NUMERICAL INVESTIGATION OF EFFECTIVE FLANGE WIDTH IN THE CLT-GLT COMPOSITE T-BEAMS

R. Masoudnia[1], S. Masoudnia[2]

[1]Corresponding Author: Emerging Professional IPENZ, Ph.D. of Structural Engineering, Research Fellow at Center of Infrastructure Engineering, Western Sydney University, Sydney, Australia. E-mail:reza.masoudniaa@gmail.com

[2]Independent Professional Structural Engineer.

ABSTRACT

This paper deals with the structural behavior of CLT-GLT composite T-beams which is made up of a Cross Laminated Timber (CLT) panel attached to a Glue Laminated Timber (GLT) beam. The technical research paper explores the effect of the CLT panel and GLT beam configuration on the effective flange width of CLT-GLT composite T-beams, which is an important requirement for simplified structural analysis and design. When the CLT-GLT composite T-beams are under positive bending moment, part of the CLT panel will act as the flange of the GLT beam resisting compression. From shear lag, the compressive stress in the CLT flange will differ with the distance from the GLT beam. When the spacing between the GLT beams becomes larger, the CLT flange becomes more highly stressed over the GLT beam than in the extremities edges of the CLT flange. Despite a large number of studies regarding steel-concrete composite structures for design purposes, there has not been comprehensive comparative research on structures that are constructed by engineered wood products. In this study, a finite element (FE) model which is experimentally verified is used to analyze the CLT-GLT composite T-beams and obtained effective flange width results are presented by tables, bar charts, and normal stress distribution figures. Based upon a detailed parametric study, it is concluded that the layer arrangement of the CLT panels and its material properties have a significant influence on the effective flange width of the CLT-GLT composite T-beams. Any changes that increase the ratio of the transverse layer's depth to the longitudinal layer's depth result in an increase of the effective flange width. FE Parametric study on conventional layers configurations of the CLT panels showed that when the boards in transverse layers replaced by two times thicker boards, the effective flange width of CLT-GLT composite T-beams increases at least 85 percent.

KEYWORDS

Composite T-beam, CLT, GLT, shear lag, effective flange width

1 INTRODUCTION

The modeling of the CLT-GLT composite T-beam that made up of a Cross Laminated Timber (CLT) acting as slab panel attached to a Glulam Laminated Timber (GLT) girder by self-tapping screws combines many of the encountered challenges in the analysis and design of timber structures. In a CLT-GLT composite T-beam, the CLT panel works as a flange under bending in the CLT-GLT composite T-beam [1-3].

Using simple beam theory leads to inaccurate results for stresses and strains in the contact surface of the composite beam. This is mainly because the simple beam theory does not take the shear lag phenomena into account [4]. Determination of the effective flange width directly affects the moments, shear forces, and deflections for the composite section. Thus, accurate evaluation of the effective width flange significantly contributes to the more efficient and economical beam design. Many theoretical and experimental studies have been conducted to assess the behavior and calculate the size of the effective flange of the composite beams. Various research formulas have been recommended by three generations of scholars to calculate the effective flange width which are summarised in Table 1[4-7]. In steel-concrete composite sections, the effective flange width concept has been used widely in international design specifications, such as AISC (LRFD:13.1), the Canadian code (CSA: S17.4) and the European code (2000). Interestingly, in all of them, the shear lag effect is taken into account. Simplified effective flange width formulas are summarized in Table 2 [4-6, 18-20].

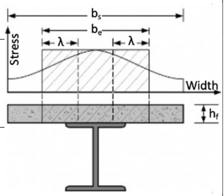
Despite the large number of studies in regard to steel-concrete composite structures, there is still a lack of data about the effective flange width of timber beams which made of new engineered wood products like CLT panels. Based on the aforementioned problem, the objective of this study is to investigate the effective flange width of the CLT-GLT composite T-beam under positive bending.

Table 1: Effective width formulas [4-6,8].

Miller	$\lambda = \frac{f}{2\delta[(H/i)^2-1]}$	Eq.1
Timoshenko	$2\lambda = \frac{2L}{\pi[3+2\nu-\nu^2]}$	Eq.2
Chiewanchakorn	$b_{eff} = \frac{C_{slab}}{F} = \frac{C_{slab}}{0.5t_{slab}(\sigma_{max}+\sigma_{min})}$	Eq.3

f = Area of steel block.
δ = Plate thickness.
H = Distance from plane of plate to centre of gravity of steel beam.
i = Radius of gyration.
L = Span of composite beam.
v = Poison's ratio.
F = Force per unit slab width.
C_{slab} = Slab compressive force.
λ = Effective width measured on one side of the plane of symmetry.
t_{slab} = Thickness of slab.
σ_{max} and σ_{min} = Maximum and minimum compressive stresses of slab.

Table 2: Effective width be formulas for steel-concrete beams in various design codes [4-6, 18-20].

Source	Formulas
AISC-LRFD:13.1	b_e is least of: (1) 2 times distance to edge of slab (2) Beam span/4 (3) b_s
CANADIAN CSA: S17.4 & Euro code(2000)	b_e is least of: (1) Beam span/4 (2) b_s 
ACI	b_e is least of: (1) Beam span/4 (2) b_w+16h_f (3) Centre to centre spacing of beams

b_e = effective width of concrete flange of composite beam.
b_s = width of concrete flange of composite beam.
h_f = thickness of flange.
b_w = breadth of web.

2 METHODOLOGY

In order to develop the effective width section, a numerical model of a timber composite T-beam assembly was analyzed. This model was further validated with the result of deformation, slip and effective flange width obtained from the experimental testing of a timber composite T-beam under a point load.

The validated model was then used to determine the normal stresses in the CLT panel longitudinal boards. These stresses were used to determine the effective width of the CLT panel in the CLT-GLT T-composite beam. Equation 4 presents the formula for the effective width flange found in the experimental and numerical results. This formula is delivered from the concept that Chiewanichakorn has previously proposed for steel-concrete T-beams. This formula requires the stresses in the layers within the CLT panel as input to be able to evaluate the effective flange width [12,13].

$$b_{eff} = \frac{1}{m} \times \sum_1^m \begin{cases} \frac{C_{Lm\ CLT\ panel}}{0.5 \times t_{Lm\ CLT\ panel} \times (\sigma_{Lm\ max\ CLT\ panel} + \sigma_{Lm\ min\ CLT\ panel})} & m = \text{odd layer} \\ 0 & m = \text{even layer} \end{cases} \quad \text{Eq.4}$$

Where m is the number of layers which starts from the first outer layer and it is indicated for all layers regardless of their orientation (longitudinal or transverse). C_{LmCLT} panel is the total compressive force of each longitudinal layer, t_{LmCLT} panel is the thickness of each CLT longitudinal layer in compression and $\sigma_{(Lm\ max\ CLT\ panel)}$ and $\sigma_{(Lm\ min\ CLT\ panel)}$ are respectively the maximum and minimum compressive stresses in each longitudinal layer. The associated concept is illustrated in Figure 1. LL and TL are the abbreviations for Longitudinal Layers and Transverse Layers.

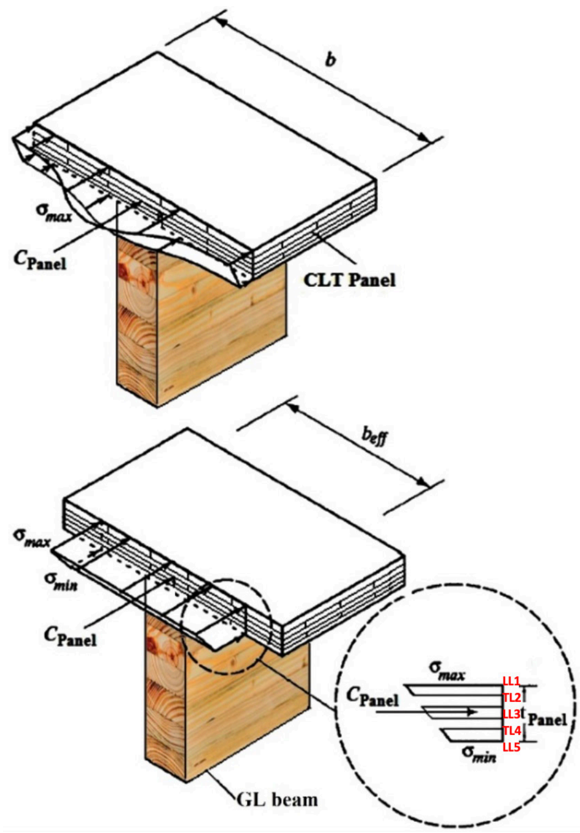


Figure 1: *Effective flange width definition in CLT-GLT composite T-beam [7].*

3 TEST SET-UP

Planning and gluing of the five pieces of Laminated Veneer Lumber (LVL) to build a larger section and the predrilling and screwing of the CLT panel and finally the fabrication of the CLT-LVL composite T-beam took a significant portion of the preparation time for the full-scale experimental test. As Figure 2 shows, a five layers CLT slab with 2000 mm width, 200 mm depth and 6000 mm length was fastened to a LVL beam with 300 × 605 mm area section by 48 self-tapping screws. The screws were penetrated in 45 degrees in two raws every 200 mm.

To monitor the vertical deflections at the mid-span, the beam rotations at the supports of and the stresses on the two surfaces of CLT panel, three linear variable differential transducers (LVDTs) and 45 portal gauges were installed (Figure 3).

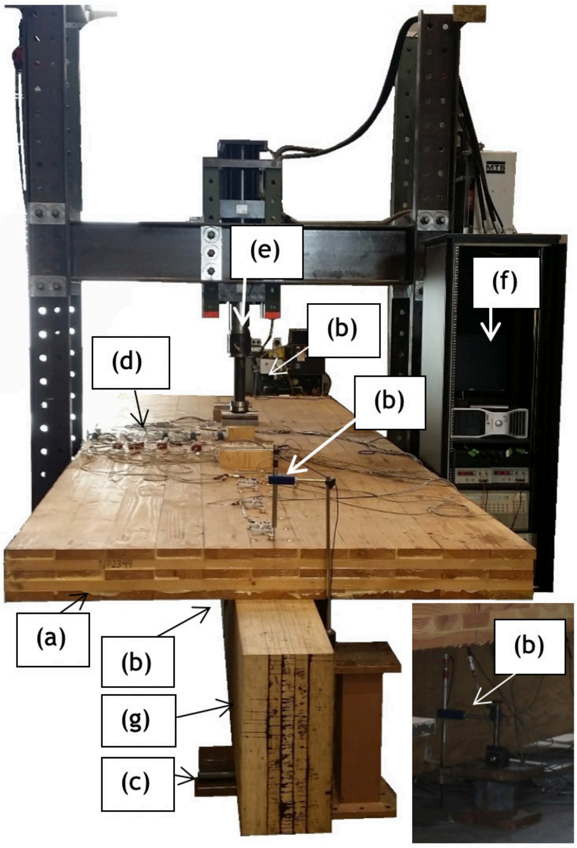


Figure 2: *The CLT-LVL composite T-beam test set-up. (a) The CLT panel, (b) LVDT (c) Roller support, (d) Portal gauges, (e) MTS Machine, (f) Data acquisition system, (g) LVL beam.*

4 MATERIAL PROPERTIES

The experimental proposed CLT-LVL composite T-beam is comprised of two common engineered wood products: CLT (Figure 4a) and LVL (Figure 4c) for experimental test and verification study. Once the numerical model was validated using experimental

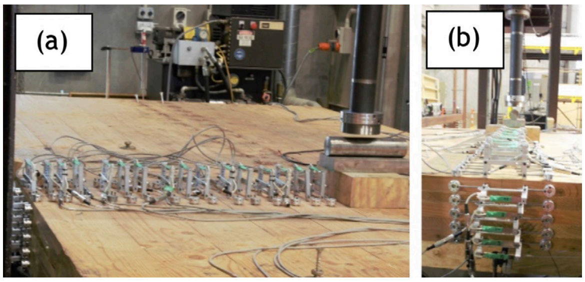


Figure 3: *Portal gauges arrangement: (a) Front view, (b) Side view.*

results, the effective width was studied using a CLT-GLT composite T-beam. The material characteristics used for modeling of CLT, LVL, and GLT are presented in Table 3 [7,9-11].

Table 3: Material properties of the GLT, LVL and CLT [7,9-11].

Component	E_L	E_R	E_T	v_{LT}	v_{TL}	v_{LR}	v_{RL}	v_{TR}	v_{RT}
LVL	11000	500	500	0.35	0.03	0.35	0.03	0.35	0.35
CLT's boards	10200	462	462	0.25	0.023	0.19	0.02	0.15	0.23
GLT	12000	530	530	0.35	0.02	0.35	0.03	0.35	0.35
CLT's boards	8000	363	363	0.2	0.018	0.15	0.018	0.21	0.18
CLT's boards	6000	272	272	0.15	0.013	0.11	0.013	0.09	0.13

E = Modulus of Elasticity (N/mm^2)
v = Poison's ratio

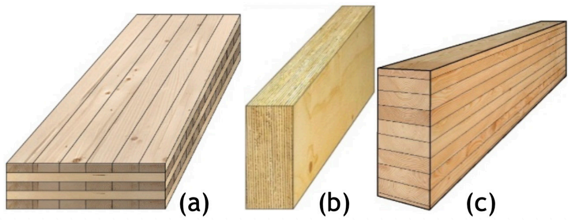


Figure 4: *Engineered wood products: (a) CLT panel (b) GLT beam (c) LVL beam.*

5 FINITE ELEMENT ANALYSIS

The ABAQUS software package version 6.13-3 was chosen to evaluate the stresses in a simply supported T-beam. A 3D sketch and a typical finite element mesh are shown in Figure 5. A 8-node element in ABAQUS (C3D8R) which is a linear 3D solid element with appropriate mesh was adopted for the T-beam with the actual geometry. The screws are defined as steel bar elements which are embedded in slab and beam to connect two parts. [14,15]. The FE model was used to investigate the effect of the arrangement of the longitudinal and transverse layers with two different material properties on the effective width flange. The hinge-roller boundary supporting conditions were modeled by restraining the nodes corresponding to the support points. An incremental single point-load over the top surface of the CLT panel was applied with an initial increment of 1 N in the negative Y direction

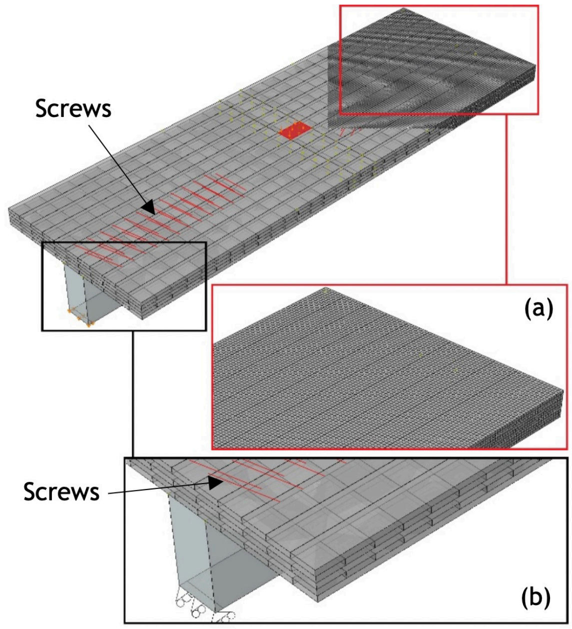


Figure 5: *Typical boundary conditions and finite element mesh used in this study: (a) FE model boundary conditions (Load and support) (b) FE mesh.*

(Figure 5) [16].

The elastic modulus and Poisson's ratio used in the ABAQUS model are presented in Table 3. Figure 6 schematically describes the stress-strain relationship for the materials that were used in the finite element model. Same as the experimental test, the finite element analysis was limited to the elastic domain. This method of testing create the chance to use this expensive test specimen and test set-up again to investigate future details in the timber composite T-beams in future.

5.1 Verification Study

The mid-span deflection of the CLT-LVL composite T-beam which comprised of the CLT and LVL in the FE

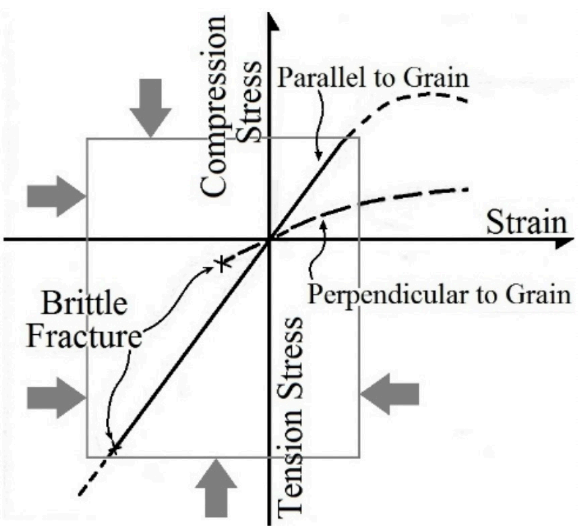


Figure 6: *Stress-strain curve for timber [10].*

model under single point load was compared to the corresponding experimental test result. The results confirm that the FE model is accurate enough for the prediction of the mid-span deflection (Table 4). To increase the accuracy of the FE model, the LVL beam and the CLT panel have been tested separately and obtained results listed in table 4 are used for the FE model.

Another factor that can significantly affect the FE results is the slip between the panel and the beam. These two structural elements are connected in a manner that the resulting composite beam is stronger than the components working together but independently. Therefore, the material properties of each constituent timber product can be exploited more efficiently. The slip obtained from the FE model and the slips measured in the experimental test that have been recorded by 4 LVDTs are summarized in Table 5. It can be seen that the difference between the numerical and experimental results is within an acceptable range which readily demonstrates the accuracy of the FE model.

Table 4: Comparison of the mid-span deflection results.

Test Specimen	$W_{(mm)}\times T_{(mm)}\times L_{(mm)}$	Deflection Experimental	Deflection Numerical
CLT	2030×200×6000	17.9 mm*	17.9 mm
LVL	300×605×6000	3.1 mm*	3.1 mm
CLT composite T-beam	CLT+LVL	1.8 mm**	1.7 mm

W: Width (mm).
T: Thickness (mm).
L: Length (mm).
** Deflection under 50 kN four points loading test.*
*** Deflection under 50 kN single pints loading test.*

Table 5: Comparison of experimental and FE slip results under 50 kN load.

Position of LVDT	Slip (mm) Experimental	Slip (mm) Numerical
At the mid-span	0	0
1m from mid-span	0.056	0.055
2m from mid-span	0.084	0.085
3m from mid-span	0.121	0.122

The numerical model was used to predict the size of the effective flange width. The length of portal gauges used at the midspan and along the width of the CLT slab in the experimental test to measure the stresses is 250 mm (Figure 7). This length is equal to the length of eleven elements in a row in the FE model. Therefore, the average normal stress of eleven elements in the FE model can be compared to the corresponding experimental result. Table 7 summarises the calculated effective flange widths from the FE model and from the test. It can be seen that the difference is less than 2% which validated the accuracy of the FE model. Therefore, the FE model has been used for further parametric investigations on the CLT-GLT composite T-beams.

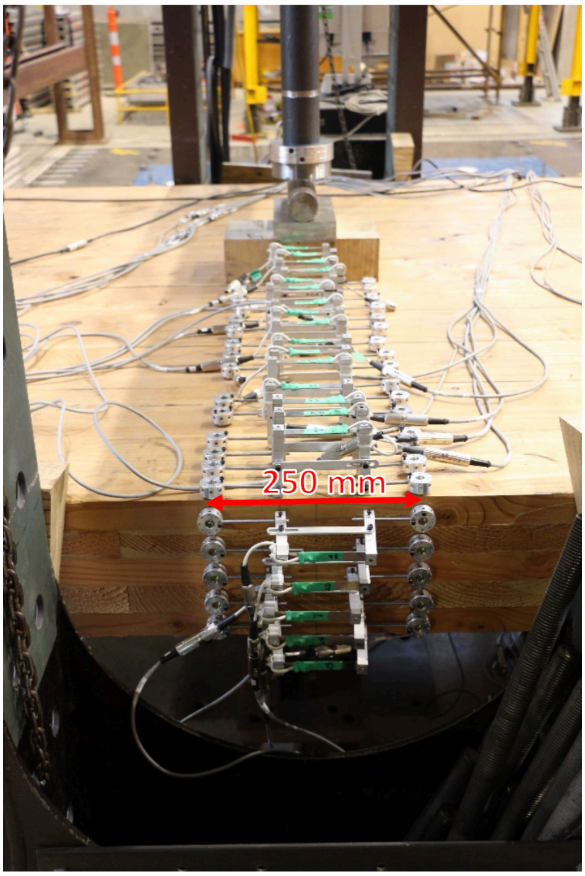


Figure 7: *Displacement measurement to calculate stresses.*

Table 6: Comparison of the experimental and the numerical results for the effective flange width [17, 21].

Effective flange width (Experimental)	Effective flange width (Numerical)
980 mm	995 mm

5.2 Finite Element Parametric Study

To investigate the effect of the layer arrangement on the effective flange width of a CLT composite T-beam that is made up of a CLT panel and a GLT beam, a series of finite element models were developed and analyzed. In all simulations, a five layers CLT panel with varying layer thicknesses are modelled. Furthermore, two conventional elastic modulus (8 GPa and 6 GPa) were considered in the models to study the influence of material properties of the boards on the effective flange width. Measured stresses from FE models are used to calculate the effective width flange of CLT-GLT composite T-beam by equation 4 (Figure 8).

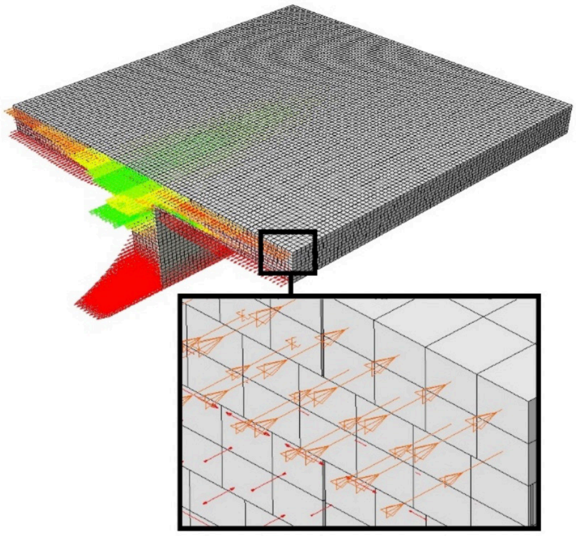


Figure 8: *Stresses measurement at midspan cross-section of Finite Element model to calculate effective flange width.*

Table 7 summarizes the geometrical specification of the CLT-GLT composite T-beams and the numerically obtained effective width. These results are derived from 25 finite element models. The CLT-GLT composite T-beams are comprised of a GLT beam with an elastic modulus of 12 GPa and CLT panels which are made up of boards with 8 GPa and 6 GPa with various layer arrangements. In the model, the panel and the beam are connected together by 48 embedded bar elements to represent the screwed connection.

Figure 9 illustrates the measured effective flange widths in simply supported 6 m beams under single vertical load considering the effect of different thicknesses of transverse layers. It can be seen that an increase in the transverse layer's depth over the longitudinal layer's depth leads to a significant rise in the effective flange width. For instance, when 40 mm longitudinal layers are replaced by 20 mm thick layers, the effective flange width increases about 2.5 times (Specimens No.1 and Specimens No.4 in Table

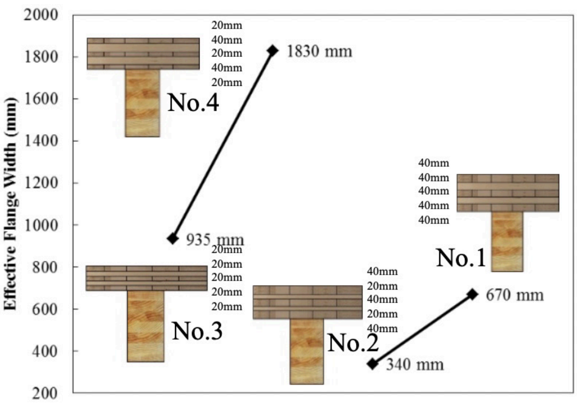


Figure 9: *Effect of transverse layer thickness on effective flange width of CLT-GLT composite T-beam.*

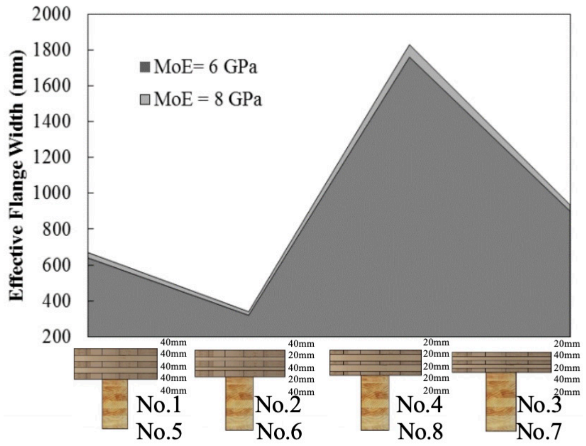


Figure 10: *Effect of CLT panel's material properties on the effective flange width of CLT-GLT composite T-beam.*

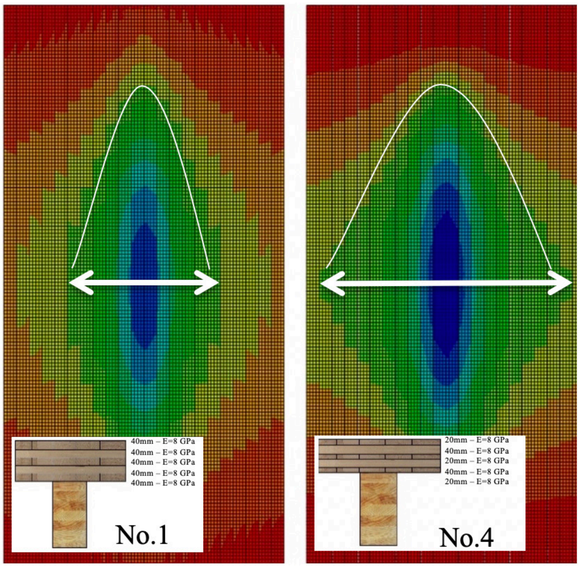


Figure 11: *Comparing the normal stress (S33) distribution patterns of the CLT-GLT composite T-beams in the longitudinal direction (Top view) (Unit is N/mm²) to consider the effect of longitudinal and transfers layers thicknesses.*

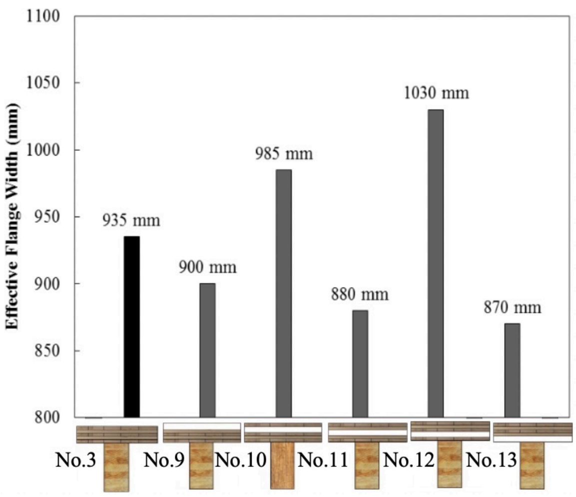


Figure 12: *Effect of the thickness increase of each layer on the effective width flange of CLT-GLT composite T-beam. Only the highlighted layer thickness is changed from 20 mm to 40 mm.*

7). In addition, the effective flange width further increases by 5% when the elastic modulus of the boards is changed from 6 GPa to 8 GPa (Figure 10).

Figure 11 compares the normal stress distribution in the top surface of the two modeled timber CLT-GLT composite T-beams. The wider normal stress distribution (Figure 11) confirms that the higher ratio of transverse layer's depth over the longitudinal layer's depth combined with higher elastic modulus leads to a considerable improvement in the size of the effective flange width (Specimen No.1 and Specimen No.4 in Table 7).

Moreover, six more CLT-GLT composite T-beams were considered individually to investigate the effect of an increase in the thickness of each layer within the CLT on the effective flange width (Figure 12). The reference CLT-GLT composite T-beam model was constructed using a GLT beam with a 630 mm depth and 180 mm width and a five layers CLT panel with 20 mm thick boards (Specimen No.3 in Table 7).

Another six CLT-GLT composite T-beams were modeled to consider the effect of thickness reduction in each layer of CLT on the effective flange width. The results in Figure 13 indicate that the effective flange width declines when the thickness of each transverse layer in CLT panel decreases.

For example, in the sample made up of a five layers CLT panel with 40mm thick boards (Specimen No.1 in Table 7), the effective flange width size dropped by 15 mm (Specimen No.16 in Table 7); and accordingly, a drop of 55 mm (Specimen No.18 in Table 7) is observed when the thickness of the top or bottom transverse layers decreases by 20 mm.

Moreover, to consider the effect of different material properties of the longitudinal and transverse layers in the CLT panel on the effective flange width, two timber T-beams made of CLT panels that have been constructed with two different elastic modulus have been compared. The first beam is made up of a five layers CLT panel consisting of 40 mm longitudinal layers with a modulus of elasticity of 8 GPa and 40 mm transverse layers with a modulus of elasticity 6 GPa. Figure 14 shows that when the arrangement of the layers is reversed, the effective flange width increases 45 mm (Specimen No.19 and Specimen No.20 in Table 7). This confirms that the material properties of the transverse layers in the CLT panels play an important role in determining the effective flange width in the

Table 7: Specifications and effective width flange of the CLT-GLT composite T-beams.

No.	CLT (mm) W×T[1]×L	CLT (GPa) $E_{L1},E_{L2},E_{L3},E_{L4},E_{L5}$	GLT (mm) W×T×L	GLT MoE (GPa)	Predicted effective width flange (mm)
1	2000×200×6000 2000×(40+40+40+40+40)1×6000	8,8,8,8,8[2]	180×630×6000	12	790
2	2000×160×6000 2000×(40+20+40+20+40)×6000	8,8,8,8,8	180×630×6000	12	460
3	2000×100×6000 2000×(20+20+20+20+20)×6000	8,8,8,8,8	180×630×6000	12	1055
4	2000×140×6000 2000×(20+40+20+40+20)×6000	8,8,8,8,8	180×630×6000	12	1950
5	2000×200×6000 2000×(40+40+40+40+40)×6000	6,6,6,6,6	180×630×6000	12	760
6	2000×160×6000 2000×(40+20+40+20+40)×6000	6,6,6,6,6	180×630×6000	12	440
7	2000×100×6000 2000×(20+20+20+20+20)×6000	6,6,6,6,6	180×630×6000	12	1015
8	2000×140×6000 2000×(20+40+20+40+20)×6000	6,6,6,6,6	180×630×6000	12	1880
9	2000×140×6000 2000×(40+20+20+20+20)×6000	8,8,8,8,8	180×630×6000	12	1020
10	2000×140×6000 2000×(20+40+20+20+20)×6000	8,8,8,8,8	180×630×6000	12	1105
11	2000×140×6000 2000×(20+20+40+20+20)×6000	8,8,8,8,8	180×630×6000	12	1000
12	2000×140×6000 2000×(20+20+20+40+20)×6000	8,8,8,8,8	180×630×6000	12	1150
13	2000×140×6000 2000×(20+20+20+20+40)×6000	8,8,8,8,8	180×630×6000	12	990
14	2000×200×6000 2000×(20+40+40+40+40)×6000	8,8,8,8,8	180×630×6000	12	775
15	2000×200×600 2000×(40+20+40+40+40)×6000	8,8,8,8,8	180×630×6000	12	755
16	2000×200×6000 2000×(40+40+20+40+40)×6000	8,8,8,8,8	180×630×6000	12	830
17	2000×200×6000 2000×(40+40+40+20+40)×6000	8,8,8,8,8	180×630×6000	12	735
18	2000×200×6000 2000×(40+40+40+40+20)×6000	8,8,8,8,8	180×630×6000	12	830
19	2000×200×6000 2000×(40+40+40+40+40)×6000	8,6,8,6,8	180×630×6000	12	800
20	2000×200×6000 2000×(40+40+40+40+40)×6000	6,8,6,8,6	180×630×6000	12	845

[1] the numbers in the bracket are the individual CLT layers thicknesses.
[2] the five numbers are the E modulus of each CLT layers.
MoE & E are Modules of Elasticity (Unit is GPa)

CLT-GLT composite T-beams.

In timber buildings, the effective flange width significantly affects the design and consequently the size of structural members. Figure 15 compares the bending stiffness and material consumption in two different CLT-GLT composite T-beams for a 6 m span. Option 2 consists of a 200 mm thick panel and a GLT beam which have been designed neglecting the composite action and option 1 is made up of same elements yet designed as fully composite. The results show that the bending stiffness of option 1 is three times more than that of option 2.

The CLT slab in FE model of option 1 is connected to the GLT beam by embedding 48 screws in the slab and beam. Also, a friction coefficient equal to 0.25 is assigned to the surface between the CLT slab and GLT beam (bottom surface of the CLT slab and top surface of the GLT beam). But in model option 2 the CLT slab and GLT beam are free to perform individually and only a friction coefficient equal to 0.25 is assigned to the surface between the slab and beam.

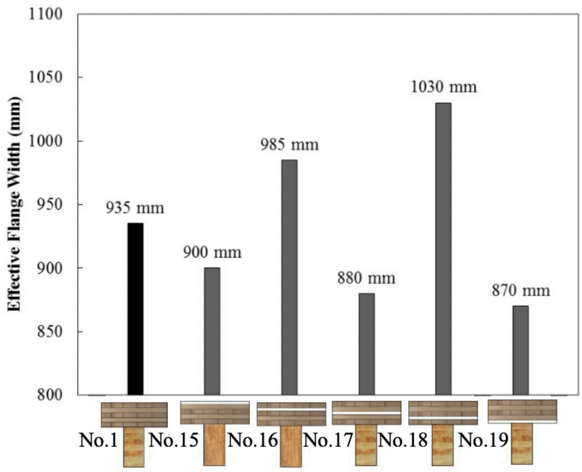


Figure 13: *Effect of the thickness decrease of each layer on the effective width flange of CLT-GLT composite T-Beam. Only the highlighted layer thickness is changed from 40 mm to 20 mm.*

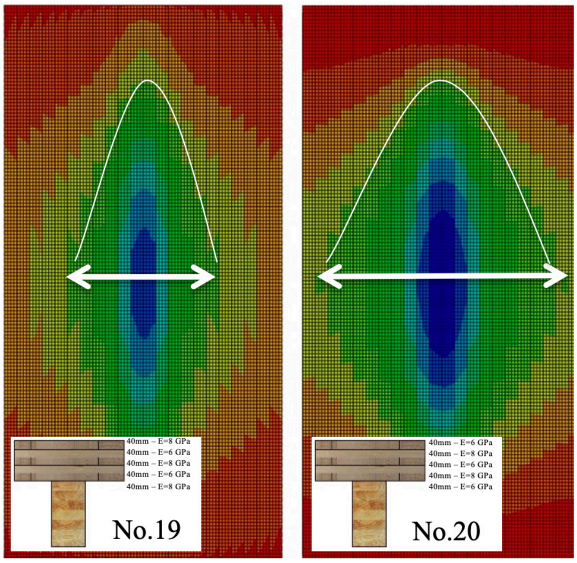


Figure 14: *Comparing the normal stress (S33) distribution patterns of the CLT-GLT composite T-beams in the longitudinal direction (Top view) (Unit is N/mm2) to consider the effect of longitudinal and transfers layers material properties.*

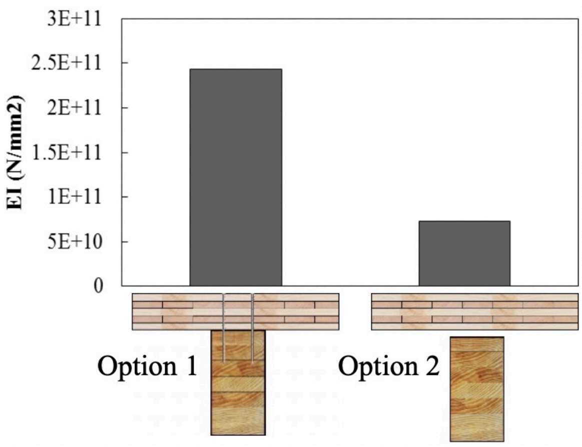


Figure 15: *Effect of composite action on EI value of the CLT-GLT composite T-beams.*

It can be seen that a relatively large CLT panel is required for option 2 to provide a same bending stiffness as option 1. These results confirm that taking the composite action into account significantly reduces the CLT material consumption and also the GLT beam size.

6 CONCLUSION

A detailed numerical model of a CLT-GLT composite T-beam with realistic geometric and material properties was developed to estimate the effective flange width. The accuracy of the numerical model was validated by comparing the experimental values and numerical predictions of the mid-span deflection, effective width flange and the slip between the panel and the beam. Agreement between the numerical and experimental results has provided the foundation for further parametric investigations. The effective flange width of various CLT-GLT composite T-beams was studied by considering various arrangements, the number of layers, thicknesses, and modulus of elasticity of the CLT boards in the numerical model. It has been shown that the effective flange width increases with any changes that lead to an increase in the ratio of the transverse layer's depth to the longitudinal layer's depth. The most significant improvement in effective flange width was observed in the CLT-GLT composite T-beams that used a CLT panel with a maximum ratio of the transverse layer's depth to the longitudinal layer's depth and a higher modulus of elasticity of the bottom transverse layer. Finally, the results indicate that considering the full composite action in the design of the CLT-GLT composite T-beams remarkably decreases the required material and related costs.

7 FUTURE CHALLENGES

Although the objectives of the current research paper were delivered, many more factors remain to consider that can affect the effective flange width of timber composite beams using CLT slab which are listed;

- Further parametric study to find out the effect of material properties in each layer of the CLT panel is required.
- The preliminary FE research study showed that the provided composite action between CLT slab and beam can affect the effective flange width significantly. Therefore, a further parametric

study is required to reveal this effect precisely (Authors are finished experimental and numerical studies and the related results will publish soon).

- Authors have a plane to do another large scale experimental test to study the effect of the plank width of the CLT panels of effective flange width. The CLT slab in the new test specimen support by GLT beam to study effect of the beam on effective flange width although authors predict the size of material of beam doesn't affect the effective flange width as long as the neutral axes remain in the web area.

Finally, in previous publications of this research [17, 21], a simplified formula was recommended to the timber industry to calculate the effective flange width of timber composite T-beams using CLT slab. That formula only recommended for conventional layers configuration of CLT panels. Therefore, authors are working to develop a new formula based further results from more parametric studies which can predict the effective flange width for all possible CLT configurations (The CLT panel with Conventional and non-conventional layers configuration).

ACKNOWLEDGMENTS

The authors would like to thank Milad Naghibi, Daniel Lowe, Behrooz Balaei Langerodi and Soroosh Haji Hosseinnejad for providing ideas and support with ABAQUS. Also, the authors thank photographer and graphic designer, Nariman Valizadeh and Navid Masoudnia for providing great photos and figures.

REFERENCES

[1] AJ Aref, M Chiewanichakorn, SS Chen, I Ahn. Effective slab width definition for negative moment regions of composite bridges, J.Bridge Eng. 12 (2007) 339-349.

[2] B Zou, A Chen, JF Davalos, HA Salim. Evaluation of effective flange width by shear lag model for orthotropic FRP bridge decks, Composite Structures. 93 (2011) 474-482.

[3] C Amadio, M Fragiacomo. Effective width evaluation for steel–concrete composite beams, Journal of Constructional Steel Research. 58 (2002) 373-388.

[4] SS Chen, AJ Aref, M Chiewanichakorn, I Ahn. Proposed effective width criteria for composite bridge girders, J.Bridge Eng. 12 (2007) 325-338.

[5] T Salama, H Nassifb. Effective Flange Width for Composite Steel Beams, The Journal of Engineering Research. 8 (2011) 28-43.

[6] J Castro, A Elghazouli, B Izzuddin. Assessment of effective slab widths in composite beams, Journal of Constructional Steel Research. 63 (2007) 1317-1327.

[7] R Masoudnia, P Quenneville. Stub Girder Flooring System for Timber Construction, Provisional Report (2013). The University of Auckland.

[8] SP Timoshenko, JM Gere, Theory of elastic stability, Courier Dover Publications 2009.

[9] S Gagnon, C Pirvu, CLT handbook: cross-laminated timber, FPInnovations 2011.

[10] AH Buchanan, Federation, New Zealand Timber Industry, Timber design guide, New Zealand Timber Industry Federation 1999.

[11]R Masoudnia, P Quenneville. Stub Girder Flooring System for Timber Construction, (2014). World Conference on Timber Engineering 2014, Quebec City, Canada, 2014.

[12] M Chiewanichakorn, AJ Aref, SS Chen, I Ahn. Effective flange width definition for steel-concrete composite bridge girder, J.Struct.Eng. 130 (2004) 2016-2031.

[13] I Ahn, M Chiewanichakorn, SS Chen, AJ Aref. Effective flange width provisions for composite steel bridges, Eng.Struct. 26 (2004) 1843-1851.

[14] ABAQUS, Theory Manual, Version 6.0, Hibbitt, Karlsson & Sorensen, Inc. 2000.

[15] ABAQUS, User Manual, Version 6.0, Hibbitt, Karlsson & Sorensen, Inc. 2000.

[16] A. Hashemi, P. Zarnani, A. Valadbeigi, R. Masoudnia, P. Quenneville. "Seismic resistant cross laminated timber structures using an innovative resilient friction damping system," Proceedings of New Zealand Society for Earthquake Engineering Conference (NZSEE), Christchurch, New Zealand, 2016.

[17]R Masoudnia, A Hashemi, P Quenneville. Predicting the Effective Flange Width of a CLT Slab in Timber Composite Beams, Proc., Journal of Structural Engineering (2018) 144 (7), 04018084.

[18]DD ENV 1994-2:2001, Eurocode 4. (1994). Design of composite steel and concrete structures. Part 2: Composite bridges and Part 1.1, general rules and rules for buildings, British Standard Institution, London.

[19]CSA (Canadian Standards Association). (2001). Limit state design of steel structures-CAN/CSA-S16-01, CSA, Rexdale, Ont., Canada.

[20]AISC. (2001). Manual of steel construction: Load and resistance factor design, American Institute of Steel Construction, Inc., Chicago, IL.

[21]R Masoudnia, A Hashemi, P Quenneville. Effective Flange Width of a CLT Slab in Timber Composite Beams, the internatonal Network on Timber Engineering Research (INTER 2017), 20-23 Ausgust 2017, Kyoto Japan.