UNIVERSITY OF BC
WOOD SCIENCE DEPARTMENT

Development of Thick Laminated MPB Wood Plates

Year Two Report

by

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EXECUTIVE SUMMARY

During the second year of this three year study, the main focus of this phase is to develop models capable of predicting the performances of thick wood laminated plates that would be verified by an experimental study on thick MPB wood plates. The modeling phase was successfully completed and the preliminary production of prototype MPB plates at the UBC lab has been initiated.

Comprehensive three dimensional finite element models were developed using commercial software package ANSYS® to analyze the behavior of cross laminated thick wood plates. With this model, several plate layouts were studied for consideration of building thick MPB panel prototypes for demonstration of concept and model verification. Based on limitations of the laboratory conditions, a three-layer cross-laminated plate with nominal dimension of 1.2 m x 2.4 m x 150 mm (4 feet × 8 feet × 6 inch) was selected. The computer model predicted that the peak deflection of glued plates (2.4 mm) is much smaller than nail plates (9.33 mm) when evaluated with the same dimensions and under the same applied load conditions. A video of the deflection pattern of the member under load has been included with this report.

Using the nominal dimension determined by the 3D model, a specimen thick MPB wood plate was manufactured at UBC using randomly selected MPB lumber from a package of #2 and better grade material. Selected members were planed, sanded and cut to final sizes. Phenol–resourcinol–formaldehyde (PRF) resin was applied between the layers (wide face) but not between lumber within the same layer (narrow face). Further specimen configurations using aluminum nails have been prepared for manufacturing.

PROJECT RATIONALE

Based on the European experience, where short length low grade members are cost effectively glue laminated into engineered wood products as thick laminated wood plates and marketed as high value structural wood products, it is believed that using shorts from MPB wood rejects in lumber production would add value and offer new market opportunities for the large amount of MPB wood that is usually either chipped or used in low quality non-structural applications.

The concept is to convert the material into engineered wood products by defect removal and reconstitution. This plate-type product is produced in modular form and can be utilized as part of a structural system for flooring, walls or roof systems. These systems are especially suited for the low rise commercial, industrial and multi-family residential building market.

For this study eight prototype floor panels are being developed. The availability of suitable material for the manufacture of thick laminated panels has been assessed. Based on a model developed to predict the strength and stiffness properties of the prototypes, specimens of thick MPB wood plates have been manufactured at the UBC lab.

PROJECT FINDINGS AND ACHIEVEMENTS FOR YEAR 2

In this year's study, three dimensional finite elements models were developed to analyze the behavior of cross-laminated thick wood plate products and to identify a prototype of a thick MPB wood plate to be manufactured.

Specimen Configuration

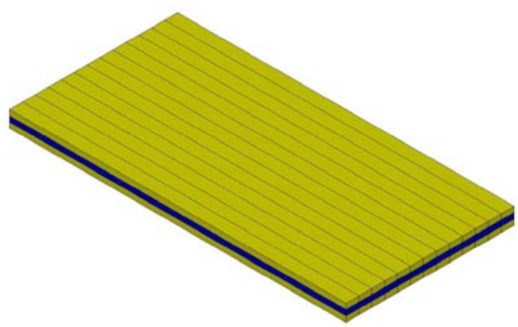


Figure 1. Profile of the 3-layer cross laminated wood plate.

Several configurations of three, five and six layer cross-laminated thick wood plates were modeled using the commercial finite element software ANSYS®. The plate layout which corresponds to the experimental prototype is shown in Figure 1. In the case of the nominal configuration used for the MPB prototype product, 2'' x 4'' (38 mm x 89 mm) lumber members were put side by side to form each individual layer. Adjacent layers were perpendicular to each other and two types of bond connection, glue and nail, were used in the analysis.

The Finite Element Model

Finite Element (FE) models of the cross laminated wood plates were developed with a commercial software package ANSYS® subject to uniform pressure on the top surface. The plate was discretized into 3-D structural solid elements SOLID45. The element is defined by eight nodes having three degrees of freedom at each node. 3-D structural surface effect elements SURF154 were used on the top surface to consider the uniform pressure.

For the simplification of the analysis, published material properties of lodgepole pine (12% MC) were used. The following relations were employed according to the Wood Handbook[1]:

Table 1. Elastic ratios for lodgepole pine at approximately 12% moisture content.

E_T/E_L	E_R/E_L	G_{LR}/E_L	G_{LT}/E_L	G_{RT}/E_L
0.068	0.102	0.049	0.046	0.005

Therefore, we have

Table 2. Elastic properties of lodgepole pine at 12% moisture content.

E_L (MPa)	E_R (MPa)	E_T (MPa)	G_{LR} (MPa)	G_{LT} (MPa)	G_{RT} (MPa)	μ_{RL}	μ_{LT}	μ_{RT}
11990	1222.98	815.32	587.51	551.54	59.95	0.032	0.347	0.469

where E represents modulus of elasticity; G modulus of rigidity; and μ Poisson's ratio. The longitudinal axis L is parallel to the fiber (grain); the radial axis R is normal to the growth rings (perpendicular to the grain in the radial direction); and the tangential axis T is perpendicular to the grain but tangent to the growth rings.

In glued plates, layers were assumed to be perfectly bonded (no slips or opening-up at the interfaces) while there was no connection between lumber members within each layer. In nailed plates, layers were connected by 63.5 mm (2½'') aluminum siding nails represented by springs in model. In the following analysis, all plates are in the same length (2314 mm) and width (1157 mm), but different thickness. Dimension details are given in the appendix part.

As shown in Figure 2, the plates were simply supported at two opposite edges and subjected to a uniform pressure of 7.184 kPa (150 lb/ft^2) on the top surfaces. The load was chosen neglecting the dead load and based on a live load of 4.8 kPa (100 lb/ft^2) with a safety factor of 1.5. The corresponding maximum deflection was calculated and analyzed.

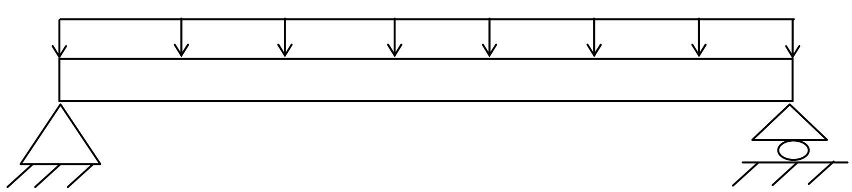


Figure 2. Simply supported plate under uniform pressure on the top surface.

[1] Forest Products Laboratory. 1999. Wood handbook—Wood as an engineering material. Gen. Tech. Rep. FPL-GTR-113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Cross laminated glued plates

- **3-layer cross laminated glued plates**

Layers were assumed to be perfectly bonded (no slips or opening-up at the interfaces) while there was no connection between lumber members within each layer (Figure 1). Thickness of the plates is 114 mm. The deflection (not to scale) of the plate is shown in Figure 3. The maximum deflection of the plate is 2.400 mm (Figure 3).

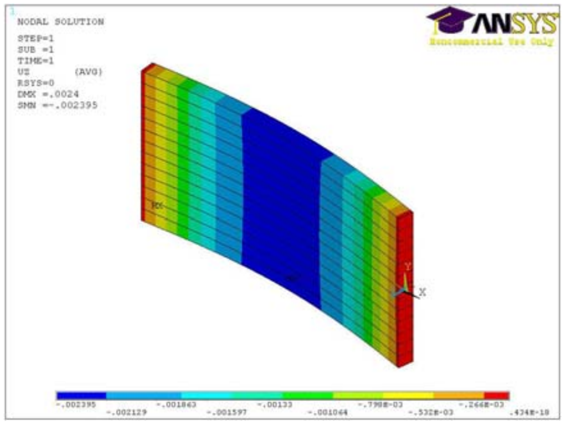


Figure 3. Contour plot of the deflection of a 3-layer cross laminated glued plate.

- **5-layer cross laminated glued plates (I)**

This model ws similar to the previous 3-layer one except that two more layers were added (Figure 4). The thickness was increased to 190 mm. Therefore deflection of the plates decreased to only 0.788 mm (Figure 5).

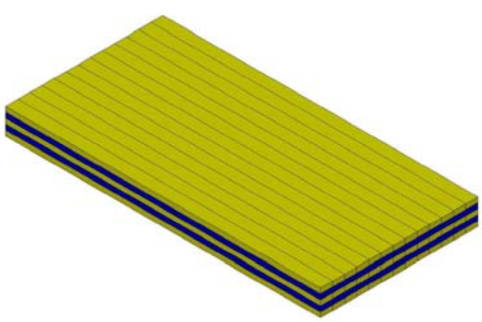


Figure 4. Profile of the 5-layer cross laminated glued plate (I).

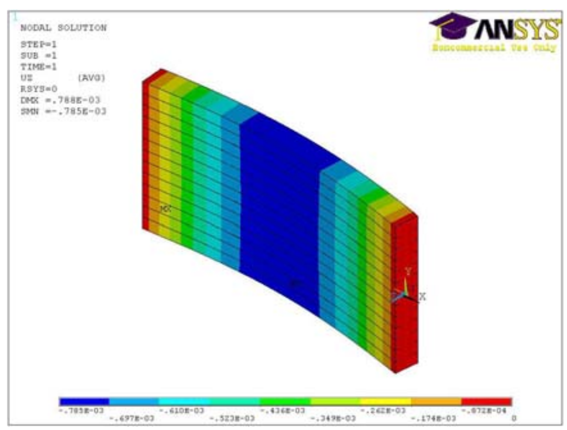


Figure 5. Contour plot of the deflection of a 5-layer cross laminated glued plate (I).

- **5-layer cross laminated glued plates (II)**

In this case, 15 pieces of 2'' × 4'' (38 mm× 89 mm) lumber were glued on the wide face. Then the laminated member was divided into two parts from the middle plane as shown in Figure 6. Therefore, flat grain lumbers could be changed to vertical grain ones which were more suitable for flooring, decking and stepping with their less shrinkage and excellent wearing properties (Figure 7). These new structural elements were be used to form individual layer of the 5-layer cross laminated plates (Figure 8). Deflection of this type of plates is 0.580 mm (Figure 9).

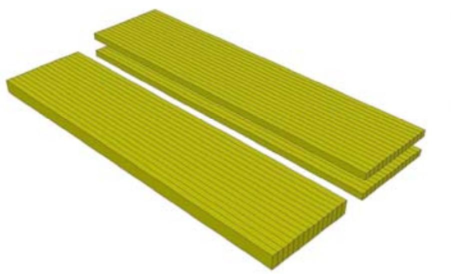


Figure 6. Laminated 2'' × 4'' lumber was divided into two parts.

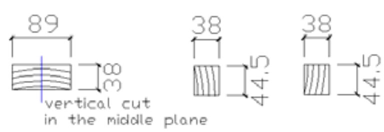


Figure 7. Cross section of a 2'' × 4'' lumber before and after vertical cut in the middle plane.

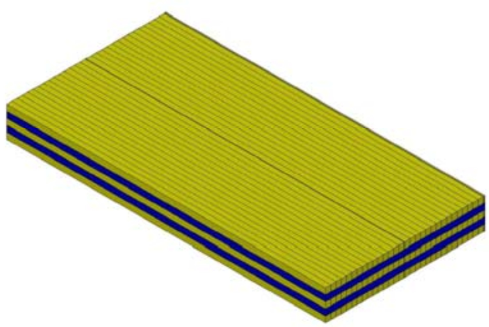


Figure 8. Profile of the 5-layer cross laminated glued plate (II).

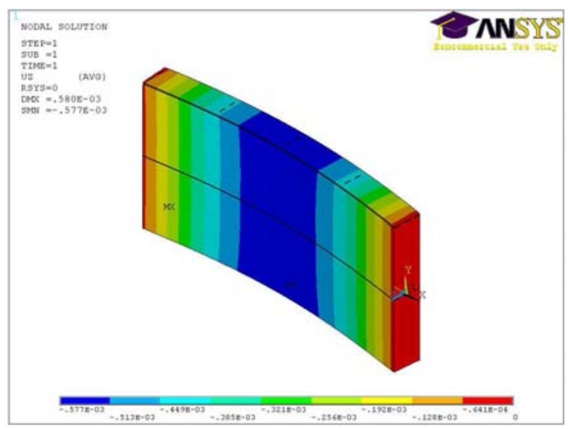


Figure 9. Contour plot of the deflection of a 5-layer cross laminated glued plate (II).

Three types of 6-layer cross laminated glued plates were developed. Adjacent layers were cross laminated except the third and fourth layers being parallel to each other. Analysis details are shown in the following sections.

- **6-layer cross laminated glued plates (I)**

The profile and deflection (0.504 mm) of the 6-layer plates (I) are shown in Figures 10 and 11, respectively.

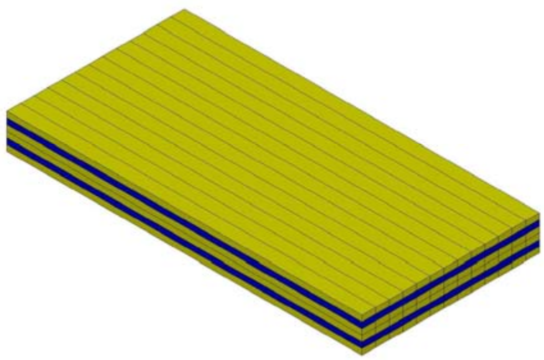


Figure 10. Profile of the 6-layer cross laminated glued plate (I).

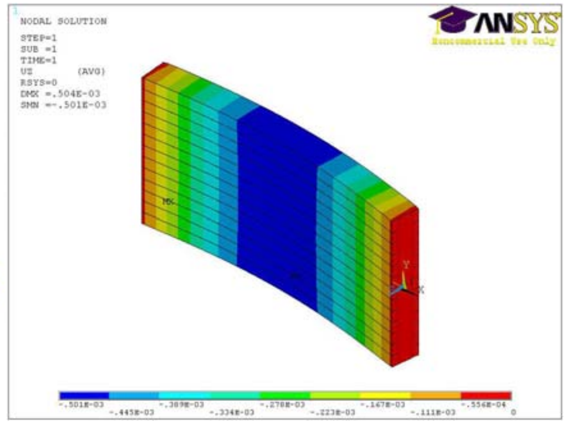


Figure 11. Contour plot of the deflection of a 6-layer cross laminated glued plate (I).

- **6-layer cross laminated glued plates (II)**

As shown in Figure 12, there are big gaps in the third and fourth layers of the plate. These gaps are for cables and insulation materials which help to provide a nice inside climate of the building. Since less lumber is used, the deflection of this type of plates (0.647 mm) is a little bit greater than that of the first 6-layer plate model (0.504 mm) (Figure 13).

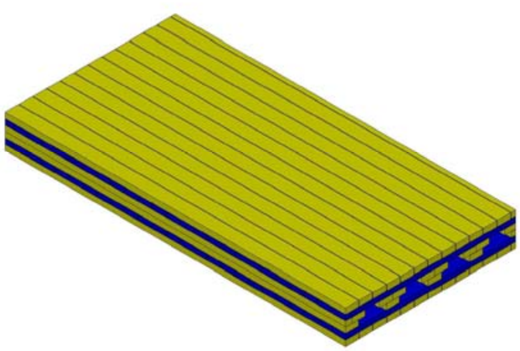


Figure 12. Profile of the 6-layer cross laminated glued plate (II).

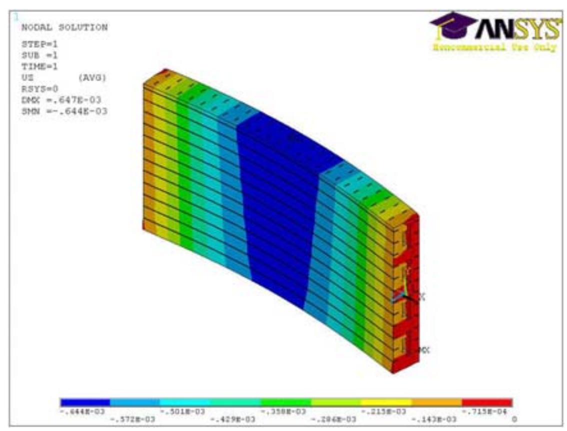


Figure 13. Contour plot of the deflection of a 6-layer cross laminated glued plate (II).

- **6-layer cross laminated glued plates (III)**

Another type of 6-layer plates which has big gaps in the middle layers is shown in Figure 14. The deflection is 0.552 mm (Figure 15).

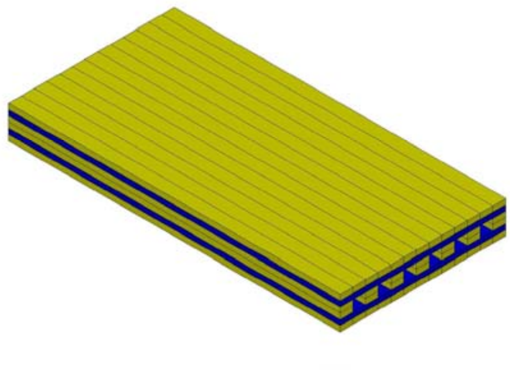


Figure 14. Profile of the 6-layer cross laminated glued plate (III).

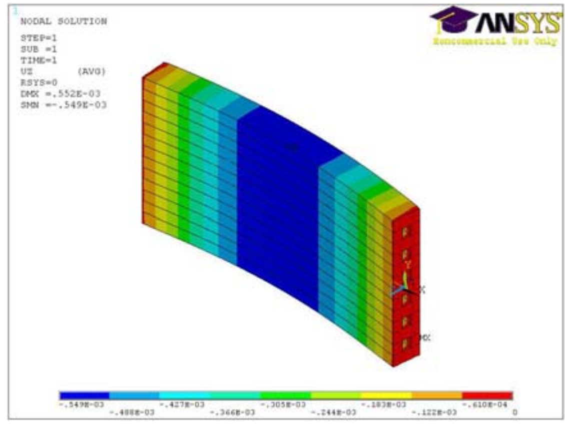


Figure 15. Contour plot of the deflection of a 6-layer cross laminated glued plate (III).

Cross laminated nailed plates

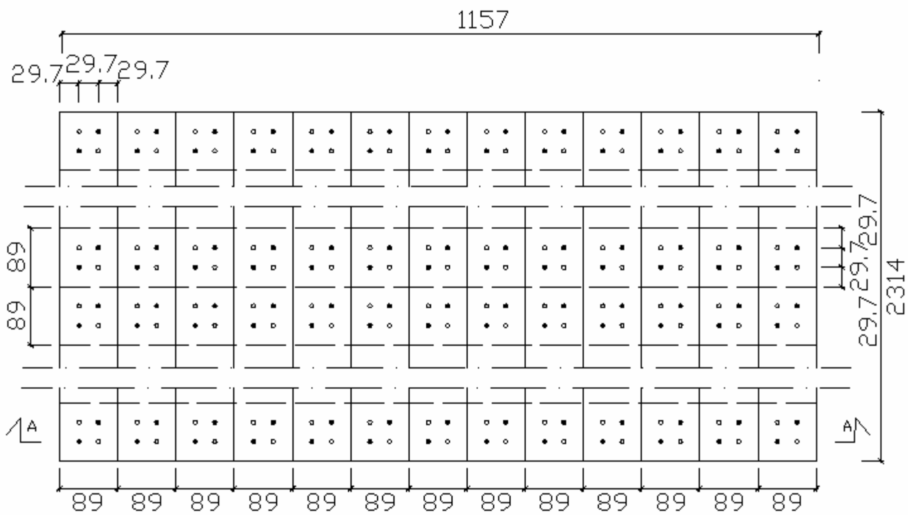
In this case, aluminum nails which are lightweight and easy to cut are used as the connection between different layers. It is well known that the nail connectors play a very important role in the structure. The capacity of each nail is simulated by a group of longitudinal springs in three directions (two horizontal and a vertical direction). The spring-damper element COMBIN14 which is defined by two nodes, a spring constant and damping coefficients is employed. Considering the thickness of each individual layer, 63.5 mm (2½'') aluminum siding nails which can go through two adjacent layers are employed. The nail carrying capacity (500 N/mm) in a lateral direction is estimated based on previous preliminary experiments.

Since the laminated layers are connected only by nails, the interfaces may maintain or break physical contact and may slide relative to each other. Therefore, another factor which should be taken into account in the modeling is the influence of friction. A 3-D 4-node surface to surface contact element CONTA173 and a 3-D target segment element TARGE170 are used in the FE model to consider the influence of friction. The friction coefficient for wood to wood connections is 0.4-1.0[2] and a value of 0.5 is chosen in this study. The schematic structure of 3-layer cross laminated nailed plates is shown in Figure 1 and two different nailing patterns are developed.

[2] Wriggers, P., 2002. Computational contact mechanics. John Wiley & Sons Ltd, England.

- **3-layer cross laminated nailed plates (I)**

The first nailing pattern is shown in Figure 16. Nails driven from the top layer and those driven from the bottom layer are represented by solid circles and open circles, respectively. The maximum deflection of this type of plates is found to be 9.330 mm (Figure 17).



Top view

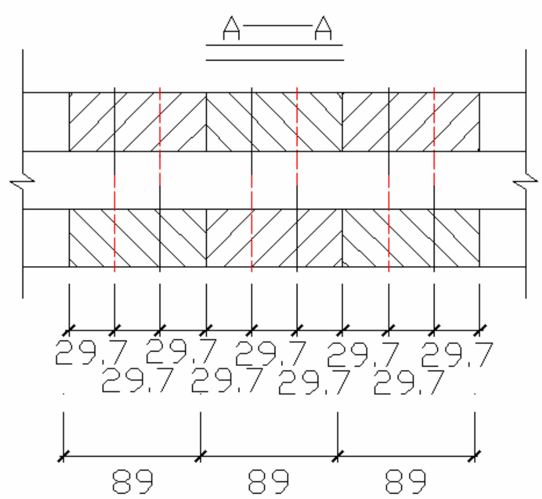


Figure 16. Nailing pattern of the 3-layer cross laminated nailed plate (I).

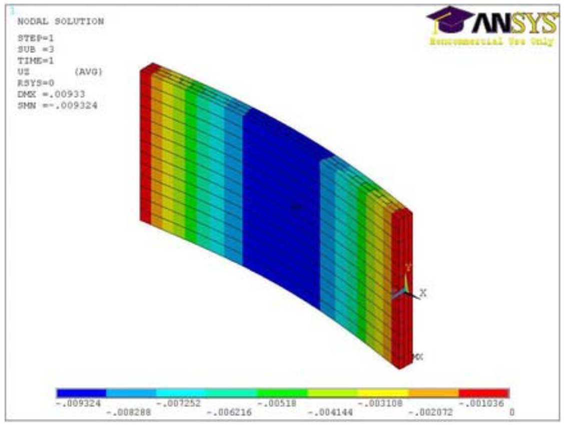
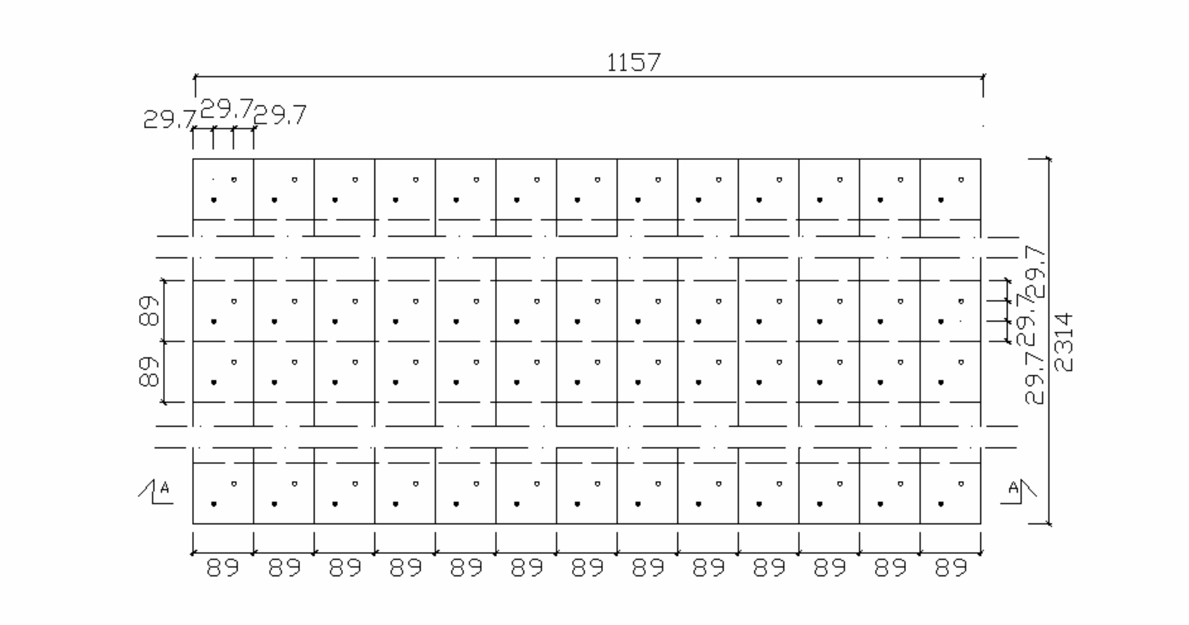


Figure 17. Contour plot of the deflection of a 3-layer cross laminated nailed plate (I).

- **3-layer cross laminated nailed plates (II)**

Figure 18 shows the nailing pattern of the second nailed plate model. Comparing with the first model, it is clear that the number of nails is decreased by half. As expected, the maximum deflection in the mid-span increases a lot (13.168 mm) (Figure 19 (a)). Since lack of connections, displacements of the middle layer caused by transverse shear effect are very obvious (Figure 19 (b)).



Top view

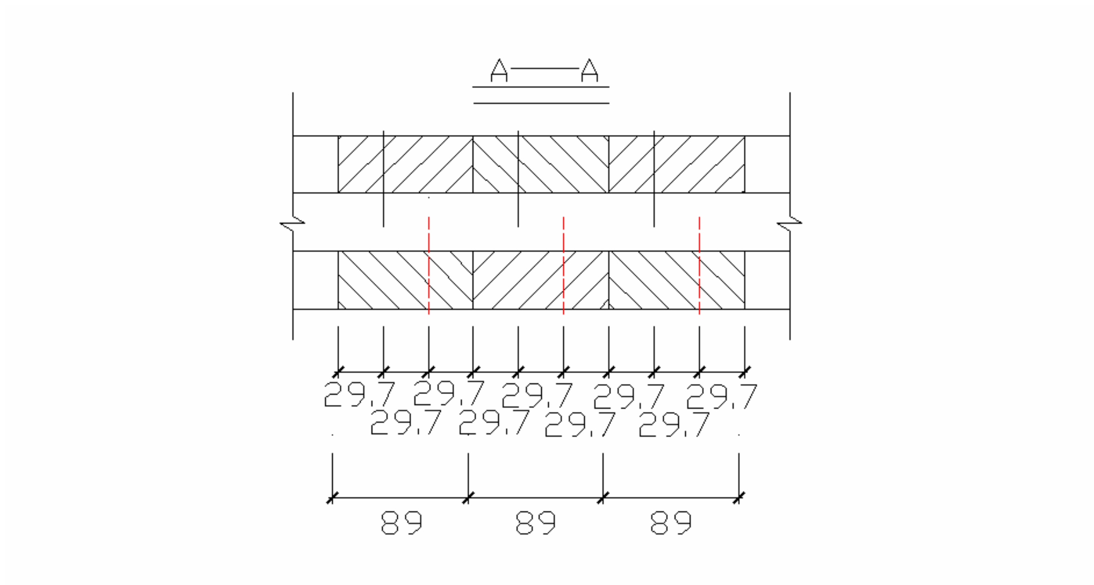
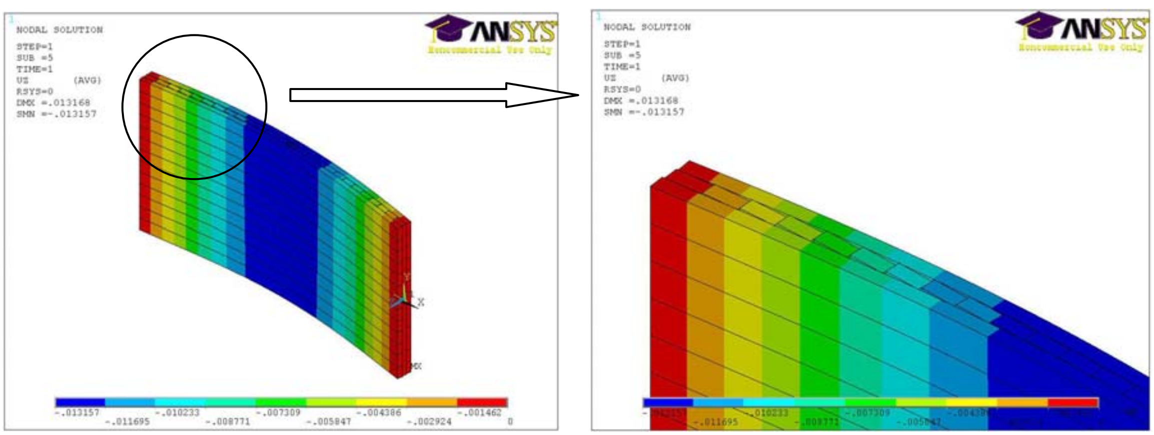


Figure 18. Nailing pattern of the 3-layer cross laminated nailed plate (II).



(a) (b)

Figure 19. Contour plot of the deflection of a 3-layer cross laminated nailed plate (II).

Comparison of different specimen configurations

Table 3 shows the maximum deflection of the above eight different specimen configurations. Generally speaking, nailed plates are more flexible and generate much greater deflections compared with glued plates.

For the glued plates, 3-layer, 5-layer (I), 5-layer (II) and 6-layer (I) are very similar configuration models, i.e. no big gaps in middle layers. It can be seen that the maximum deflection decreases with increasing thickness. Considering 6-layer (I), (II) and (III) models which have the same thickness (228 mm), big gaps in the middle layers (models II and III) lead to an increment of maximum deflection by 28.4% and 9.5%, respectively. It is interesting to note that the performance of 6-layer (II) and (III) plates, which have similar layout and use almost the same amount of materials, is very different. The maximum deflection decreases by about 15% by changing the specimen configuration from 6-layer (II) to 6-layer (III).

Nailing patterns have a big influence on the bending behavior of nailed plates. For 3-layer (I) and (II), reducing number of nails by half will lead to an increment of maximum deflection by 41%.

Table 3. Maximum deflection of different specimen configurations.

Configuration	Glued plates						Nailed plates	
	3-layer	5-layer (I)	5-layer (II)	6-layer (I)	6-layer (II)	6-layer (III)	3-layer (I)	3-layer (II)
Thickness (mm)	114	190	222.5	228	228	228	114	114
Max. deflection (mm)	2.400	0.788	0.580	0.504	0.647	0.552	9.330	13.168

Test Specimen Production

One package of 2'' × 4'' (38 x 89 mm) #2/Btr MPB lumber, 16 feet (4.88 m) in length, with a moisture content of about 15% was received courtesy of Canfor. The MPB lumber comes from the beetle pine infested area around Quesnel, BC.

The MPB lumber was stored inside to reach the equilibrium moisture content (Figure 20). To get a good representative of the MPB damaged wood, the lumber members were selected randomly from the package. Selected members were then planed, sanded and cut into proper sizes.

With spread weight[3] of 43 kg (95 lbs), Phenol-resorcinol-formaldehyde (PRF) resin was used and a 3-layer glued cross-laminated plate was made in the Centre for Advanced Wood Processing at UBC (Figures 21 and 22).

63.5 mm (2½'') aluminum siding nails have been used in the 3-layer (I) specimen configuration with nail connections.

[3] Spread weight means pounds of glue per 1000 square feet of single glue line.

Figure 20. Pack of 2'' × 4'' #2/Btr MPB lumber.

Figure 21. 3-layer glued cross laminated MPB wood plate.

Figure 22. Specimen of MPB wood plate in the Italpresse.

Testing

More specimens will be produced and the evaluation of the performance of the plates will be conducted according to the principle of ASTM E 2322-03, “Standard test method for conducting transverse and concentrated load tests on panels used in floor and roof construction”. The load-deflection relationship and maximum load for each specimen will be recorded.

Compression parallel to grain, tension parallel to grain and shear block tests will be conducted to get evaluations of MPB lumber according to the ASTM D 198-05a, “Standard test methods of static tests of lumber in structural sizes” and ASTM D 143-94, “Standard test methods for small clear specimens of timber”. Lateral nail resistance test is also needed for the strength and performance of nail connections.

The numerical models will be verified based on the experimental results.

Conclusion

During the second year of the project, three dimensional Finite Element models were established to analyze the behavior of thick laminated MPB wood plates. Several different specimen configurations were developed and eight of them were included in this report. The following conclusions were drawn from the study.

1) With the same dimensions, nailed plates are more flexible and develop greater deflections compared with glued plates.

2) For similar configurations, e.g. no big gaps in middle layers, maximum deflection decreases with increasing thickness.

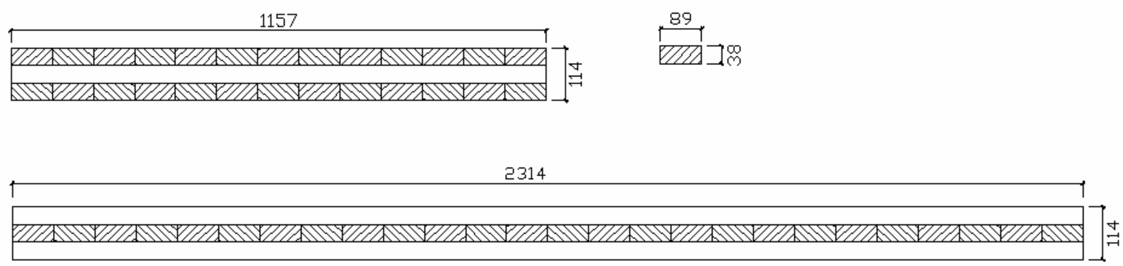
3) With the same dimensions, configurations have a big influence on bending behavior of the specimens.

4) Nailing pattern is an important factor to affect the performance of wood plates with nail connections.

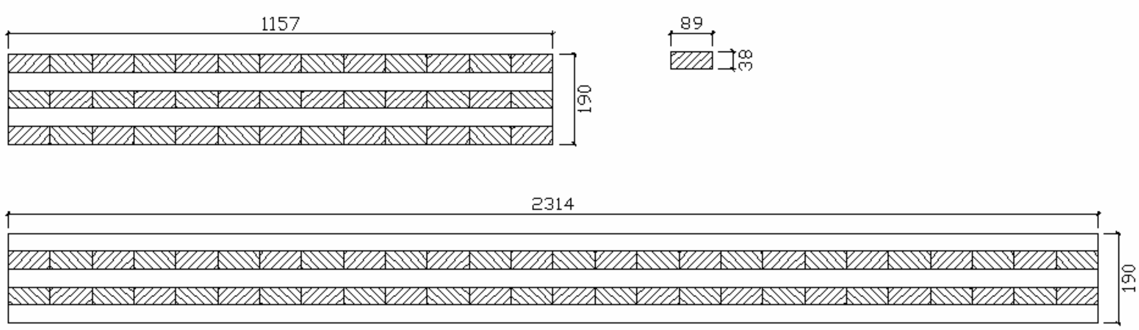
APPENDIX

Dimension details of different specimen configurations. All measurements are in mm.

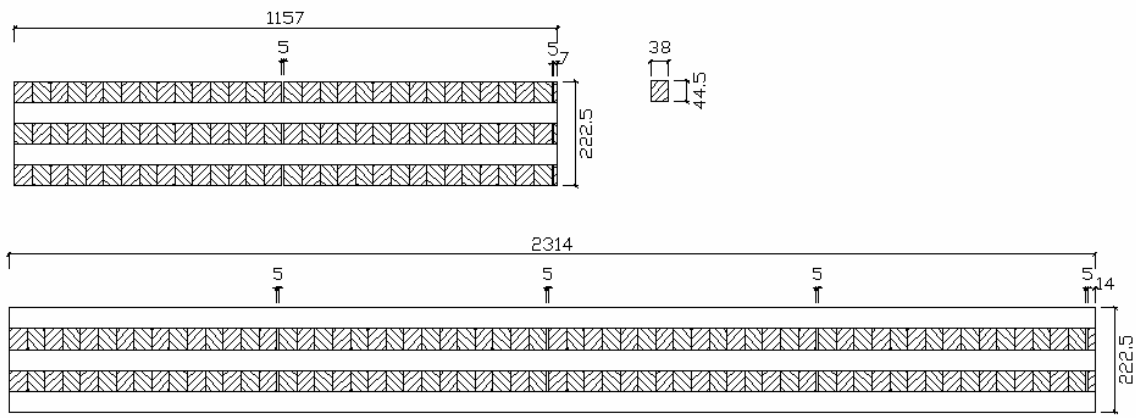
- 3-layer cross laminated glued/nailed plates



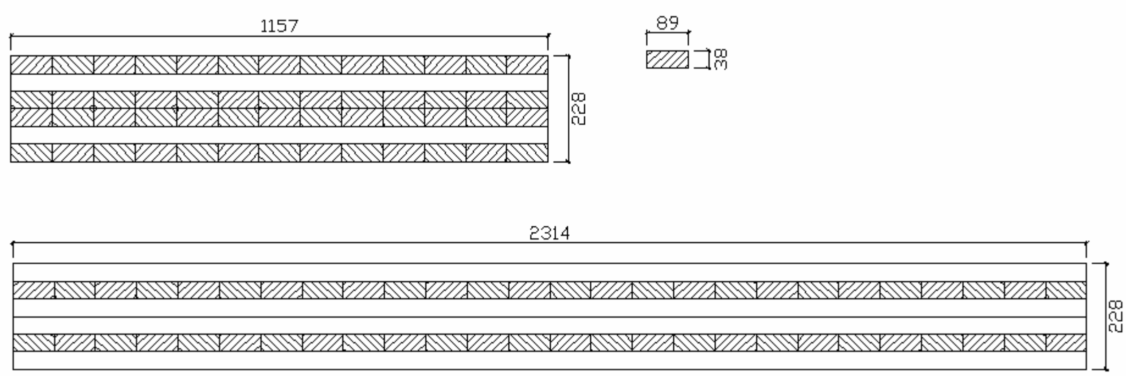
- 5-layer cross laminated glued plates (I)



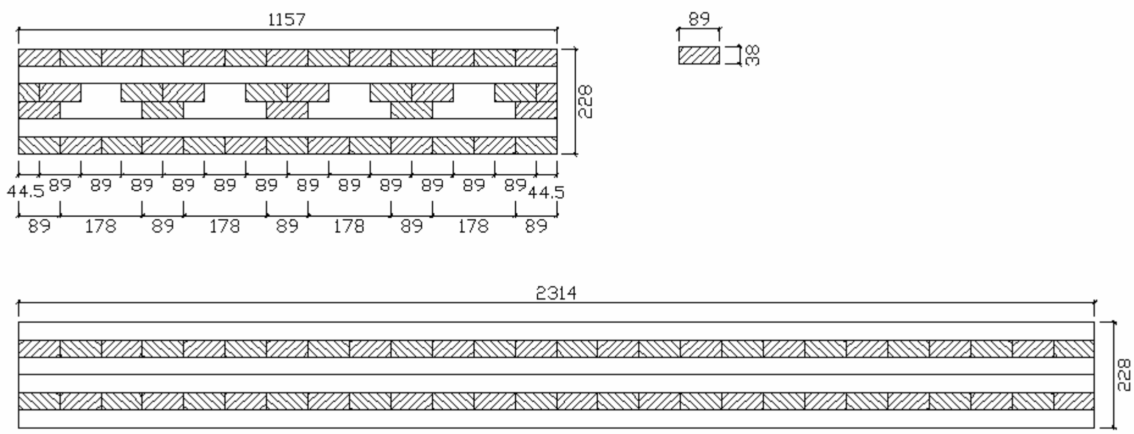
- 5-layer cross laminated glued plates (II)



- 6-layer cross laminated glued plates (I)



- 6-layer cross laminated glued plates (II)



- 6-layer cross laminated glued plates (III)