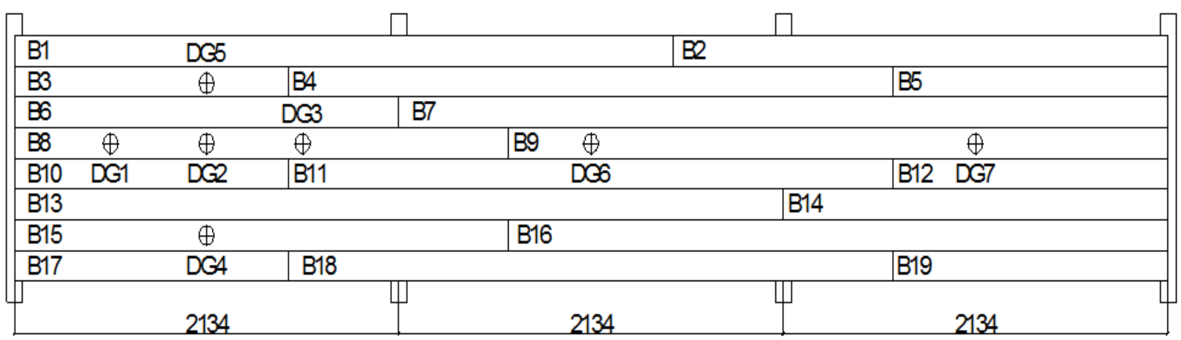
Species	Test #	b (mm)	d (mm)	Layup Type	Finish
D.Fir-L	3	127	36	Controlled Random	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3658	2743	1524	3353	1524	2134	4267	2743
MOE (Mpa)	11723	11879	9883	11790	11879	11440	10980	10902

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	3658	1524	3353	1524	4267	2134	2743	3658
MOE (Mpa)	11701	10422	9957	10902	11211	10525	10700	10369

Board	B17	B18	B19
L (mm)	1524	3353	1524
MOE (Mpa)	10859	10039	11790

Average MOE (Mpa)	10997



	Deflection (mm) at 1.3 kN Concentrated Load						
CL200 Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Span 1 Loaded	4.64	6.71	3.90	3.56	3.25	-1.36	0.29
Span 2 Loaded		-1.29				5.33	-1.48
Span 3 Loaded		0.35				-1.24	6.16

	Deflection (mm) at UDL (0.231 N/mm)						
UDL Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Balanced	5.12	6.41	4.26	6.20	7.58	1.35	4.92

Figure 6.27: B.20 – ND-CR-4-DFL-S2

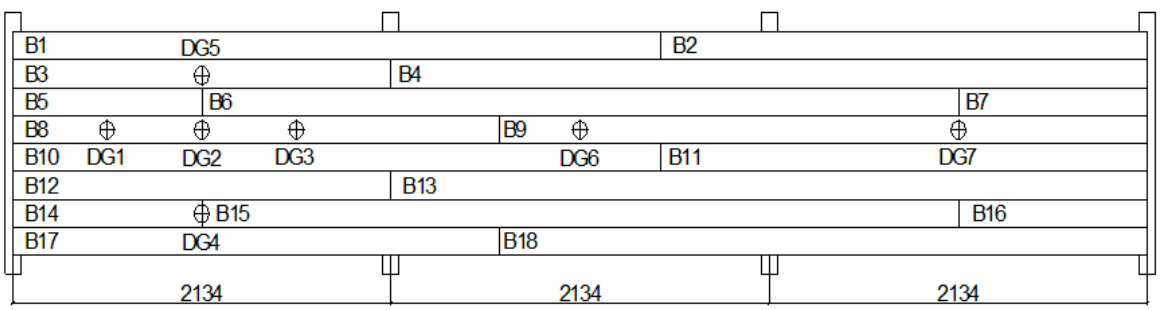
Species	Test #	b (mm)	d (mm)	Layup Type	Finish
D.Fir-L	4	127	36	Controlled Random	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3658	2743	2134	4267	1067	4267	1067	2743
MOE (Mpa)	11723	11879	11440	10980	10422	11211	9883	10902

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	3658	3658	2743	2134	4267	1067	4267	1067
MOE (Mpa)	11701	10369	10700	10525	10525	10859	11676	10369

Board	B17	B18
L (mm)	2743	3658
MOE (Mpa)	11790	10369

Average MOE (Mpa)	10962



	Deflection (mm) at 1.3 kN Concentrated Load						
CL200 Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Span 1 Loaded	4.58	6.68	3.80	3.63	3.84	-1.35	0.32
Span 2 Loaded	-0.91	-1.52	-1.36			5.04	-1.30

	Deflection (mm) at UDL (0.231 N/mm)						
UDL Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Balanced	4.52	5.53	3.31	4.77	7.62	0.93	5.46

Figure 6.28: B.21 – ND-CR-1-SPF-S2

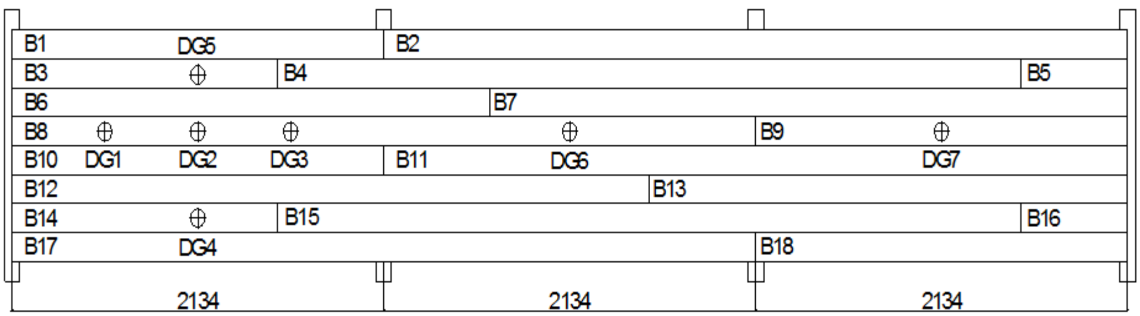
Species	Test #	b (mm)	d (mm)	Layup Type	Finish
S-P-F	1	127	36	Controlled Random	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	2134	4267	1524	4267	610	2743	3658	4267
MOE (Mpa)	12788	8011	10704	9466	7697	10704	9314	9466

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	2134	2134	4267	3658	2743	1524	4267	610
MOE (Mpa)	11674	8732	9291	7697	10704	10704	8011	9314

Board	B17	B18
L (mm)	4267	2134
MOE (Mpa)	8611	6550

Average MOE (Mpa)	9413



	Deflection (mm) at 1.3 kN Concentrated Load						
CL200 Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Span 1 Loaded	4.45	6.77	4.06	2.91	2.99	-1.09	0.28
Span 2 Loaded	-0.66	-1.16	-1.17			5.95	-1.17
Span 3 Loaded		0.22				-1.18	6.61

	Deflection (mm) at UDL (0.231 N/mm)						
UDL Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Balanced	4.02	5.38	3.35	5.73	6.03	2.17	6.39

Figure 6.29: B.22 – ND-CR-2-SPF-S2

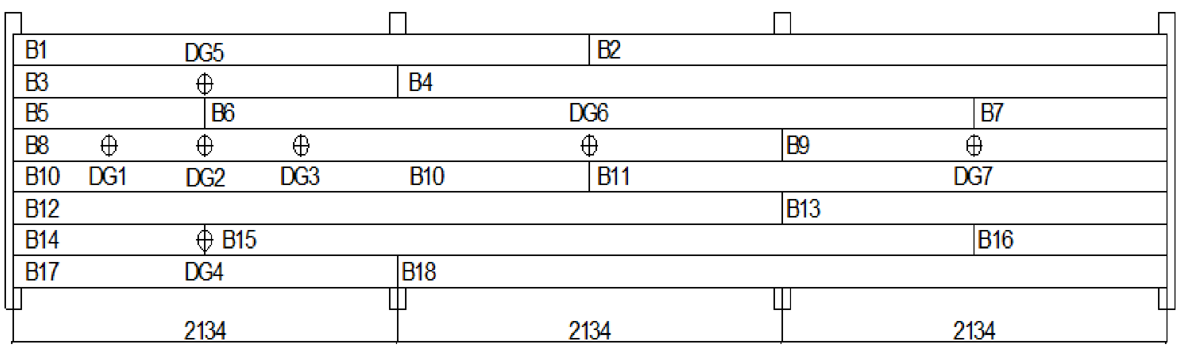
Species	Test #	b (mm)	d (mm)	Layup Type	Finish
S-P-F	2	127	36	Controlled Random	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3200	3200	2134	4267	1067	4267	1067	4267
MOE (Mpa)	12586	9488	5820	8779	9488	9291	11039	8611

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	2134	3200	3200	4267	2134	1067	4267	1067
MOE (Mpa)	11674	9145	11039	8732	9466	12586	12788	9145

Board	B17	B18
L (mm)	2134	4267
MOE (Mpa)	9466	5820

Average MOE (Mpa)	9720



	Deflection (mm) at 1.3 kN Concentrated Load						
CL200 Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Span 1 Loaded	4.54	6.80	4.07	3.06	4.58	-1.12	0.32
Span 2 Loaded	-0.74	-1.29	-1.01			6.31	-1.50

	Deflection (mm) at UDL (0.231 N/mm)						
UDL Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Balanced	4.49	6.09	3.76	6.22	7.75	1.61	7.29

Figure 6.30: B.23 – ND-CR-1-AYC-S2

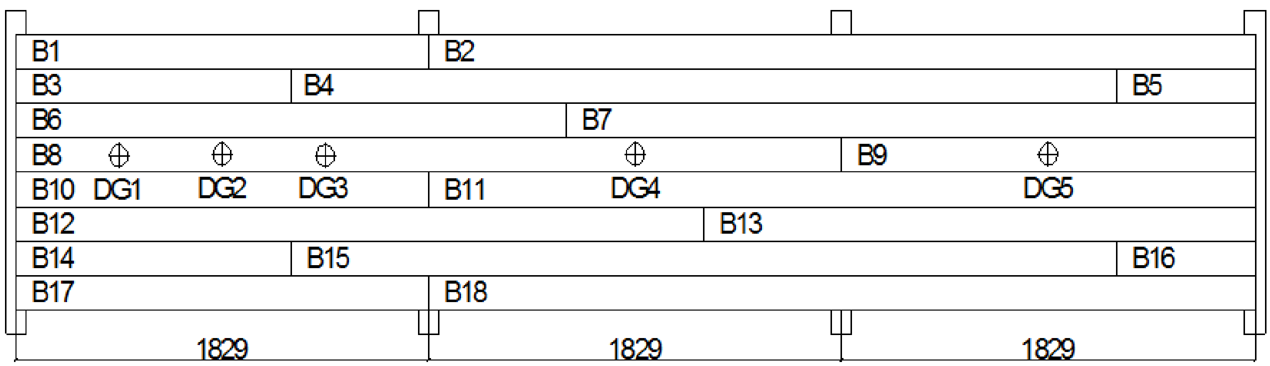
Species	Test #	b (mm)	d (mm)	Layup Type	Finish
Alaskan Yellow Cedar	1	127	36	Controlled Random	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	1829	3658	1219	3658	610	2438	3048	3658
MOE (Mpa)	5138	10927	8591	10018	9508	8591	10177	11050

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	1829	1829	3658	3048	2438	1219	3658	610
MOE (Mpa)	11067	6451	10018	10177	9508	9508	10316	8591

Board	B17	B18
L (mm)	1829	3658
MOE (Mpa)	8969	10621

Average MOE (Mpa)	9401



	Deflection (mm) at 1.3 kN Concentrated Load				
CL200 Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	3.11	4.45	2.43	-1.01	0.14
Span 2 Loaded		-0.74		4.58	-0.65
Span 3 Loaded		0.15		-0.99	5.64

	Deflection (mm) at UDL (0.231 N/mm)				
UDL Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	3.07	4.15	2.63	-1.47	0.20
Span 1 and 2 Loaded	2.23	2.89	1.62	2.12	-0.66
All Spans Loaded	2.89	3.64	2.07	0.90	2.97

Figure 6.31: B.24 – ND-CR-1-DFL-L2

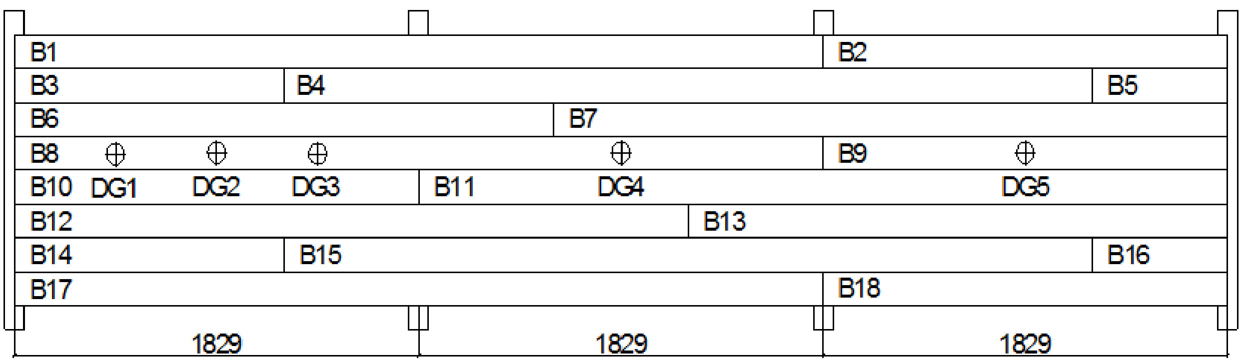
Species	Test #	b (mm)	d (mm)	Layup Type	Finish
D.Fir-L	1	127	36	Controlled Random	Laminated

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3658	1829	1219	3658	610	2438	3048	3658
MOE (Mpa)	11124	13309	11629	13462	13454	15050	11629	11845

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	1829	1829	3658	3048	2438	1219	3658	610
MOE (Mpa)	12069	14528	13166	11947	12918	13188	12663	13309

Board	B17	B18
L (mm)	3658	1829
MOE (Mpa)	11956	12183

Average MOE (Mpa)	12746



	Deflection (mm) at 1.3 kN Concentrated Load				
CL200 Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	2.37	3.70	2.20	-0.69	0.12
Span 2 Loaded		-0.39		4.31	-0.70
Span 3 Loaded		0.09		-0.95	3.60

	Deflection (mm) at UDL (0.231 N/mm)				
UDL Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	1.86	2.72	1.88	-0.83	0.14
Span 1 and 2 Loaded	1.30	1.86	1.12	1.84	-0.50
All Spans Loaded	1.61	2.26	1.49	1.38	2.23

Figure 6.32: B.25 – ND-CR-1-POP-L2

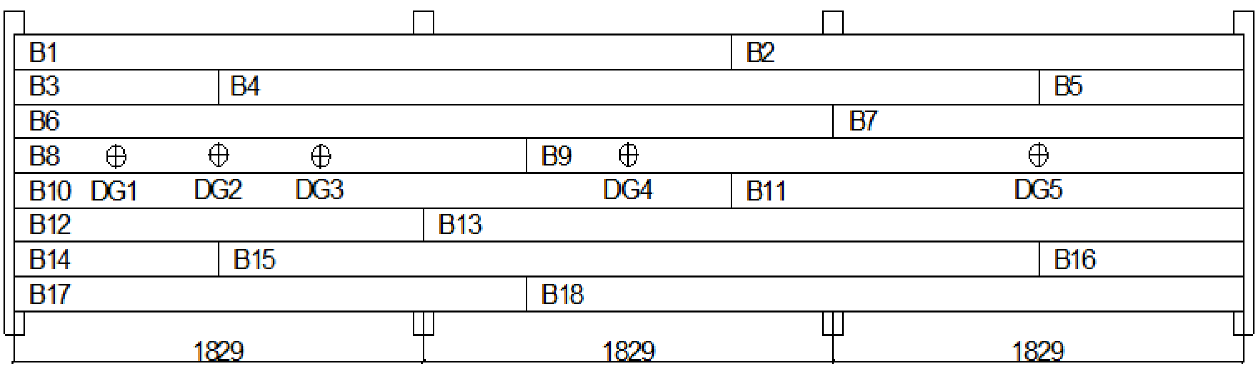
Species	Test #	b (mm)	d (mm)	Layup Type	Finish
Ponderosa Pine	1	127	36	Controlled Random	Laminated

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3200	2286	914	3658	914	3658	1829	2286
MOE (Mpa)	8097	9203	8097	9073	8754	9915	8883	9268

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	3200	3200	2286	1829	3658	914	3658	914
MOE (Mpa)	8754	7107	9069	10399	10313	7996	12183	7107

Board	B17	B18
L (mm)	2286	3200
MOE (Mpa)	8699	7996

Average MOE (Mpa)	8469



	Deflection (mm) at 1.3 kN Concentrated Load				
CL200 Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	3.23	5.42	3.17	-1.24	0.19
Span 2 Loaded		-0.58		5.04	-1.08
Span 3 Loaded		0.16		-1.12	5.20

	Deflection (mm) at UDL (0.231 N/mm)				
UDL Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	3.61	5.16	3.14	-1.71	0.14
Span 1 and 2 Loaded	2.48	3.28	1.69	2.29	-0.93
All Spans Loaded	2.79	3.84	2.21	1.59	2.44

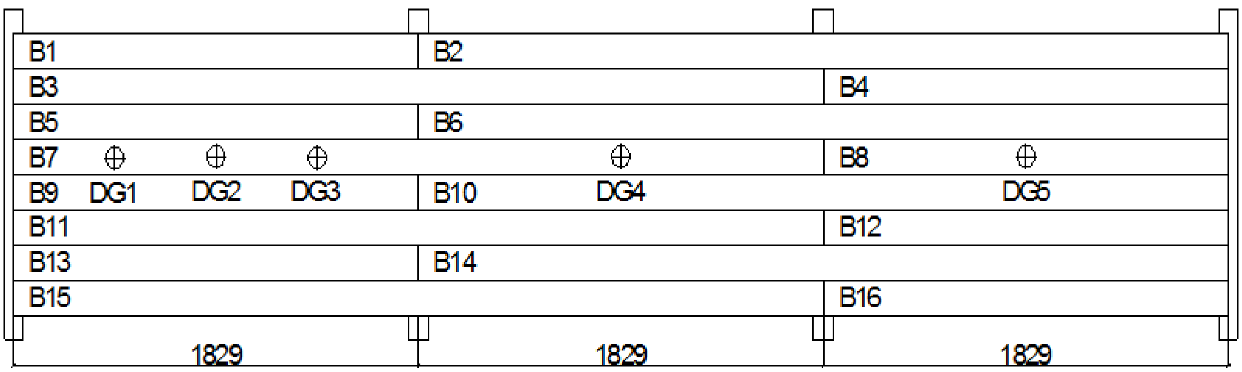
Figure 6.33: B.26 – ND-SC-2-DFL-S2

Species	Test #	b (mm)	d (mm)	Layup Type	Finish
D.Fir-L	1	127	36	Combination Simple and Two-span Continuous	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	1829	3658	3658	1829	1829	3658	3658	1829
MOE (Mpa)	13580	15166	13467	13580	11879	14227	13844	13746

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	1829	3658	3658	1829	1829	3658	3658	1829
MOE (Mpa)	12307	13653	12763	12307	12219	13653	11720	12668

Average MOE (Mpa)	13174



	Deflection (mm) at 1.3 kN Concentrated Load				
CL200 Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	2.20	3.37	1.99	-0.52	0.19
Span 2 Loaded		-0.62		3.31	-0.56

	Deflection (mm) at UDL (0.231 N/mm)				
UDL Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	1.75	2.53	1.71	-0.67	0.10
Span 1 and 2 Loaded	1.39	1.85	1.10	1.71	-0.49
All Spans Loaded	1.56	2.24	1.51	1.00	1.83

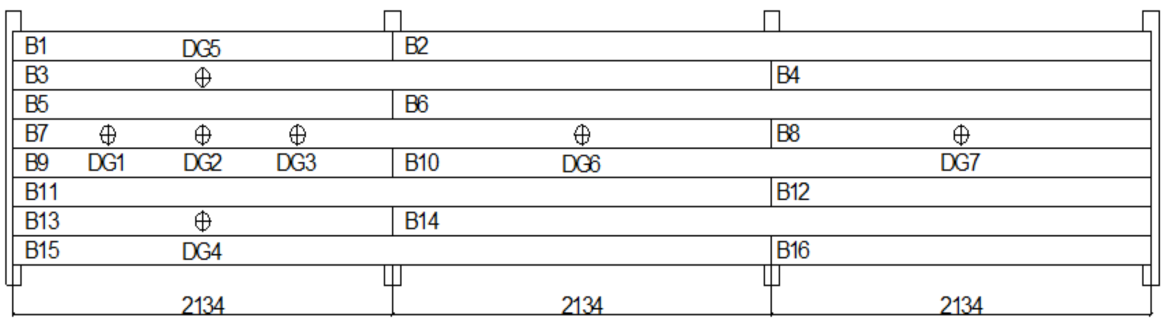
Figure 6.34: B.27 – ND-SC-2-DFL-S2

Species	Test #	b (mm)	d (mm)	Layup Type	Finish
D.Fir-L	2	127	36	Combination Simple and Two Span Continuous	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	2134	4268	2134	4268	2134	4268	2134	4268
MOE (Mpa)	11211	10525	10525	11914	11211	11211	11914	11914

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	2134	4268	2134	4268	2134	4268	2134	4268
MOE (Mpa)	10525	11676	10980	11440	10525	10980	10751	11440

Average MOE (Mpa)	11171



	Deflection (mm) at 1.3 kN Concentrated Load						
CL200 Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Span 1 Loaded	4.43	6.45	3.83	2.84	3.36	-0.86	0.17
Span 2 Loaded	-0.65	-1.10	-1.00			5.52	-1.04

	Deflection (mm) at UDL (0.231 N/mm)						
UDL Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Balanced	4.30	5.82	3.59	5.57	5.40	2.76	5.35

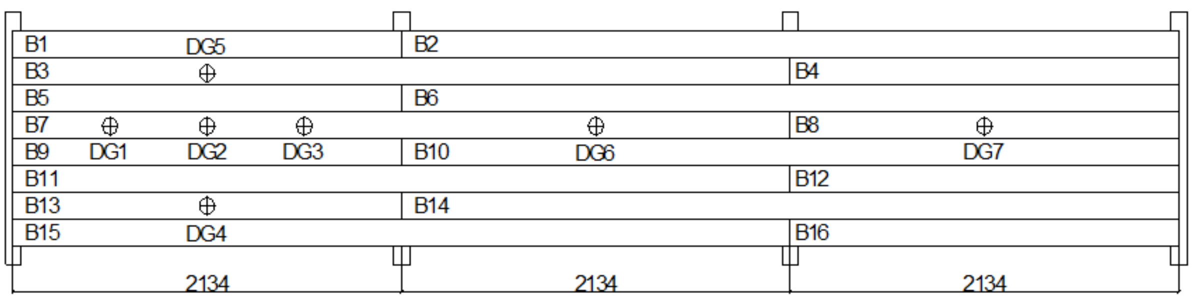
Figure 6.35: B.28 – ND-SC-1-SPF-S2

Species	Test #	b (mm)	d (mm)	Layup Type	Finish
S-P-F	1	127	36	Combination Simple and Two Span Continuous	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	2134	4268	2134	4268	2134	4268	2134	4268
MOE (Mpa)	6639	8946	8611	11173	8011	13570	8779	11674

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	2134	4268	2134	4268	2134	4268	2134	4268
MOE (Mpa)	8011	9291	9466	8732	5820	9466	12788	6550

Average MOE (Mpa)	9220



	Deflection (mm) at 1.3 kN Concentrated Load						
CL200 Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Span 1 Loaded	4.44	6.71	3.92	3.19	2.51	-1.08	0.20
Span 2 Loaded		-1.14				4.94	-1.10

	Deflection (mm) at UDL (0.231 N/mm)						
UDL Test Results	DG1	DG2	DG3	DG4	DG5	DG6	DG7
Balanced	4.92	6.51	3.97	6.34	6.66	1.72	6.40

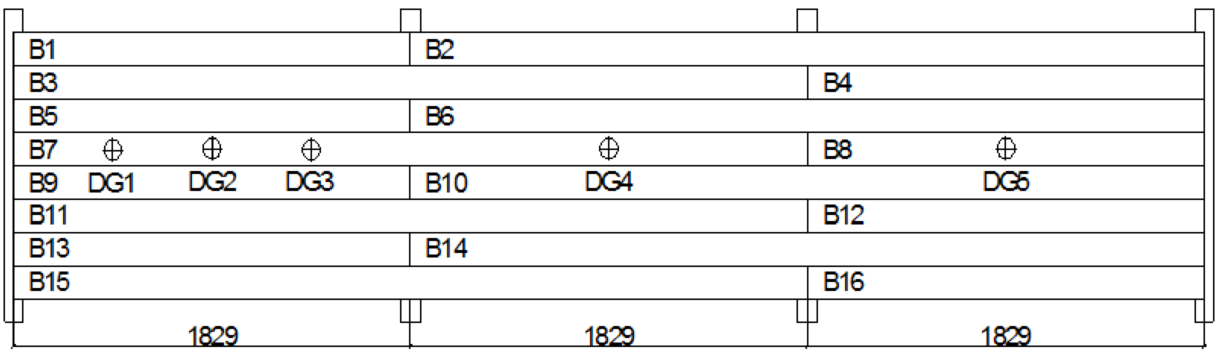
Figure 6.36: B.29 – ND-ST-1-AYC-S2

Species	Test #	b (mm)	d (mm)	Layup Type	Finish
Alaskan Yellow Cedar	1	127	36	Combination Simple and Two-span Continuous	Solid Sawn

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	1829	3658	3658	1829	1829	3658	3658	1829
MOE (Mpa)	9813	8651	12621	8568	7474	9874	10927	8568

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	1829	3658	3658	1829	1829	3658	3658	1829
MOE (Mpa)	10621	9611	8760	6451	9962	7231	11050	10168

Average MOE (MPa)	9397



	Deflection (mm) at 1.3 kN Concentrated Load				
CL200 Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	3.13	4.89	2.89	-0.73	0.11
Span 2 Loaded		-0.23		4.95	-0.52

	Deflection (mm) at UDL (0.231 N/mm)				
UDL Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	2.14	1.51	1.85	0.72	0.11
Span 1 and 2 Loaded	1.77	2.41	2.75	2.35	-0.58
All Spans Loaded	1.86	2.39	1.26	1.74	2.92

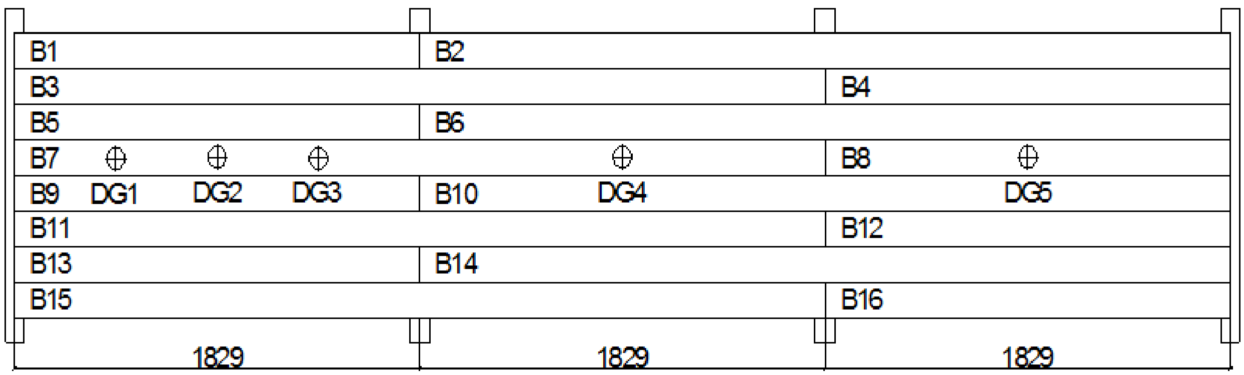
Figure 6.37: B.30 – ND-ST-1-DFL-L2

Species	Test #	b (mm)	d (mm)	Layup Type	Finish
D.Fir-L	1	127	36	Combination Simple and Two-span Continuous	Laminated

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	1829	3658	3658	1829	1829	3658	3658	1829
MOE (Mpa)	13188	14058	13462	10837	12181	8559	11321	11736

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	1829	3658	3658	1829	1829	3658	3658	1829
MOE (Mpa)	13120	10841	13324	13188	11947	14374	13608	11728

Average MOE (MPa)	12342



	Deflection (mm) at 1.3 kN Concentrated Load				
CL200 Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	2.88	4.63	2.65	-0.65	0.03
Span 2 Loaded		-0.48		5.70	-0.39

	Deflection (mm) at UDL (0.231 N/mm)				
UDL Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	1.83	2.59	1.56	-0.90	-0.02
Span 1 and 2 Loaded	1.42	1.90	0.88	1.95	-0.32
All Spans Loaded	1.59	2.35	1.22	1.37	2.58

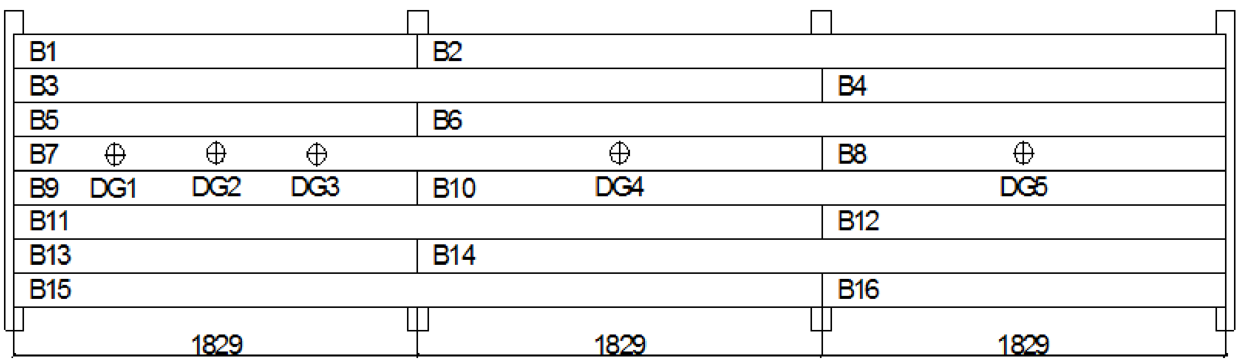
Figure 6.38: B.31 – ND-ST-1-POP-L2

Species	Test #	b (mm)	d (mm)	Layup Type	Finish
Ponderosa Pine	1	127	36	Combination Simple and Two-span Continuous	Laminated

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	1829	3658	3658	1829	1829	3658	3658	1829
MOE (Mpa)	7347	9203	9396	9073	9009	9406	11028	10309

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	1829	3658	3658	1829	1829	3658	3658	1829
MOE (Mpa)	8692	9270	11217	13601	9840	9472	11319	6560

Average MOE (MPa)	9671



	Deflection (mm) at 1.3 kN Concentrated Load				
CL200 Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	3.44	5.53	2.98	-0.96	0.10
Span 2 Loaded		-0.51		4.49	-0.58

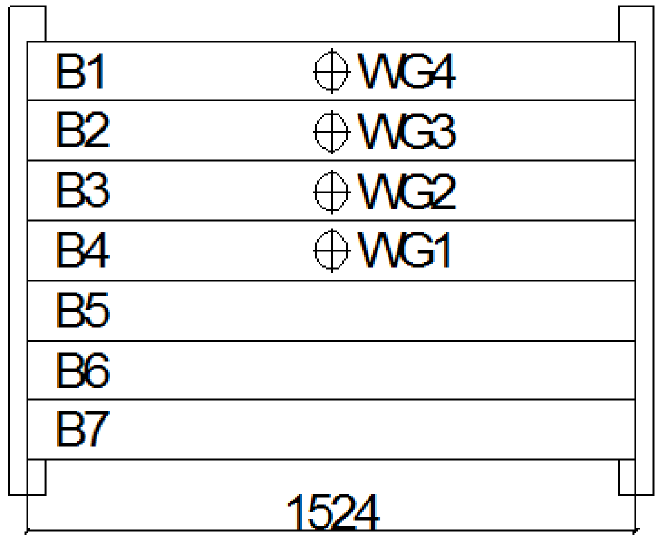
	Deflection (mm) at UDL (0.231 N/mm)				
UDL Test Results	DG1	DG2	DG3	DG4	DG5
Span 1 Loaded	2.66	3.83	2.23	-1.05	0.11
Span 1 and 2 Loaded	2.09	2.75	1.40	2.20	-0.44
All Spans Loaded	2.29	3.12	1.49	1.51	3.09

APPENDIX C-Destructive Test Results

Figure 6.39: C.1 – Destructive Simple Span 4PB Tests – DFL-S2

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Nailed

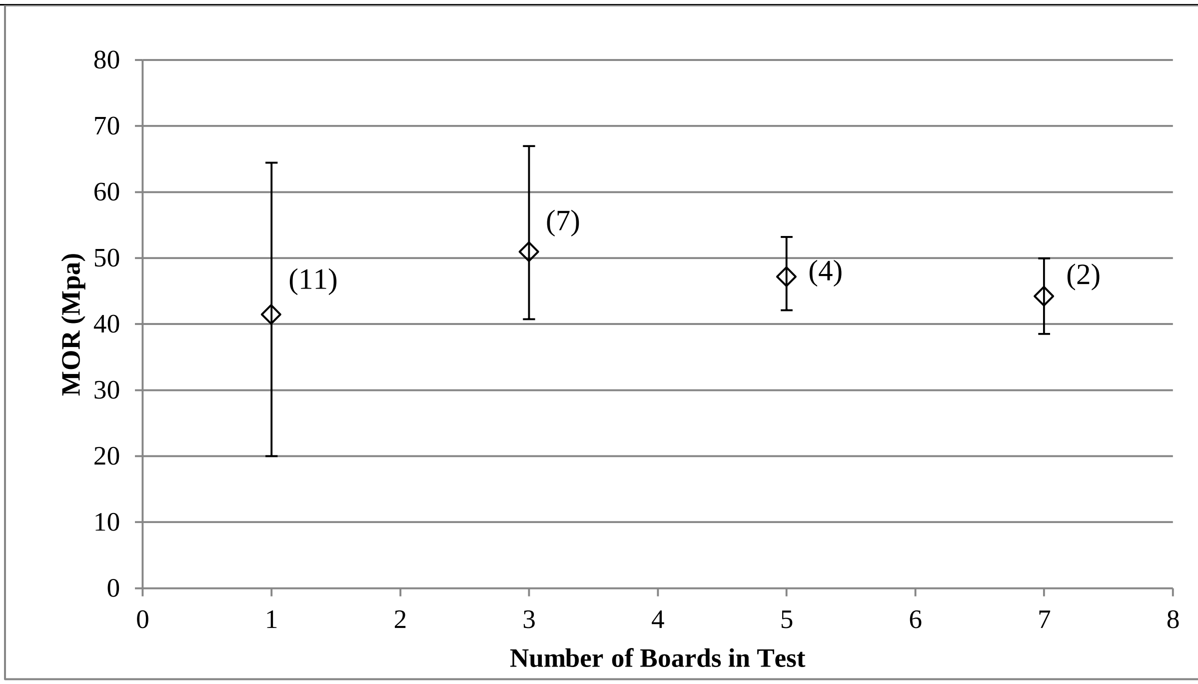
Simple Span (1 Board) Test Name	MOE (Mpa) (B4)	MOR (Mpa)
D-4PB-SS-1-DFL-S2-1	11336	39
D-4PB-SS-2-DFL-S2-1	12433	20
D-4PB-SS-3-DFL-S2-1	11927	41
D-4PB-SS-4-DFL-S2-1	13101	40
D-4PB-SS-5-DFL-S2-1	12809	49
D-4PB-SS-6-DFL-S2-1	12581	49
D-4PB-SS-7-DFL-S2-1	9999	36
D-4PB-SS-8-DFL-S2-1	11927	26
D-4PB-SS-9-DFL-S2-1	12581	64
D-4PB-SS-10-DFL-S2-1	12222	44
D-4PB-SS-11-DFL-S2-1	12354	47



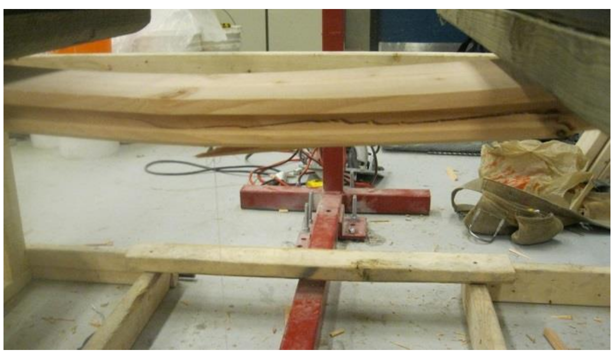
Simple Span (3 Boards)	MOE (Mpa)				MOR (Mpa)
Test Name	B3	B4	B5	AVG	
D-4PB-SS-1-DFL-S2-3	13410	14103	14568	14027	51
D-4PB-SS-2-DFL-S2-3	13410	13487	9880	12259	41
D-4PB-SS-3-DFL-S2-3	13252	13252	14798	13767	67
D-4PB-SS-4-DFL-S2-3	14025	14166	13410	13867	48
D-4PB-SS-5-DFL-S2-3	13176	14103	15377	14219	57
D-4PB-SS-6-DFL-S2-3	13941	11507	13487	12978	48
D-4PB-SS-7-DFL-S2-3	12869	14025	13410	13435	44

Simple Span (5 Boards)	MOE (Mpa)						MOR (Mpa)
Test Name	B2	B3	B4	B5	B6	AVG	
D-4PB-SS-1-DFL-S2-5	13329	12222	12655	13410	14798	13283	53
D-4PB-SS-2-DFL-S2-5	8613	12072	13025	13941	11999	11930	43
D-4PB-SS-3-DFL-S2-5	13626	11999	13941	11649	14245	13092	51
D-4PB-SS-4-DFL-S2-5	12735	10269	11431	12433	12072	11788	42

Simple Span (7 Boards)	MOE (Mpa)								MOR (Mpa)
Test Name	B1	B2	B3	B4	B5	B6	B7	AVG	
D-4PB-SS-1-DFL-S2-7	13025	10739	13786	12945	13101	13626	12507	12818	39
D-4PB-SS-2-DFL-S2-7	14409	13176	11361	12945	12869	13708	11927	12914	50



D.Fir-L Solid Sawn 127 mm x 36 mm Four Point Bending Simple Span Modulus of Rupture Summary



Simple Span 1 Board Failure

Simple Span 3 Board Failure

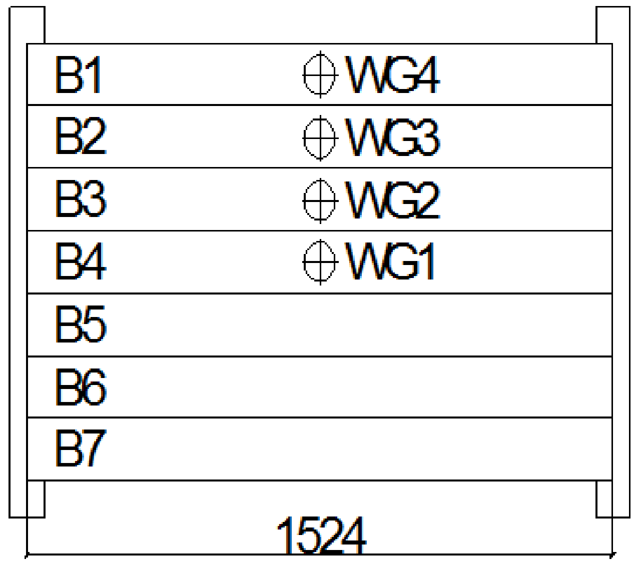
Simple Span 5 Board Failure

Simple Span 7 Board Failure

Figure 6.40: C.2 – Destructive Simple Span 4PB Tests – AYC-S2

Species	Finish	b (mm)	d (mm)	End Conditions
Alaskan Yellow Cedar	Solid Sawn	127	36	Nailed

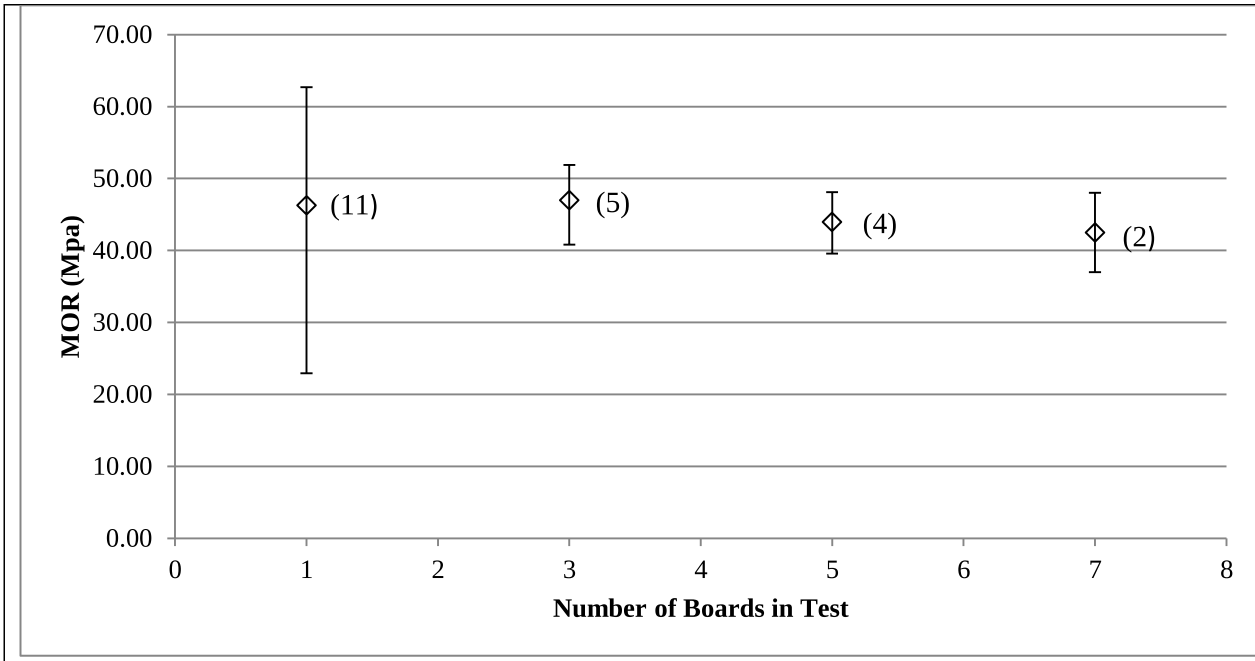
Simple Span (1 board) Test Name	MOE (Mpa) (B4)	MOR (Mpa)
D-4PB-SS-1-AYC-S2-1	6228	45
D-4PB-SS-2-AYC-S2-1	8940	40
D-4PB-SS-3-AYC-S2-1	11423	63
D-4PB-SS-4-AYC-S2-1	6707	29
D-4PB-SS-5-AYC-S2-1	10483	51
D-4PB-SS-6-AYC-S2-1	9995	59
D-4PB-SS-7-AYC-S2-1	10117	61
D-4PB-SS-8-AYC-S2-1	10914	63
D-4PB-SS-9-AYC-S2-1	5177	36
D-4PB-SS-10-AYC-S2-1	9171	38
D-4PB-SS-11-AYC-S2-1	9338	23



Simple Span (3 Boards)	MOE (Mpa)				MOR (Mpa)
Test Name	B3	B4	B5	AVG	
D-4PB-SS-1-AYC-S2-3	11050	7231	8760	9014	52
D-4PB-SS-2-AYC-S2-3	9874	9874	11050	10266	44
D-4PB-SS-3-AYC-S2-3	10621	10927	10927	10825	48
D-4PB-SS-4-AYC-S2-3	10621	10244	10056	10307	50
D-4PB-SS-5-AYC-S2-3	11046	11046	11825	11306	41

Simple Span (5 Boards)	MOE (Mpa)						MOR (Mpa)
Test Name	B2	B3	B4	B5	B6	AVG	
D-4PB-SS-1-AYC-S2-5	7369	9702	8760	8659	9870	8872	48
D-4PB-SS-2-AYC-S2-5	10018	10018	9962	11050	11050	10420	46
D-4PB-SS-3-AYC-S2-5	7231	9611	10018	10018	9611	9298	40
D-4PB-SS-4-AYC-S2-5	7474	10177	8591	10851	10927	9604	42

Simple Span (7 Boards)	MOE (Mpa)								MOR (Mpa)
Test Name	B1	B2	B3	B4	B5	B6	B7	AVG	
D-4PB-SS-1-AYC-S2-7	6654	8330	10177	8602	7369	5053	6318	7500	37
D-4PB-SS-2-AYC-S2-7	7789	7789	6415	12148	12215	10316	11050	9675	48



Alaskan Yellow Cedar Solid Sawn 127 mm x 36 mm Four Point Bending Simple Span Modulus of Rupture Summary

Simple Span 1 Board Failure

Simple Span 3 Board Failure

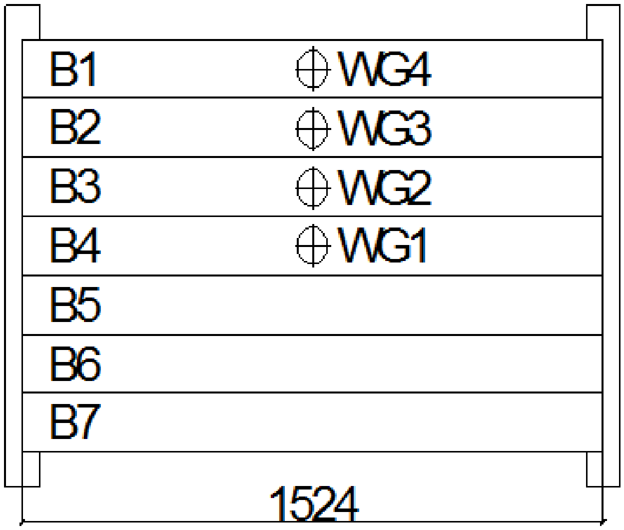
Simple Span 5 Board Failure

Simple Span 7 Board Failure

Figure 6.41: C.3 – Destructive Simple Span 4PB Tests – DFL-L2

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Laminated	127	36	Nailed

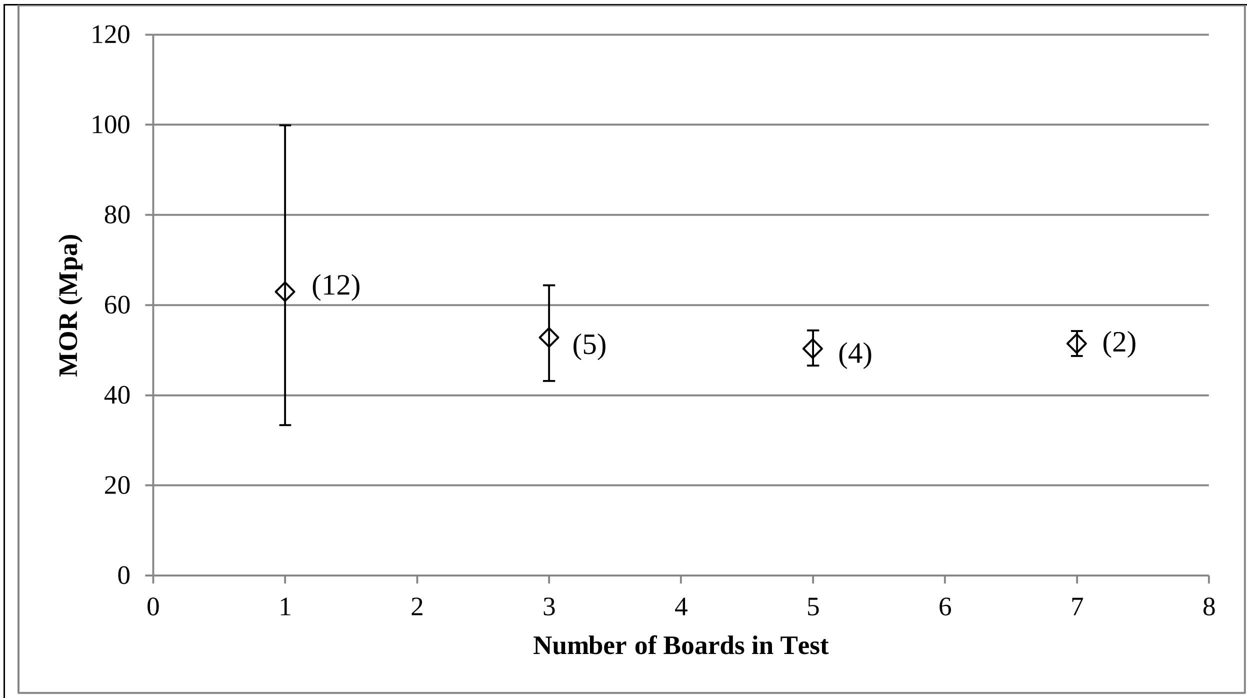
Simple Span (1 Board) Test Name	MOE (Mpa) (B4)	MOR (Mpa)
D-4PB-SS-1-DFL-L2-1	13581	100
D-4PB-SS-2-DFL-L2-1	13212	96
D-4PB-SS-3-DFL-L2-1	14737	33
D-4PB-SS-4-DFL-L2-1	14191	55
D-4PB-SS-5-DFL-L2-1	11440	93
D-4PB-SS-6-DFL-L2-1	13734	50
D-4PB-SS-7-DFL-L2-1	13676	73
D-4PB-SS-8-DFL-L2-1	12154	49
D-4PB-SS-9-DFL-L2-1	14369	65
D-4PB-SS-10-DFL-L2-1	14380	51
D-4PB-SS-11-DFL-L2-1	12988	48
D-4PB-SS-9-DFL-L2-2	13769	43



Simple Span (3 Boards)	MOE (Mpa)				MOR (Mpa)
Test Name	B3	B4	B5	AVG	
D-4PB-SS-1-DFL-L2-3	14086	12114	12015	12738	55
D-4PB-SS-2-DFL-L2-3	12636	11695	11288	11873	47
D-4PB-SS-3-DFL-L2-3	10845	12807	12776	12143	43
D-4PB-SS-4-DFL-L2-3	11047	11793	13101	11981	64
D-4PB-SS-5-DFL-L2-3	12053	13676	10404	12044	54

Simple Span (5 Boards)	MOE (Mpa)						MOR (Mpa)
Test Name	B2	B3	B4	B5	B6	AVG	
D-4PB-SS-1-DFL-L2-5	13676	12128	10639	12811	10349	11921	49
D-4PB-SS-2-DFL-L2-5	10349	14281	12636	11559	13202	12406	54
D-4PB-SS-3-DFL-L2-5	10101	14191	11627	13172	14835	12785	51
D-4PB-SS-4-DFL-L2-5	12053	12886	15166	10404	13403	12782	47

Simple Span (7 Boards)	MOE (Mpa)								MOR (Mpa)
Test Name	B1	B2	B3	B4	B5	B6	B7	AVG	
D-4PB-SS-1-DFL-L2-7	12660	13101	11793	12783	12886	12811	11024	12437	54
D-4PB-SS-2-DFL-L2-7	14191	13088	11440	11024	11559	11440	13088	12262	49



D.Fir-L Laminated 127 mm x 36 mm Four Point Bending Simple Span Modulus of Rupture Summary

Simple Span 1 Board Failure

Simple Span 3 Board Failure

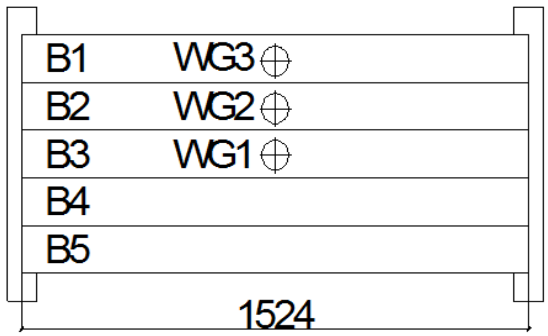
Simple Span 5 Board Failure

Simple Span 7 Board Failure

Figure 6.42: C.4 – Destructive Simple Span 4PB Tests – DFL-L3

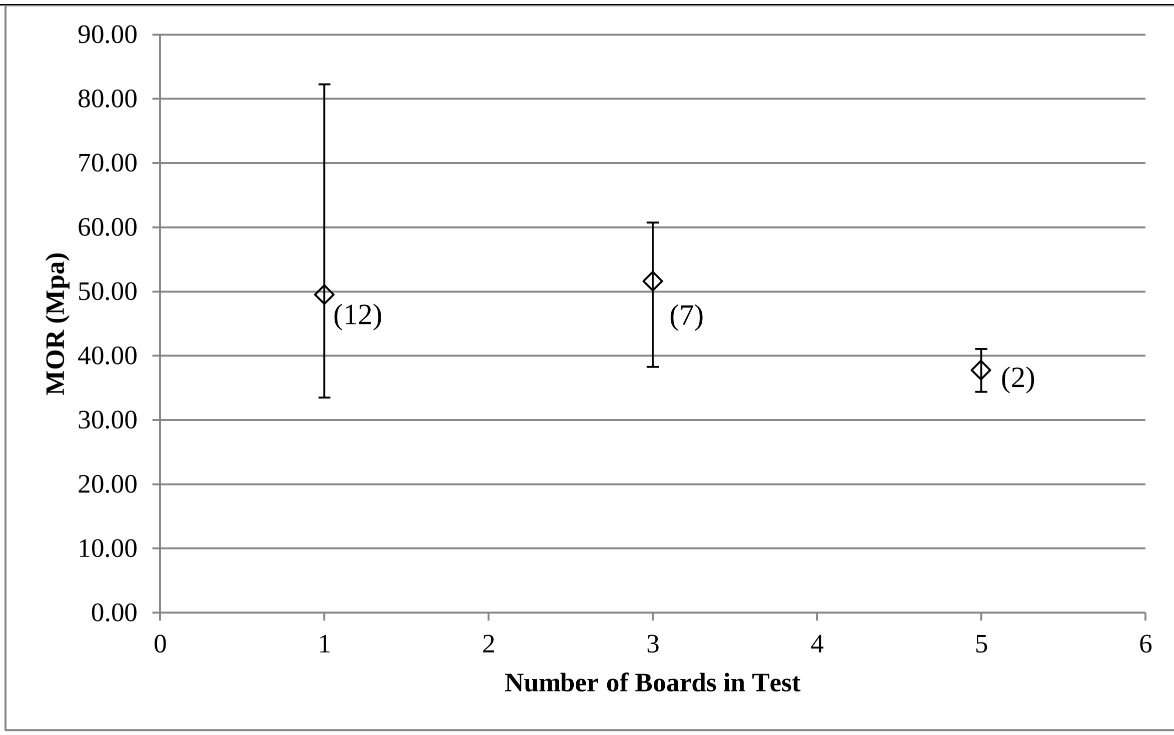
Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Laminated	131	55	Nailed

Simple Span (1 Board) Test Name	MOE (Mpa) (B3)	MOR (Mpa)
D-4PB-SS-1-DFL-L3-1	11773	41
D-4PB-SS-2-DFL-L3-1	11665	41
D-4PB-SS-3-DFL-L3-1	14816	53
D-4PB-SS-4-DFL-L3-1	14816	50
D-4PB-SS-5-DFL-L3-1	11859	43
D-4PB-SS-6-DFL-L3-1	11859	33
D-4PB-SS-7-DFL-L3-1	16114	82
D-4PB-SS-8-DFL-L3-1	16114	58
D-4PB-SS-9-DFL-L3-1	11298	45
D-4PB-SS-10-DFL-L3-1	12718	52
D-4PB-SS-11-DFL-L3-1	12718	37
D-4PB-SS-9-DFL-L3-2	8390	58



Simple Span (3 Boards)	MOE (Mpa)				MOR (Mpa)	Toe Nails
Test Name	B2	B3	B4	AVG		
D-4PB-SS-1-DFL-L3-3	12531	11906	11160	11866	52	Yes
D-4PB-SS-2-DFL-L3-3	12395	9899	12132	11475	38	No
D-4PB-SS-3-DFL-L3-3	8844	16688	11665	12399	53	Yes
D-4PB-SS-4-DFL-L3-3	12151	12308	12395	12284	61	Yes
D-4PB-SS-5-DFL-L3-3	14263	11192	11516	12324	51	Yes
D-4PB-SS-6-DFL-L3-3	10616	11534	13559	11903	57	Yes
D-4PB-SS-7-DFL-L3-3	13456	12696	13036	13063	49	Yes

Simple Span (5 Boards)	MOE (Mpa)						MOR (Mpa)	Toe Nails
Test Name	B1	B2	B3	B4	B5	AVG		
D-4PB-SS-1-DFL-L3-5	16387	14564	12395	11521	12395	13453	41	Yes
D-4PB-SS-2-DFL-L3-5	9899	12531	11906	11160	8844	10868	34	Yes



D.Fir-L Laminated 131 mm x 55 mm Four Point Bending Simple Span Modulus of Rupture Summary

Simple Span 1 Board Failure

Simple Span 1 Board Failure

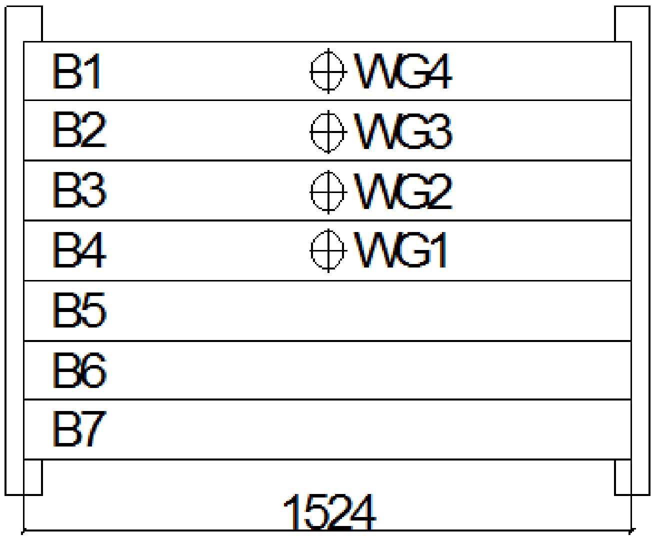
Simple Span 3 Board Failure

Simple Span 5 Board Failure

Figure 6.43: C.5 – Destructive Simple Span 4PB Tests with Sheathing – DFL-S2

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Nailed

Simple Span with sheathing (5 Boards)	MOE (Mpa)						MOR (Mpa)
Test Name	B2	B3	B4	B5	B6	AVG	
D-4PB-SSS-1-DFL-S2-5	12354	12281	13101	11431	13025	12438	39
D-4PB-SSS-2-DFL-S2-5	10951	11507	14959	12354	13487	12652	44



Simple Span 5 Board Failure with Sheathing

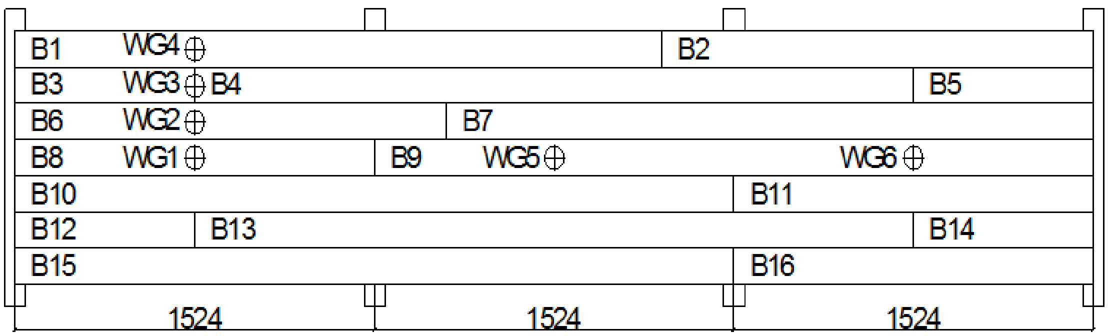
Figure 6.44: C.6 – D-4PB-CR-1-DFL-S2-7

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Nailed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-4PB-CR-1-DFL-S2-7	32	12604

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	2743	1829	762	3048	762	1829	2743	1524
MOE (Mpa)	14959	11706	12579	12396	12396	12489	14615	13580

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	3048	3048	1524	762	3048	762	3048	1524
MOE (Mpa)	11336	13313	12668	12668	12943	11115	11720	11185



Controlled Random Failure

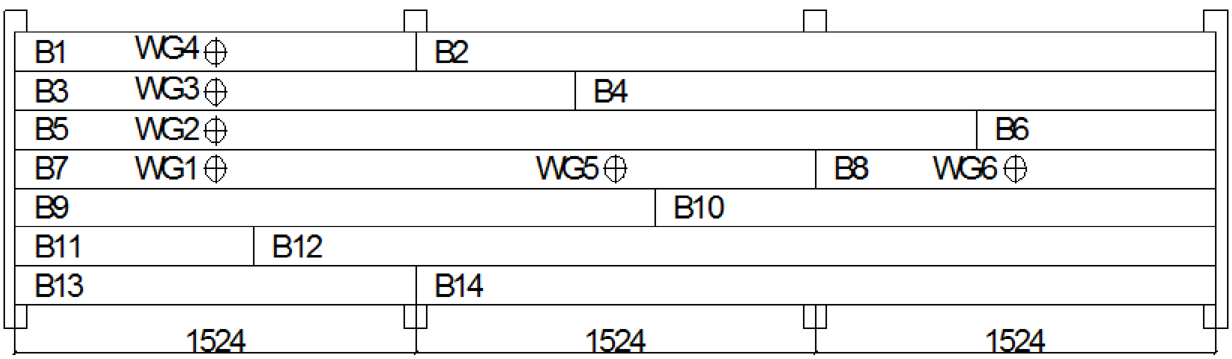
Figure 6.45: C.7 – D-4PB-CR-1-AYC-S2-7

Species	Finish	b (mm)	d (mm)	End Conditions
Alaskan Yellow Cedar	Solid Sawn	127	36	Nailed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-4PB-CR-1-AYC-S2-7	46	9055

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	1524	3048	2134	2438	3658	914	3048	1524
MOE (Mpa)	7474	10177	7231	9508	12621	8591	7231	9813

Board	B9	B10	B11	B12	B13	B14
L (mm)	2439	2133.6	914	3658	1524	3048
MOE (Mpa)	8591	7231	9508	8651	9962	10177



Controlled Random Test

Controlled Random Failure

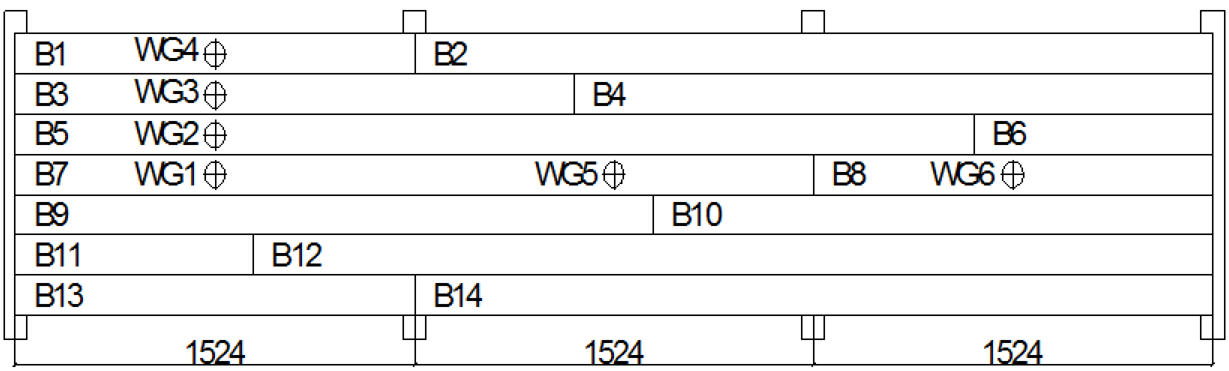
Figure 6.46: C.8 – D-4PB-CR-1-DFL-L2-7

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Laminated	127	36	Nailed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-4PB-CR-1-DFL-L2-7	57	12979

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	1524	3048	2134	2438	3658	914	3048	1524
MOE (Mpa)	12660	11047	15166	15472	11793	12776	13101	12376

Board	B9	B10	B11	B12	B13	B14
L (mm)	2438	2134	914	3658	1524	3048
MOE (Mpa)	13403	14182	14182	12128	12783	10639



Controlled Random Failure (Top View)

Controlled Random Failure (Bottom View)

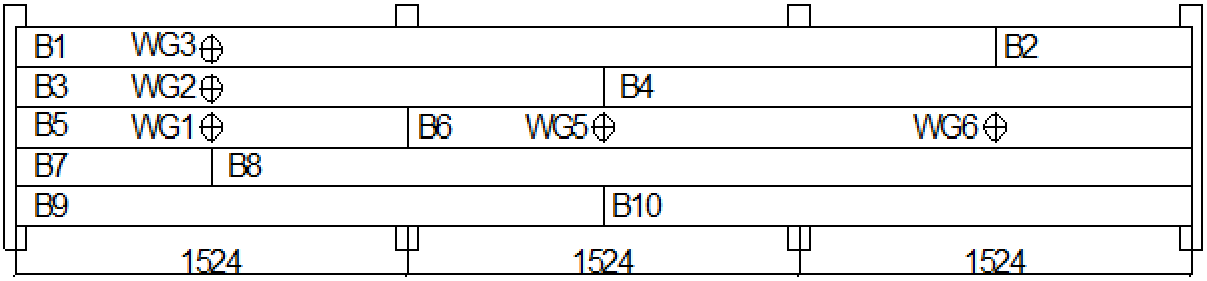
Figure 6.47: C.9 – D-4PB-CR-1-DFL-L3-5

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Laminated	131	55	Nailed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-4PB-CR-1-DFL-L3-5	37	12862

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3810	762	2286	2286	1524	3048	762	3810
MOE (Mpa)	11665	11665	13264	11298	13524	12718	16114	16114

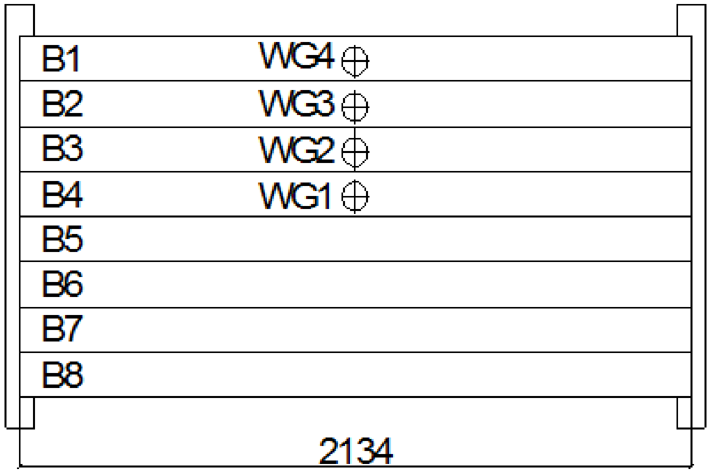
Board	B9	B10
L (mm)	2286	2286
MOE (Mpa)	13871	8390



Controlled Random Failure

Figure 6.48: C.10 – Destructive Simple Span CL200 – SPF-S2

Species	Finish	b (mm)	d (mm)	End Conditions
S-P-F	Solid Sawn	127	36	Screwed

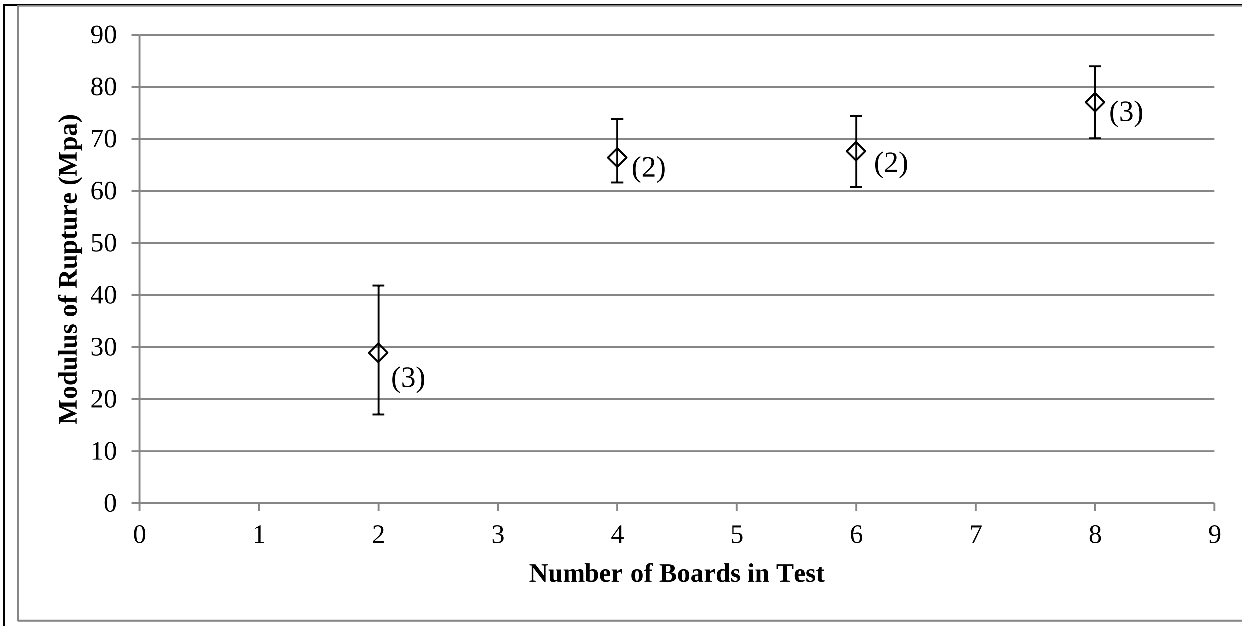


Simple Span (2 Board)	MOE (Mpa)			MOR (Mpa)
Test Name	B4	B5	AVG	
D-CL200-SS-1-SPF-S2-2	8732	8732	8732	24
D-CL200-SS-2-SPF-S2-2	9408	9408	9408	36
D-CL200-SS-3-SPF-S2-2	8900	8900	8900	26

Simple Span (4 Boards)	MOE (Mpa)					MOR (Mpa)
Test Name	B3	B4	B5	B6	AVG	
D-CL200-SS-1-SPF-S2-4	9408	9927	7016	11470	9455	60
D-CL200-SS-2-SPF-S2-4	9408	8103	9120	7792	8606	73

Simple Span (6 Boards)	MOE (Mpa)							MOR (Mpa)
Test Name	B2	B3	B4	B5	B6	B7	AVG	
D-CL200-SS-1-SPF-S2-6	9481	10580	4805	9240	8884	11603	9099	75
D-CL200-SS-2-SPF-S2-6	11470	10580	9726	10073	11204	11603	10776	61

Simple Span (8 Boards)	MOE (Mpa)									MOR (Mpa)
Test Name	B1	B2	B3	B4	B5	B6	B7	B8	AVG	
D-CL200-SS-1-SPF-S2-8	11230	9380	9380	7400	8088	6747	9640	9380	8906	78
D-CL200-SS-2-SPF-S2-8	10236	11973	7928	9380	11230	6747	9640	9380	9564	66
D-CL200-SS-3-SPF-S2-8	10924	10654	8740	13945	10236	9380	11973	9380	10654	87



S-P-F Solid Sawn 127 mm x 36 mm Concentrated Load (200x200) Simple Span Modulus of Rupture Summary

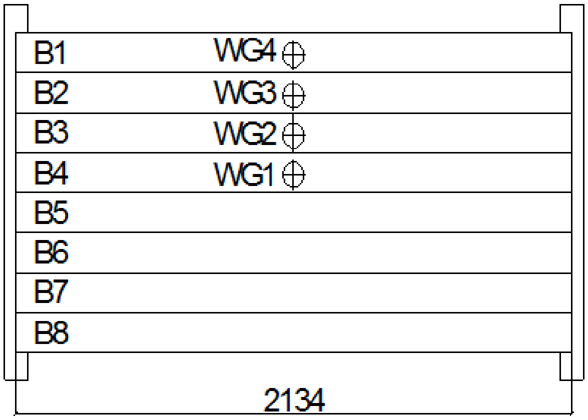
Simple Span 2 Board Failure

Simple Span 4 Board Failure

Simple Span 6 Board Failure

Figure 6.49: C.11 – Destructive Simple Span CL200 – DFL-S2

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Screwed



Simple Span (8 Boards)	MOE (Mpa)									MOR (Mpa)
Test Name	B1	B2	B3	B4	B5	B6	B7	B8	AVG	
D-CL200-SS-1-DFL-S2-8	9413	9413	11303	11706	9413	12199	10265	10530	10530	88
D-CL200-SS-2-DFL-S2-8	11303	11022	10531	9413	11223	9413	12199	10265	10671	82
D-CL200-SS-3-DFL-S2-8	11421	10610	10380	12199	9413	11303	12199	10265	10974	57

Simple Span 8 Board Failure

Figure 6.50: C.12 – D-CL200-CR-1-SPF-S2-8

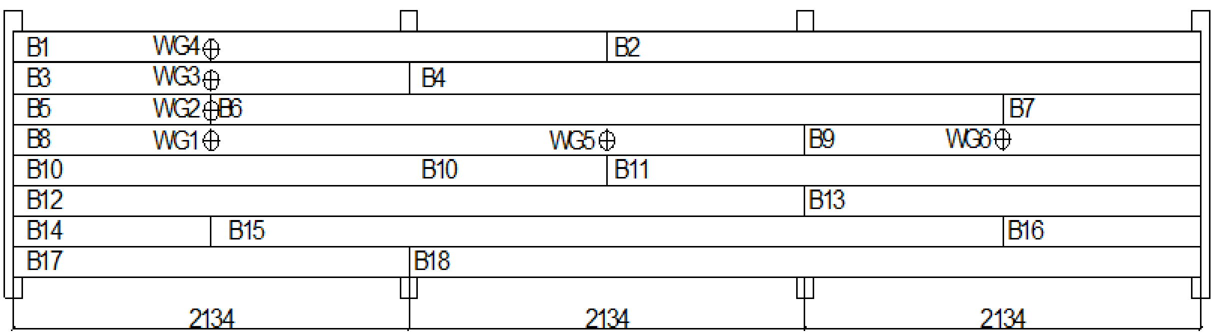
Species	Finish	b (mm)	d (mm)	End Conditions
S-P-F	Solid Sawn	127	36	Screwed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL200-CR-1-SPF-S2-8	43	9857

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3200	3200	2134	4267	1067	4267	1067	4267
MOE (Mpa)	10924	8740	11230	9291	8740	9408	8943	8011

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	2134	3200	3200	4267	2134	1067	4267	1067
MOE (Mpa)	5525	13945	8943	12788	8011	10924	9466	13945

Board	B17	B18
L (mm)	2134	4267
MOE (Mpa)	9120	9466



Controlled Random Failure

Figure 6.51: C.13 – D-CL200-CR-2-SPF-S2-8

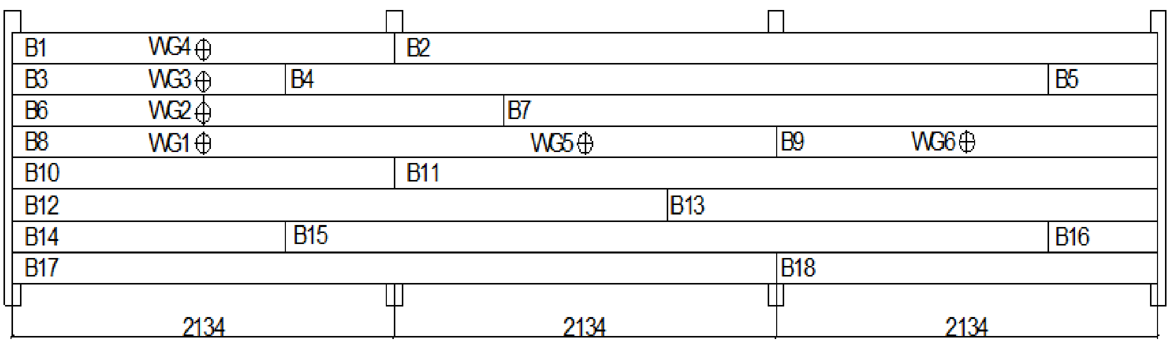
Species	Finish	b (mm)	d (mm)	End Conditions
S-P-F	Solid Sawn	127	36	Screwed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL200-CR-2-SPF-S2-8	54	9347

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	2134	4267	1524	4267	610	2743	3658	4267
MOE (Mpa)	11230	9408	10249	8900	8884	9927	7016	9069

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	2134	2134	4267	3658	2743	1524	4267	610
MOE (Mpa)	8088	9640	12285	11204	10249	9380	9408	7016

Board	B17	B18
L (mm)	4267	2134
MOE (Mpa)	9546	6747



Controlled Random Failure

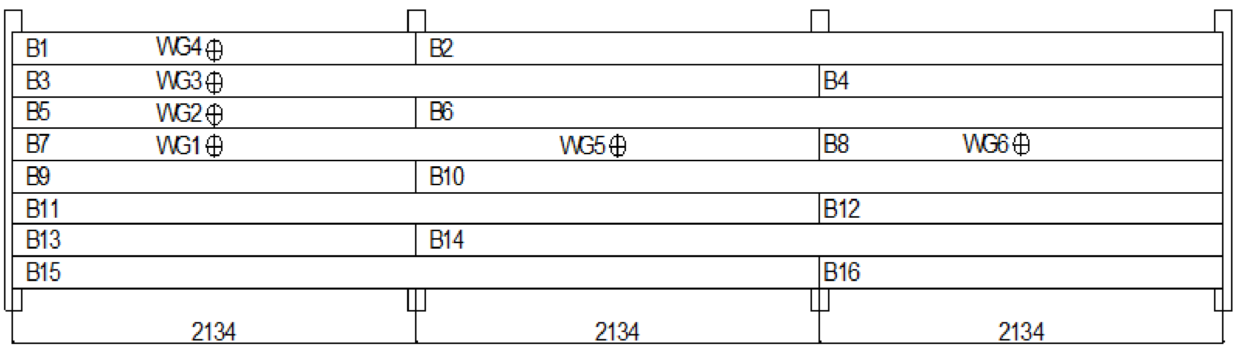
Figure 6.52: C.14 – D-CL200-ST-1-DFL-S2-8

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Screwed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL200-ST-1-DFL-S2-8	77	10820

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	2134	4267	4267	2134	2134	4267	4267	2134
MOE (Mpa)	12199	10823	9413	11706	11706	10077	11421	11303

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	2134	4267	4267	2134	2134	4267	4267	2134
MOE (Mpa)	10531	11223	9413	10436	11303	9413	10659	11501



Combination Simple and Two-Span Continuous Failure

Figure 6.53: C.15 – D-CL200-CR-1-DFL-S2-8

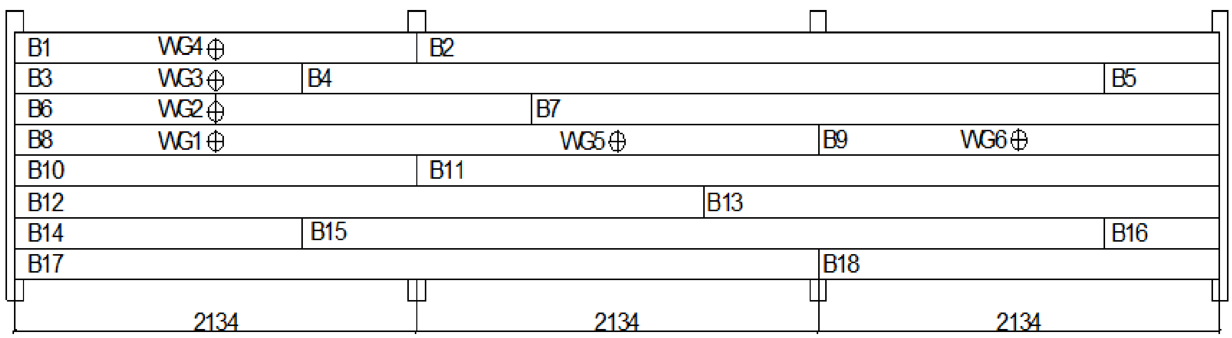
Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Screwed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL200-CR-1-DFL-S2-8	71	10451

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	2134	4267	1524	4267	610	2743	3658	4267
MOE (Mpa)	11303	10077	8778	9413	10610	10380	9037	11421

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	2134	2134	4267	3658	2743	1524	4267	610
MOE (Mpa)	10531	10436	11421	10354	9603	10730	10823	10198

Board	B17	B18
L (mm)	4267	2134
MOE (Mpa)	11303	11706



Controlled Random Failure

Figure 6.54: C.16 – D-CL200-CR-2-SPF-S2-8

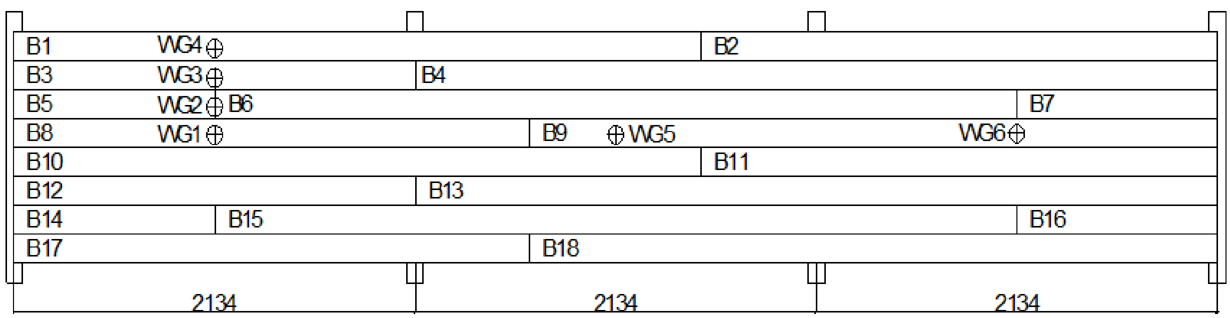
Controlled Random Test 2

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL200-CR-2-SPF-S2-8	54	10423

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3658	2743	2134	4267	1067	4267	1067	2743
MOE (Mpa)	10354	10380	11706	11421	12199	10823	9603	10610

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	3658	3658	2743	2134	4267	1067	4267	1067
MOE (Mpa)	10198	11112	9603	10436	11223	8778	9413	11112

Board	B17	B18
L (mm)	2743	3658
MOE (Mpa)	9603	9037

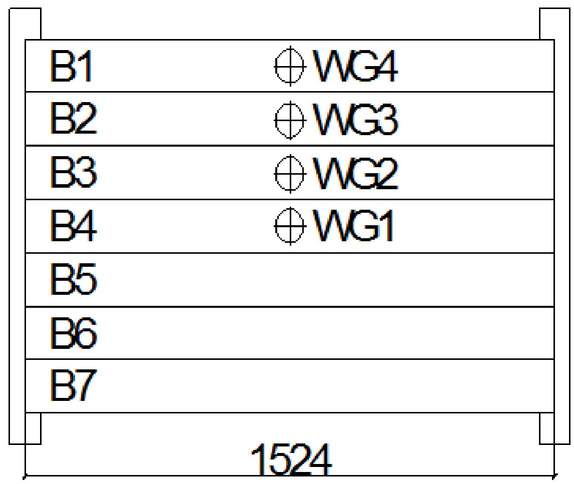


Controlled Random Failure

Figure 6.55: C.17 – Destructive Simple Span CL127 – DFL-S2

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Nailed

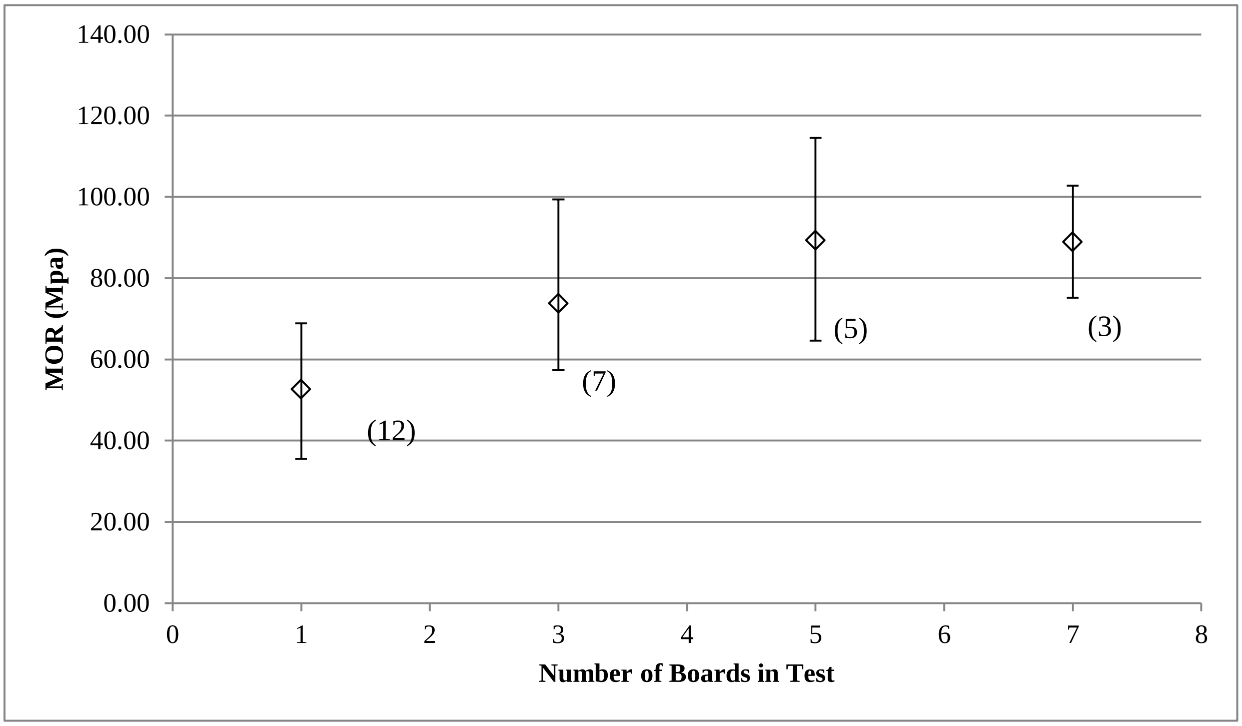
Simple Span (1 Board) Test Name	MOE (Mpa) (B4)	MOR (Mpa)
D-CL127-SS-1-DFL-S2-1	13653	61
D-CL127-SS-2-DFL-S2-1	14889	69
D-CL127-SS-3-DFL-S2-1	13207	61
D-CL127-SS-4-DFL-S2-1	12994	36
D-CL127-SS-5-DFL-S2-1	13176	58
D-CL127-SS-6-DFL-S2-1	13410	47
D-CL127-SS-7-DFL-S2-1	12354	37
D-CL127-SS-8-DFL-S2-1	13941	60
D-CL127-SS-9-DFL-S2-1	13941	60
D-CL127-SS-10-DFL-S2-1	12072	48
D-CL127-SS-11-DFL-S2-1	12072	44
D-CL127-SS-12-DFL-S2-1	14245	51



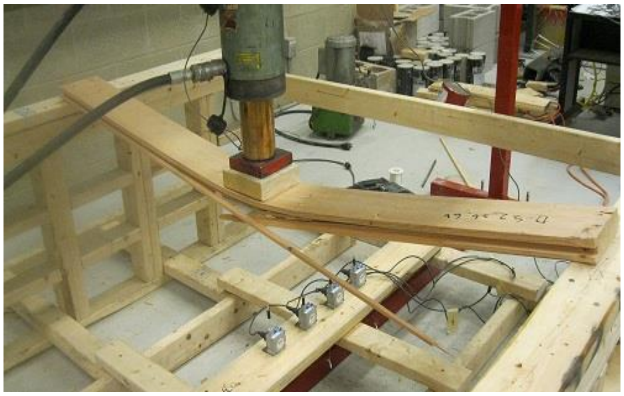
Simple Span (3 Boards)	MOE (Mpa)				MOR (Mpa)
Test Name	B3	B4	B5	AVG	
D-CL127-SS-1-POP-S2-3	12219	13207	14418	13281	90
D-CL127-SS-2-DFL-S2-3	15166	13653	12763	13861	99
D-CL127-SS-3-DFL-S2-3	14245	12354	13941	13513	71
D-CL127-SS-4-DFL-S2-3	13467	13467	11971	12968	57
D-CL127-SS-5-DFL-S2-3	13329	12149	12072	12517	63
D-CL127-SS-6-DFL-S2-3	14324	13941	12072	13446	70
D-CL127-SS-7-DFL-S2-3	15690	13941	12072	13901	66

Simple Span (5 Boards)	MOE (Mpa)						MOR (Mpa)
Test Name	B2	B3	B4	B5	B6	AVG	
D-CL127-SS-1-DFL-S2-5	13176	13941	12354	13548	13025	13209	72
D-CL127-SS-2-DFL-S2-5	13176	13941	12354	12433	13025	12986	115
D-CL127-SS-3-DFL-S2-5	13176	12994	13653	13222	12068	13023	92
D-CL127-SS-4-DFL-S2-5	13176	13410	12281	13487	13025	13076	65
D-CL127-SS-5-DFL-S2-5	13176	13410	12281	14103	13410	13276	103

Simple Span (7 Boards)	MOE (Mpa)								MOR (Mpa)
Test Name	B1	B2	B3	B4	B5	B6	B7	AVG	
D-CL127-SS-1-DFL-S2-7	13548	13025	13410	13941	12072	13941	14245	13455	96
D-CL127-SS-2-DFL-S2-7	13548	13025	13329	13941	12072	13941	14245	13443	96
D-CL127-SS-3-DFL-S2-7	13548	13025	13329	12354	12072	13941	14245	13216	75



D.Fir-L Solid Sawn 127 mm x 36 mm Concentrated Load (127x127) Simple Span Modulus of Rupture Summary



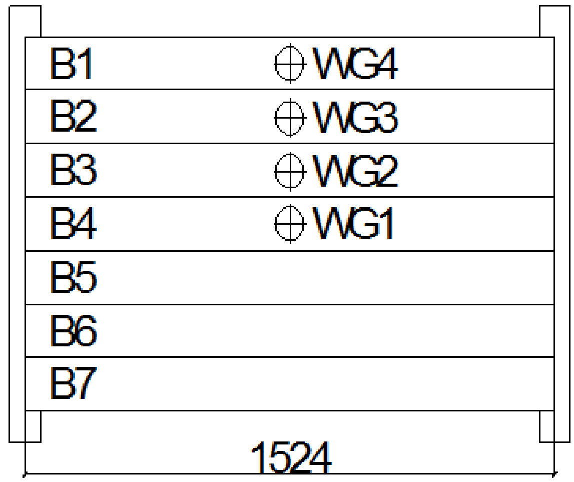
Simple Span 1 Board Failure

Simple Span 7 Boards Failure

Figure 6.56: C.18 – Destructive Simple Span CL127 – POP-L2

Species	Finish	b (mm)	d (mm)	End Conditions
Ponderosa Pine	Laminated	127	36	Nailed

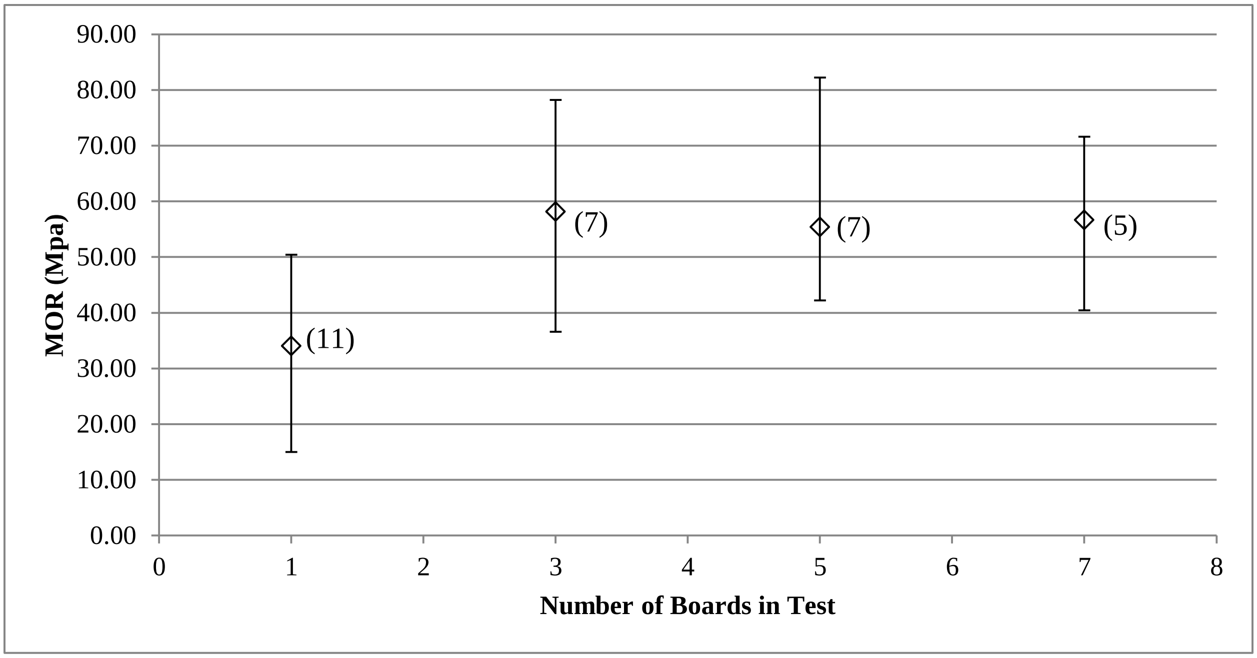
Simple Span (1 Board)	MOE (Mpa) (B4)	MOR (Mpa)
Test Name		
D-CL127-SS-1-POP-S2-1	10867	41
D-CL127-SS-2-POP-S2-1	6986	15
D-CL127-SS-3-POP-S2-1	7844	24
D-CL127-SS-4-POP-S2-1	10059	36
D-CL127-SS-5-POP-S2-1	11874	50
D-CL127-SS-6-POP-S2-1	9521	31
D-CL127-SS-7-POP-S2-1	8786	30
D-CL127-SS-8-POP-S2-1	9244	38
D-CL127-SS-9-POP-S2-1	7870	34
D-CL127-SS-10-POP-S2-1	8301	30
D-CL127-SS-11-POP-S2-1	10335	45



Simple Span (3 Boards)	MOE (Mpa)				MOR (Mpa)
Test Name	B3	B4	B5	AVG	
D-CL127-SS-1-POP-S2-3	10059	8410	9244	9238	49
D-CL127-SS-2-POP-S2-3	10059	7870	8410	8780	64
D-CL127-SS-3-POP-S2-3	10059	7870	9015	8981	78
D-CL127-SS-4-POP-S2-3	10565	9015	8901	9494	37
D-CL127-SS-5-POP-S2-3	10565	9015	9063	9548	45
D-CL127-SS-6-POP-S2-3	10565	9015	8419	9333	64
D-CL127-SS-7-POP-S2-3	8796	8654	8419	8623	69

Simple Span (5 Boards)	MOE (Mpa)						MOR (Mpa)
Test Name	B2	B3	B4	B5	B6	AVG	
D-CL127-SS-1-POP-S2-5	10937	10335	9263	7766	9070	9474	48
D-CL127-SS-2-POP-S2-5	10937	10335	9263	8893	9070	9700	47
D-CL127-SS-3-POP-S2-5	10937	10335	7367	8688	9070	9279	65
D-CL127-SS-4-POP-S2-5	10937	10335	7367	6296	9070	8801	45
D-CL127-SS-5-POP-S2-5	10937	10335	9488	8901	9070	9746	42
D-CL127-SS-6-POP-S2-5	10937	10335	9693	7124	9070	9432	58
D-CL127-SS-7-POP-S2-5	9070	7214	13811	8796	10937	9965	82

Simple Span (7 Boards)	MOE (Mpa)								MOR (Mpa)
Test Name	B1	B2	B3	B4	B5	B6	B7	AVG	
D-CL127-SS-1-POP-S2-7	7214	10937	10335	9693	8893	9070	13811	9993	59
D-CL127-SS-2-POP-S2-7	7214	10937	10335	9693	10277	9070	13811	10191	40
D-CL127-SS-3-POP-S2-7	7214	10937	10335	9693	8996	9070	13811	10008	66
D-CL127-SS-4-POP-S2-7	7214	10937	10335	9693	11982	9070	13811	10434	46
D-CL127-SS-5-POP-S2-7	7214	10937	10335	9693	9070	9070	13811	10018	72



Ponderosa Pine Laminated 127 mm x 36 mm Concentrated Load (127x127) Simple Span Modulus of Rupture Summary

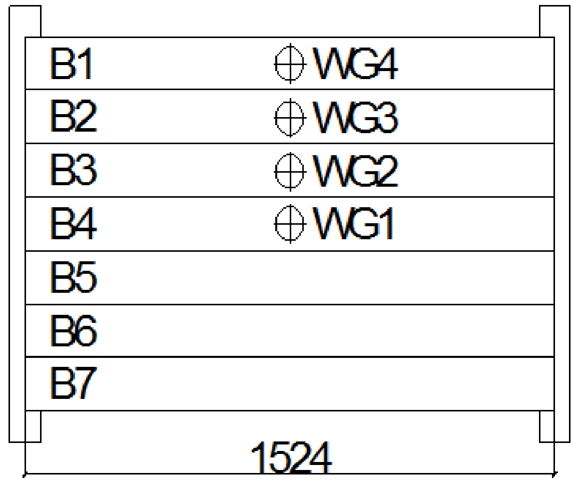
Simple Span 3 Board Failure

Simple Span 5 Board Failure

Figure 6.57: C.19 – Destructive Simple Span CL127 – DFL-L3

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Laminated	131	55	Nailed

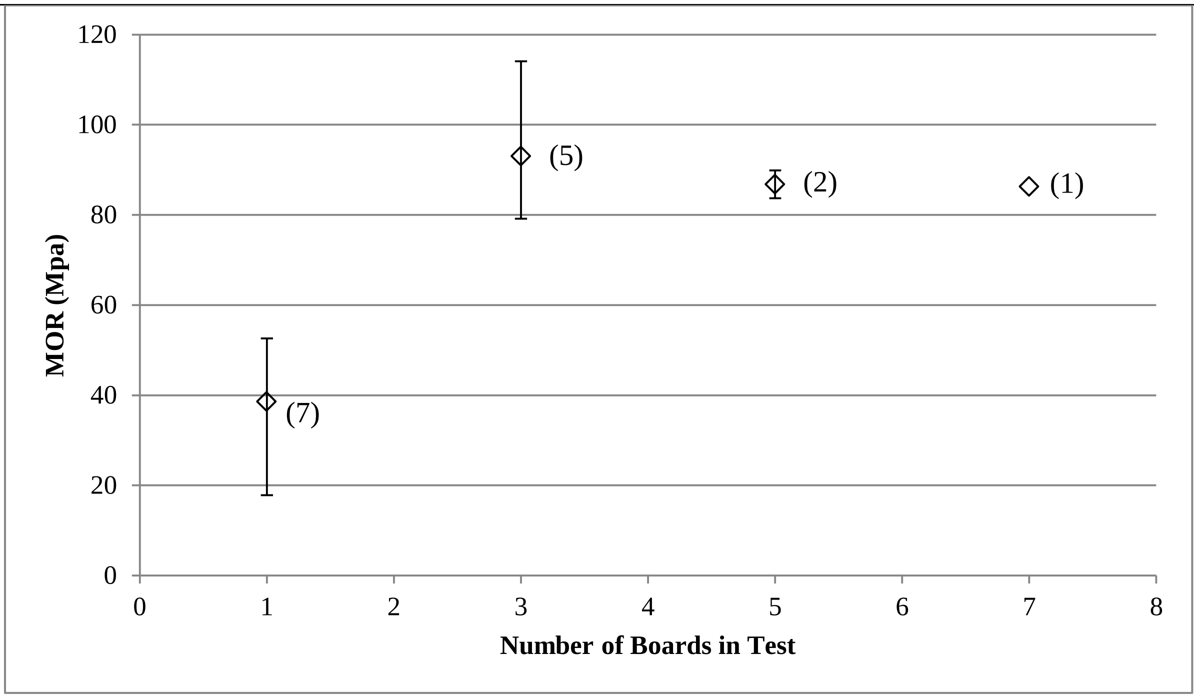
Simple Span (1 Board)	MOE (Mpa) (B4)	MOR (Mpa)
Test Name		
D-CL127-SS-1-DFL-L3-1	12351	53
D-CL127-SS-2-DFL-L3-1	10768	50
D-CL127-SS-3-DFL-L3-1	8202	34
D-CL127-SS-4-DFL-L3-1	10768	49
D-CL127-SS-5-DFL-L3-1	11516	23
D-CL127-SS-6-DFL-L3-1	9830	44
D-CL127-SS-7-DFL-L3-1	11534	18



Simple Span (3 Boards)	MOE (Mpa)				MOR (Mpa)	Toe Nails
Test Name	B3	B4	B5	AVG		
D-CL127-SS-1-POP-L3-3	13524	9892	15534	12983	74	no
D-CL127-SS-2-DFL-L3-3	13720	13524	12351	13198	86	yes
D-CL127-SS-3-DFL-L3-3	10585	9926	8946	9819	79	yes
D-CL127-SS-4-DFL-L3-3	10585	14201	10076	11621	114	yes
D-CL127-SS-5-DFL-L3-3	11534	11534	12767	11945	19	no

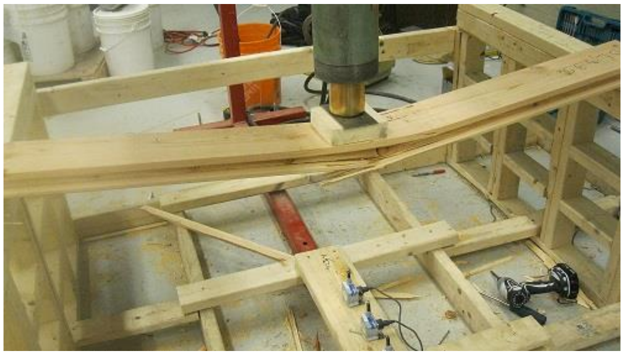
Simple Span (5 Boards)	MOE (Mpa)						MOR (Mpa)	Toe Nails
Test Name	B2	B3	B4	B5	B6	AVG		
D-CL127-SS-1-DFL-L3-5	12718	9866	12984	13068	9221	11571	68	no
D-CL127-SS-2-DFL-L3-5	12023	13801	9221	10716	9221	10997	90	yes
D-CL127-SS-3-DFL-L3-5	10171	12023	10595	12096	10595	11096	84	yes
D-CL127-SS-4-DFL-L3-5	13098	11534	11534	12767	13098	12406	19	no

Simple Span (7 Boards)	MOE (Mpa)								MOR (Mpa)	Toe Nails
Test Name	B1	B2	B3	B4	B5	B6	B7	AVG		
D-CL127-SS-1-DFL-L3-7	13801	13098	11534	11534	12767	13098	12487	12617	86	yes



Ponderosa Pine Laminated 127 mm x 36 mm Concentrated Load (127x127) Simple Span Modulus of Rupture Summary

Simple Span 1 Board Failure



Simple Span 1 Board Failure

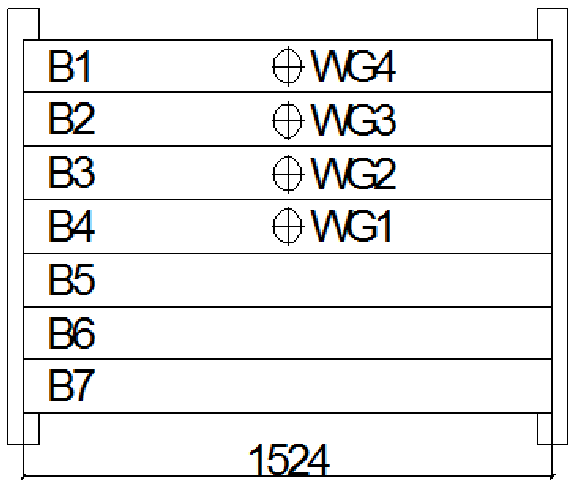
Simple Span 3 Board Failure

Simple Span 5 Board Failure

Figure 6.58: C.20 – Destructive Simple Span CL127 Tests with Sheathing – DFL-S2

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Nailed

Simple Span with sheathing (7 Boards)	MOE (Mpa)								MOR (Mpa)
Test Name	B1	B2	B3	B4	B5	B6	B7	AVG	
D-CL127-SSS-1-DFL-S2-7	11783	13487	15045	12433	14245	12222	12735	13136	197
D-CL127-SSS-2-DFL-S2-7	13626	14959	13548	13329	11649	14568	11578	13322	224
D-CL127-SSS-3-DFL-S2-7	13487	13025	13101	14025	13101	13487	12809	13291	199



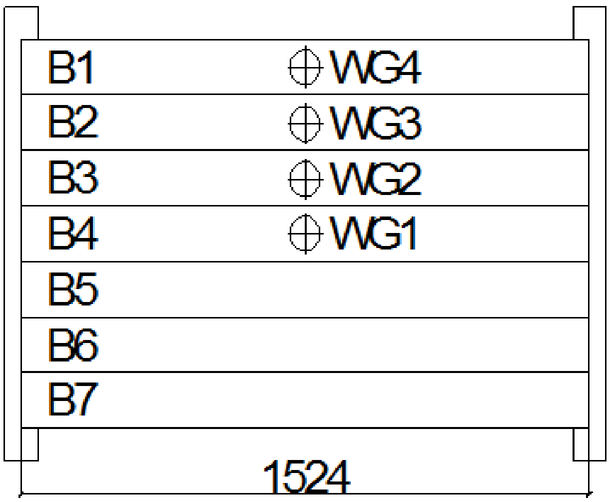
Simple Span 7 Board Failure with sheathing (Top View)

Simple Span 7 Board Failure with sheathing (Bottom View)

Figure 6.59: C.21 – Destructive Simple Span CL127 Tests with Sheathing – POP-L2

Species	Finish	b (mm)	d (mm)	End Conditions
Ponderosa Pine	Laminated	127	36	Nailed

Simple Span with sheathing	MOE (Mpa)								MOR (Mpa)
Test Name	B1	B2	B3	B4	B5	B6	B7	AVG	
D-CL127-SSS-1-POP-S2-7	8870	10937	8796	13811	8688	9070	8436	9801	178
D-CL127-SSS-2-POP-S2-7	10059	6986	9693	7844	9405	8765	9263	8859	158
D-CL127-SSS-3-POP-S2-7	9488	6296	9693	9833	11982	7124	13811	9747	197



Simple Span 7 Board Failure with Sheathing (Top View)

Simple Span 7 Board Failure with Sheathing (Bottom View)

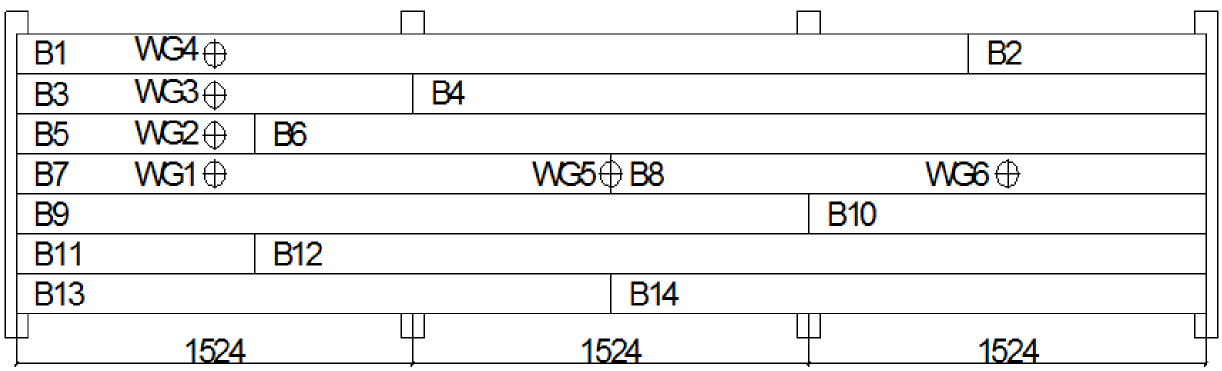
Figure 6.60: C.22 – D-CL127-CR-1-DFL-S2-7

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Nailed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL127-CR-1-DFL-S2-7	58	13127

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3658	914	1524	3048	914	3658	2286	2286
MOE (Mpa)	12943	14227	14322	11336	14322	13844	13110	13222

Board	B9	B10	B11	B12	B13	B14
L (mm)	3048	1524	914	3658	2286	2286
MOE (Mpa)	13313	11115	13844	12396	12994	12783



Controlled Random Failure

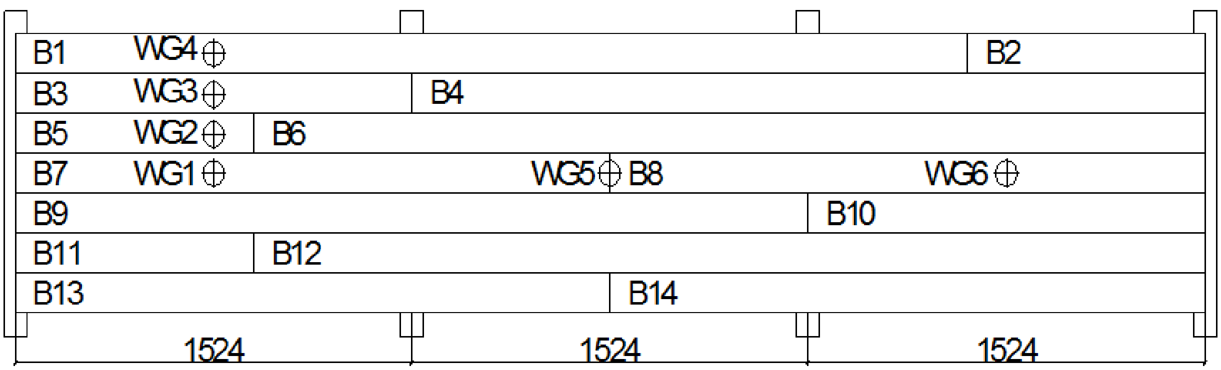
Figure 6.61: C.23 – D-CL127-CR-2-DFL-S2-7

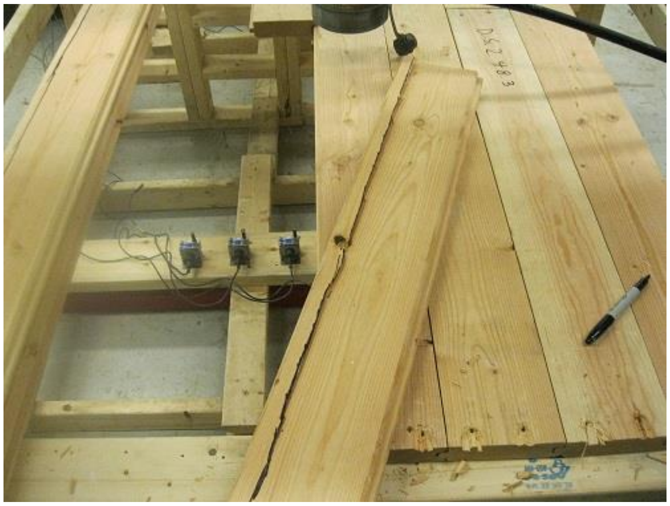
Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Nailed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL127-CR-2-DFL-S2-7	95	13134

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3658	914	1524	3048	914	3658	2286	2286
MOE (Mpa)	12943	14227	14322	11336	13653	14615	13110	13222

Board	B9	B10	B11	B12	B13	B14
L (mm)	3048	1524	914	3658	2286	2286
MOE (Mpa)	13313	11115	13844	12396	12994	12783





Controlled Random Failure

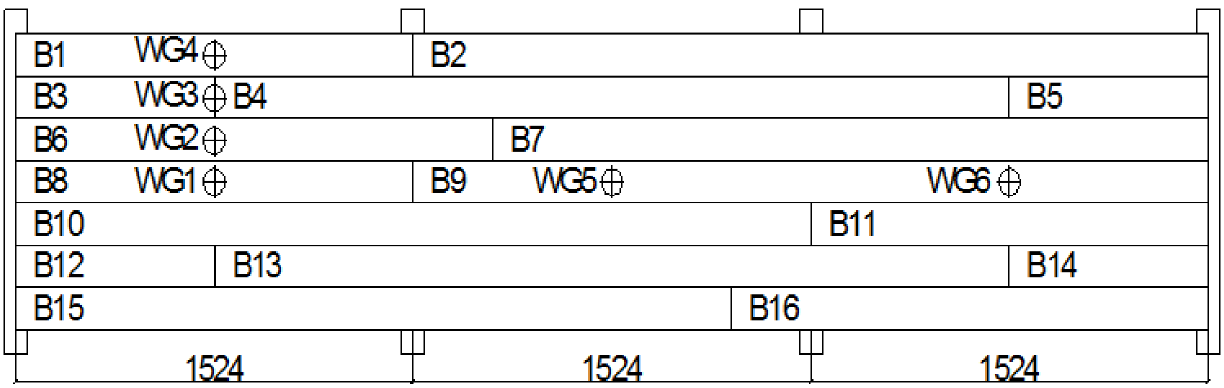
Figure 6.62: C.24 – D-CL127-CR-3-DFL-S2-7

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Solid Sawn	127	36	Nailed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL127-CR-3-DFL-S2-7	112	12493

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	1524	3048	762	3048	762	1829	2743	1524
MOE (Mpa)	13580	11336	13653	11185	11971	12489	14615	11115

Board	B9	B10	B11	B12	B13	B14	B15	B16
L (mm)	3048	3048	1524	762	3048	762	2743	1829
MOE (Mpa)	13313	12068	12668	12668	12396	11115	13844	11879



Controlled Random Failure

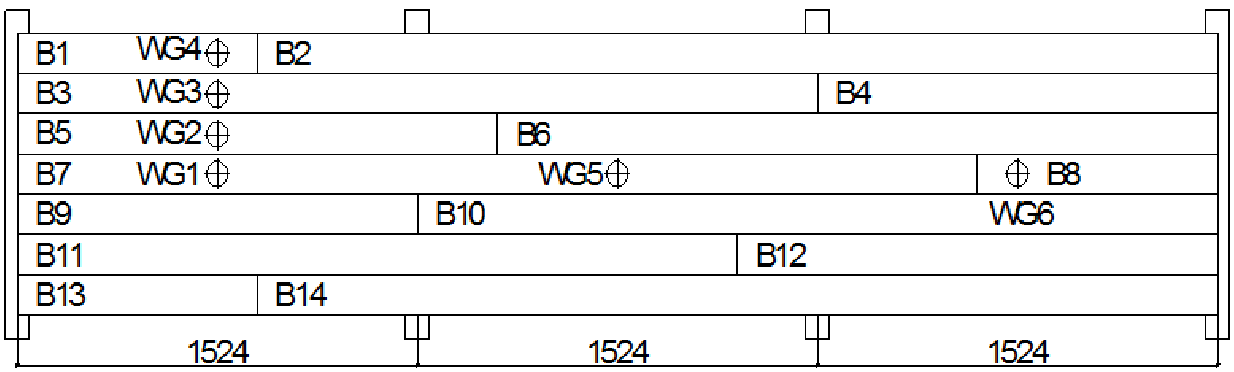
Figure 6.63: C.25 – D-CL127-CR-1-POP-S2-7

Species	Finish	b (mm)	d (mm)	End Conditions
Ponderosa Pine	Laminated	127	36	Nailed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL127-CR-1-POP-S2-7	37	8969

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	914	3658	3048	1524	1829	2743	3658	914
MOE (Mpa)	7870	9244	7870	9157	6885	11874	10867	6986

Board	B9	B10	B11	B12	B13	B14
L (mm)	1524	3048	2743	1829	914	3658
MOE (Mpa)	8786	9015	8410	9521	9015	10059



Controlled Random Failure

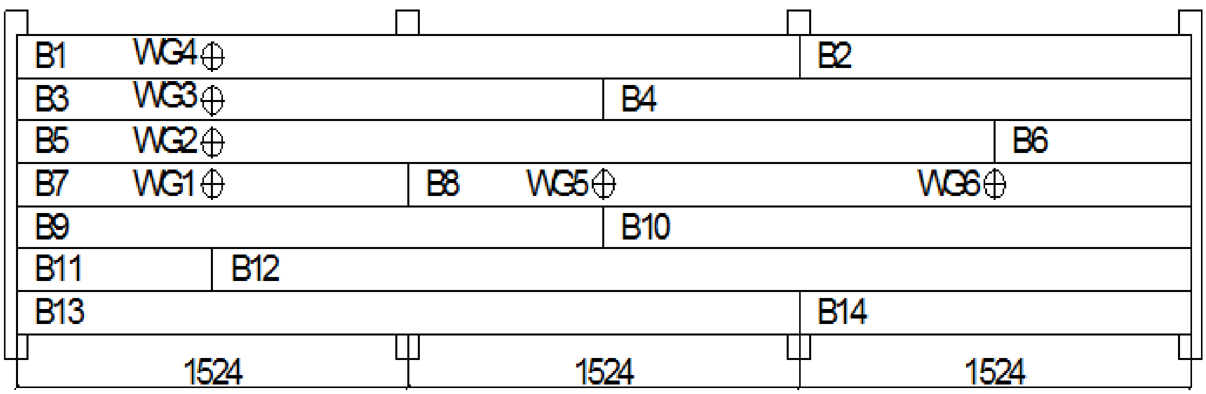
Figure 6.64: C.26 – D-CL127-CR-1-DFL-L3-7

Species	Finish	b (mm)	d (mm)	End Conditions
D.Fir-L	Laminated	131	55	Nailed

Layup	Test Name	MOR (Mpa)	AVG MOE (Mpa)
Controlled Random	D-CL127-CR-1-DFL-L3-7	103	12447

Board	B1	B2	B3	B4	B5	B6	B7	B8
L (mm)	3048	1524	2286	2286	3658	914	1524	3048
MOE (Mpa)	13068	9221	13720	12984	13098	13098	14886	13801

Board	B9	B10	B11	B12	B13	B14
L (mm)	2286	2286	914	4572	3048	1524
MOE (Mpa)	14605	12767	11534	11534	9221	10716



Controlled Random Failure