COMPARISON BETWEEN THE VIBRATION PERFORMANCE OF LVL-CONCRETE COMPOSITE (LCC) FLOORING SYSTEM MADE OF MALAYSIAN AND NEW ZEALAND LVL

Lee Yen Fong[1]*, Nor Hayati Abd. Ghafar[1, 2*], Norashidah Abd Rahman[1], Massimo Fragiacomo[3], Zainah Ibrahim[4] & Andrew Buchanan[2]

[1]*Faculty of Civil Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia*
[2]*Dept of Civil Eng., University of Canterbury, Christchurch, New Zealand*
[3]*Dept. of Architecture, Design and Urban Planning, University of Sassari, Italy*
[4]*Dept. of Civil Engineering, University of Malaya, Malaysia*

*Corresponding Author: *yenfong8866@gmail.com*

Abstract: Laminated Veneer Lumber (LVL) was categorized in engineered wood which it can be produced in billets up to 18 m long and 1.2 m wide. LVL is a high stiffness material, almost three times the strength of sawn timber. It is also more reliable and with a higher modulus of elasticity. However, modern technologies led to longer span flooring system, the higher flexibility of the LVL may be susceptible to vibrations of the system. This paper investigates the vibration performance of long span LVL-concrete composite (LCC) flooring system. LCC is a hybrid system made of a concrete slab and a LVL joist, with shear connectors to prevent slip. LVL is extensively used in Australasia as main structure for timber buildings, but not in Malaysia. The LCC was modelled with the finite element software package SAP 2000 v.15 to determine the natural frequency and mode shapes of the specimens. The properties of LVL Malaysian were obtained from mechanical testing and both properties from Malaysia and New Zealand were implemented in the Finite Element (FE) model to compare their vibration performance respectively. Since the flooring system was designed as a lower resonance frequency floor, the results show that the natural frequencies of the modeling are more than 8 Hz. The vibration performances of the floors with New Zealand and Malaysian LVL were found to be greatly similar, with natural frequency of about 9 Hz to 10Hz for 8 m span length respectively.

Keywords: *Laminated veneer lumber, LVL-concrete composite, floor vibration*

1.0 Introduction

Timber-concrete composite (TCC) is an advance materials of flooring system to improve the dynamic and static behavior at serviceability limit state from traditional timber floor. TCC systems are used either to upgrade existing timber floors or for new construction [3]. The combination of timber and concrete provide higher strength and stiffness, better thermal mass and better acoustic separation than traditional timber [1]. TCC structures primarily consist of a concrete slab mechanically connected to a timber joist through the use of connectors [2]. The timber and concrete utilize their best performance as timber is designed to resist tension and bending, while concrete resists compression and bending, and shear is transferred through the connectors [2, 3, 4].

Laminated Veneer Lumber (LVL) is Figure 1 showed a sample of LVL produced in Malaysia from local rubber wood and it is categorized in engineered wood where the material is laminated from rotary peeled timber veneers parallel to grain by adhesive glue for each layer. This product can be produced in billets up to 18m long and 1.2m wide. LVL is specifically produced to reduce the wide variation in timber strength even within the same log. The advantages of LVL also included reduced effects of knots, greater strength to resist splitting and withstand concentrated loads. The strength of LVL is almost three times the strength of sawn timber, and its modulus of elasticity is about 1.5 times higher than sawn timber [5, 7, 8].

Timber structure rarely found in Malaysia, furthermore TCC as well. Since Malaysia have plenty sources of timber, why not utilize our resources for our own country. This paper investigates the vibration performance of long span LVL-concrete composite (LCC) flooring system. LCC is an upgrade of TCC, and is a hybrid system made of a concrete slab and an LVL joist, with shear connectors to prevent slip. LVL is suitable for long span floor system when used as joists due to its high modulus elasticity and higher modulus of elasticity in parallel to the grain direction. Therefore LCC is more suitable than TCC to be used as long span in structure.

Figure 1: Sample of LVL produced in Malaysia

Modern technologies preferred lighter weight and longer span floor systems which brings trouble to vibrations. Activities such as walking, running, jumping and dancing may induce vibrations. Vibrations of floors have been categorized with respect to human response as follows: (a) vibration, though present, is not perceived by the occupants; (b) vibration is perceived but does not annoy; (c) vibration annoys and disturbs; (d) vibration is so severe that it makes occupants ill. To be acceptable, a floor system must fall into the first two categories, and the structural designer needs a criterion to determine the suitability of a proposed floor system [18]. This paper present FE model to investigate the vibration performance of LVL-concrete composite (LCC) flooring system made of Malaysian and New Zealand LVL. The FE model results are compared with the result from experimental tests done by Abd Ghafar [6] using New Zealand LVL showing acceptable approximation. The purpose of this research is preliminary of investigate the experiment of LCC flooring system in Malaysia by using Malaysian LVL in term of vibration.

According to Pavic [11] the comparison of natural frequencies between numerical and experimental tests is acceptable when the highest difference is around 5.8%. Raebel [12] concluded that finite element software packages have adequate power to analyze floor system for vibrations. Dias' [10] paper investigates the accuracy of the results by comparing laboratory observations and numerical simulations of timber-concrete joints. The research of El Dadiry [13] proves that the floor-column model gives the most appropriate representation of the actual structure for studying the dynamic behaviour based on a comparison between the numerical predictions and the corresponding experimental measurements.

2.0 Experimental of LCC specimen

The LCC simply supported T-beam experimentally tested was modeled by Abd Ghafar [6] as illustrated in Figure 2(a). The actual beam size was 8000mm length, 400mm x 63mm LVL joist, 65mm thick and 600mm wide concrete slab. Figure 3(a) showed the simply supported T-beam with roller and pinned support at both end. The position of the notch connectors is represented in Figure 4. The connector was used to connect the LVL joist and concrete topping and prevent the slip modulus on the system. Five rectangular 150x25 mm notches as illustrated in Figure 4 were cut into the top surface of the LVL beam, with reduced spacing at the beam ends to accommodate the greater shear forces at the ends. A 16mm diameter coach screw as shown in Figure 3(b) was used to improve the performance of the connection system. According to Yeoh [9], the shear connectors made of notches cut in the LVL, filled with concrete and reinforced with coach screw are one of the best connectors. The deflection of the composite system can be reduced by using stiff connections. Therefore, the choice of the mechanical connection is crucial to ensure an effective behavior of the composite structures both at ultimate and serviceability limit states [10].The vibration experiments were carried out by an electrodynamic shaker as displayed in Figure 2(b) and accelerometer attached at mid span of the beams. The frequency started from 5 Hz to 25Hz with 1 Hz of increment to develop frequency response functions for the beams. The function of accelerometer was to record the specimen response and a second accelerometer was attached at the inertial mass. Abd Ghafar [6] concluded that the boundary conditions were found slightly affected the dynamic behaviour. There were 3 different boundary conditions beams tested but this paper only reported one end pinned and the other one end with a roller. The experiment of the simply supported beam with one end roller and one end pinned resulted at 9.24 Hz natural frequency.

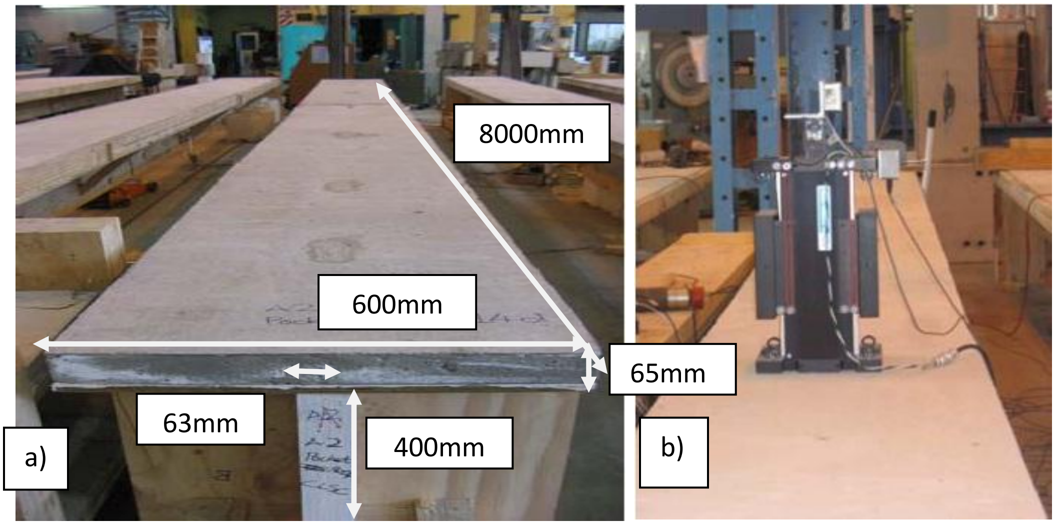


Figure 2: (a) Experimental specimen from previous study [6] (b) electrodynamic shaker used to produce vibration in experiment [6]

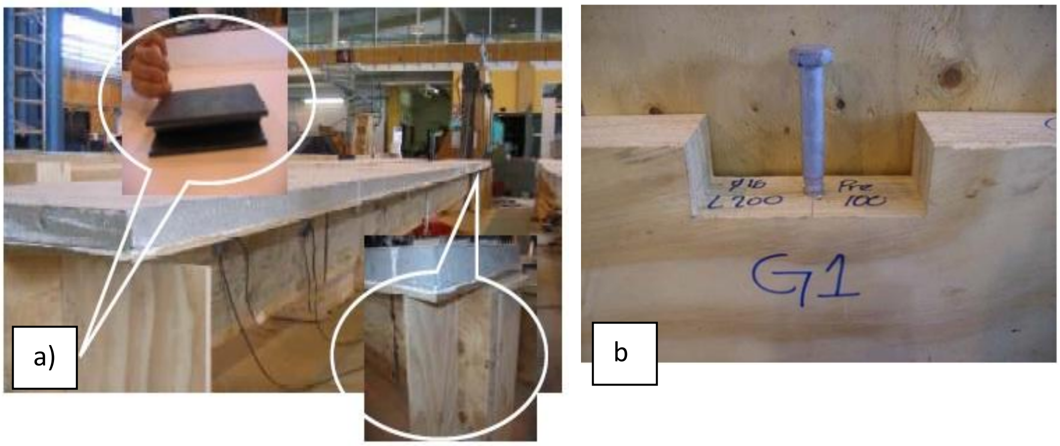


Figure 3: (a) Solid timber block at one end and solid steel roller at the other end of the beam [6] (b) Notch and coach screw on the LVL joist [6]

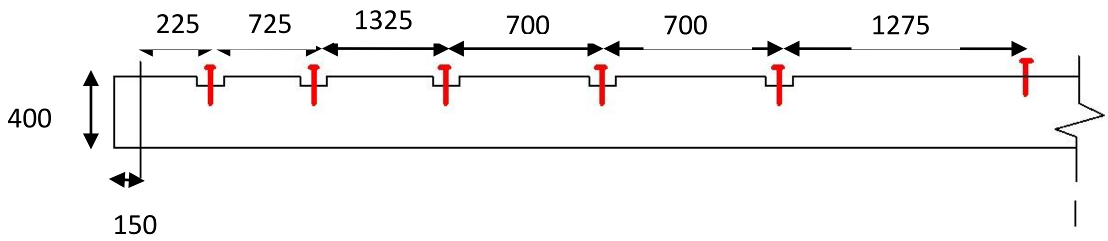


Figure 4: Position of notches and coach screw applied in FE modal 8m span

3.0 LCC modeling

In finite element modelling, the actual object is simplified into simple form of line structure element that connected by nodes. Thus, the shape of the T-beam can be generated by using nodes connected by lines. The model of the TCC T-beam was illustrated in Figure 5, where the concrete slab is schematized with shell elements, and the joist with beam elements. The connector was modeled as link element in SAP 2000. The optimum number of elements for the mesh was determined by increasing the number of shell elements for the slab until no significant variations in the analysis results was found. The best shell element to use is a square size with an aspect ratio of one [15].

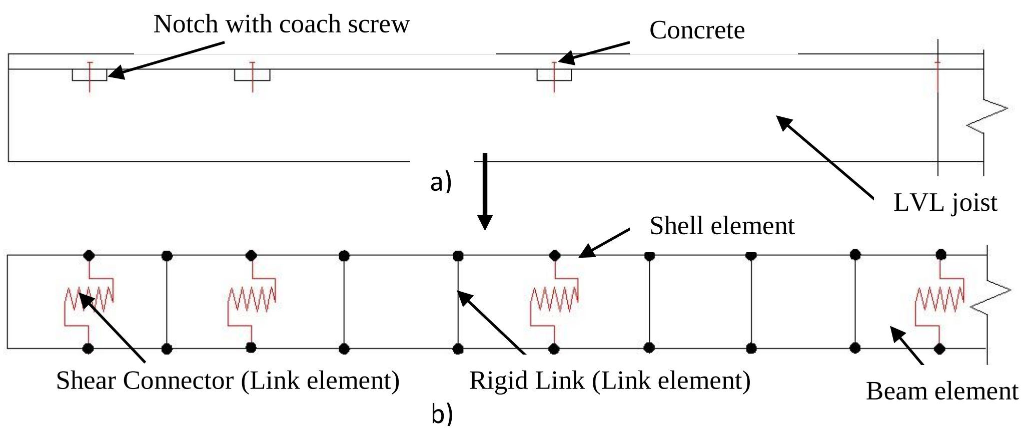
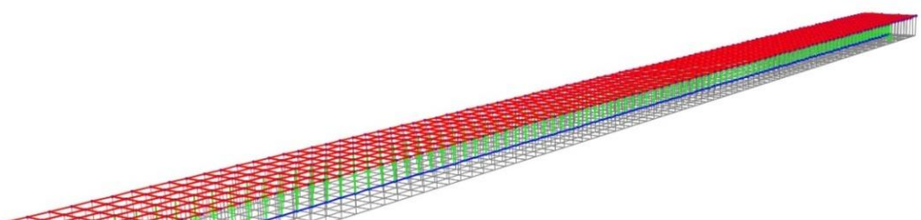


Figure 5: a) Actual span specimen side view b) Beam and shell elements with shear connectors and rigid links

The modeling of LVL (timber) material is slightly complicated than concrete material. It is because of the LVL is categories in orthotropic material in where timber have three planes axes. The modulus of elasticity parallel to grain was inserted in x axes equivalent to longitudinal, other than that the modulus of elasticity perpendicular to grain was inserted in y axes and z axes (radial and tangential) as well. According to Fellmoser and Blab [26] and BS 5268-2 [27], generally the modulus of elasticity perpendicular to grain is factor 30 of modulus of elasticity parallel to grain. The reason for that is timber stronger all the time in parallel direction than perpendicular direction. Shear modulus, poisson ratio and density were inserted in the SAP 2000, respectively. In term of simplicity in finite element model, the LVL joist in finite element model was modeled as beam element in a straight line. Concrete was modeled as an isotropic material by using grade 30 concrete properties. The modulus of elasticity, poisson ratio, density and compressive strength all were refer to EC2 [28]. Then the concrete slab was modeled as shell element because in finite element model the slab was simplified as a plate with mesh. Thus the link elements connected the beam element nodes to center of y axes shell element nodes along the longitudinal x axes. The link elements consist of rigid link and shear connectors. The rigid links were fixed at all the direction whereas the shear connectors were fixed at all the direction except horizontal slip. The reason for that is shear connectors were not rigid at horizontal slip and the stiffness connectors were obtained from push-out test. The rigid links were inserted between the shell and beam element to transfer the loads from the upper part of concrete slab to lower part of LVL joist. Two types of boundary conditions were selected in the simply supported beam. The modeling was applied roller-pinned as support exactly same boundary condition as the experimental LCC beam done by Abd Ghafar [6].

Figure illustrated the 3D view final form of 8 meters TCC T-beam modeling in SAP 2000 software package. The red color mesh represented shell element, whereas the green color represented link element and lastly the blue color represented beam element.



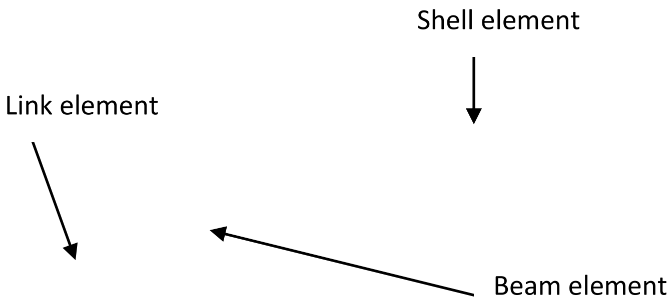


Figure 6: TCC modeling using SAP 2000 software package

The purpose of the numerical simulations is to evaluate the ability of the model to predict the mechanical behavior obtained in the experiment [10]. The LCC T-beam dimension, coach screw material properties, concrete material properties and location of notches remain unchanged as constant variables; the only changing parameter is the properties of LVL. The properties of LVL from Malaysia and New Zealand that have been used are shown in **Error! Reference source not found.**. The LVL from Malaysia is made from Rubber wood that belongs to grade C strength group of light hardwood species and it from category medium to high density with density approximately 900kg/m^3. Each properties of LVL from Malaysia was measured from mechanical testing in according to ASNZS4063.1-2010 [24] standard and the mean value was converted into minimum modulus of elasticity by taking account of probability value and standard deviation which referred to Chik [25]. Whereas LVL from New Zealand is made from Radiata Pine that belongs to grade D strength group of softwood species and is from the category low to medium density with density approximately 600kg/m^3.

Table 1: Material properties of LVL

Type of LVL	Species of veneer lumber	Density	Modulus of elasticity (Parallel)
		D, (Kg/m^3)	E, (N/mm^2)
LVL from New Zealand	Radiata Pine	600	12700
LVL from Malaysia	Rubberwood	900	14327

Types of LVL	Bending strength	Shear in beam	Compression perpendicular	Compression parallel	Tension strength
	f_b (MPa)	f_v (MPa)	$f_{c,90}$ (MPa)	f_c (MPa)	f_t (MPa)

LVL from Malaysia	36.29	2.58	23.72	30.81	14.18
LVL from New Zealand	48	5.3	12	45	33

4.0 Comparison between LVL from Malaysia and LVL from New Zealand

Figure 7 presented the natural frequency of LVL New Zealand concrete composite beam in experiment and modeling is virtually the same. Thus, the outcome of the modeling is acceptable for the differences of 4.45%. The natural frequency of LVL from New Zealand is slightly higher than LVL from Malaysia concrete composite beam with less than 1 Hz. This is because the modulus of elasticity and the mass influenced the natural frequency. Meaning that the lighter weight of the object offer higher natural frequency of the object. Thus the LVL from New Zealand is slightly better than LVL from Malaysia being lighter weight and high strength in terms of properties shown in Table 1. The bending strength, modulus of elasticity and density are important for a beam material. Therefore from the point of view, the New Zealand LVL is slightly better than Malaysian LVL. Although they were from different group strength, but the results presented that the LVL New Zealand produced higher natural frequency. Al-Foqoha'a [19] mentions that a floor with higher fundamental frequency performs better than a floor with lower fundamental frequency. The Figure 7 consists a blue dot line showed the limitation of 8 Hz according to Smith and Chui [20], Ohlsson [21] and Eurocode 5 [22] where they verified the natural frequency of the floor should be at least 8 Hz or greater. However Murray [18] suggested that the structural system should have a minimum natural frequency of approximately 9 Hz to prevent significant resonance problems due to activities such as weight lifting. Most of the problems happen when a forcing frequency is equal or close to the natural frequency of the system. Hence, the design should ensure that the natural frequency of the structural system must be greater than the highest forcing frequency. Since the Malaysian LVL concrete composite span exceeded the 8 Hz limitation, therefore it is passed the requirement of vibration category.

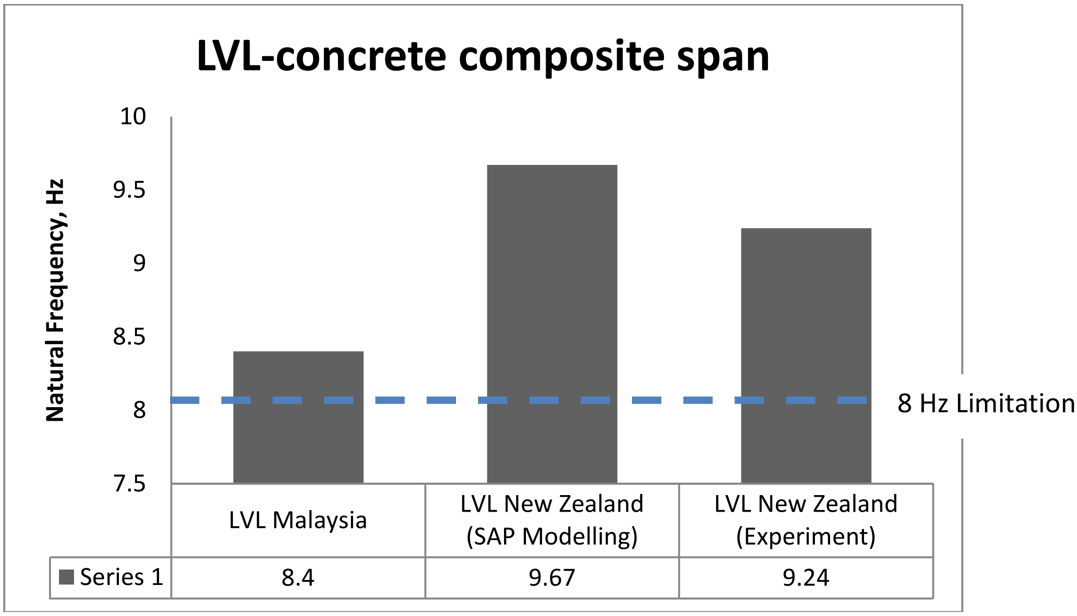


Figure 7: Parameter comparison on LVL-concrete composite span

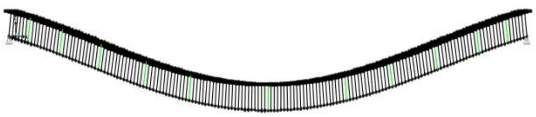
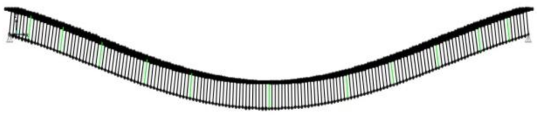
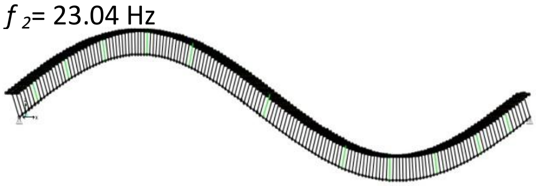
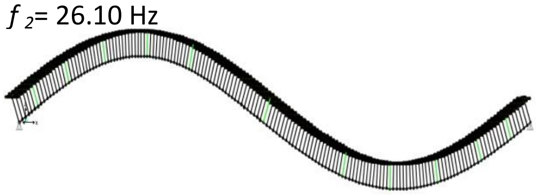
Table 2 presents the mode shapes of the first six natural frequencies of LCC beam with different LVL obtained from SAP 2000 software package. The mode shapes represent a real waveform as simpler sine waves. The half sine shape was obtained for the first mode with the natural frequency; f1 is 8.4 Hz for LVL from Malaysia and 9.67 Hz for LVL from New Zealand. The second mode shapes represented as full sine shape, for each mode as illustrated in Table 2(c) to (f). It can be seen that the natural frequency is not related to the mode shape because each mode shape of simply supported beam generate same pattern wave. The higher modes of natural frequencies were continued with additional half sine shape These mode shapes were similar with the theoretical mode shape of simply supported beam that can be found in Chopra, 2007 [16]. However for full scale flooring system the mode shape will be different. Once the mode shape can be determined, the anti-node can be determined as well. Anti-node located at each the maximum point of deflection amplitude. Alvis [29] mentioned that the best way to solve the vibration problem such as earthquake is by placing the retrofit at the anti-node to limit participation of the vibration.

5.0 Conclusions and Recommendations

The mode shapes of LVL-concrete composite beams made of New Zealand and Malaysia LVL were calculated using a FE model implemented in the software package SAP 2000. A natural frequency of 9.67 Hz was obtained for 8m span length using New

Zealand LVL, where as a natural frequency of 8.40 Hz was obtained for the same span length when using Malaysia LVL. Both TCC systems were lower resonance frequency floor as designed. The most important reason for the slight shift in natural frequency when moved from New Zealand LVL to Malaysia LVL is the different density of LVL even though the modulus of elasticity still affects the natural frequency value. The New Zealand LVL is slightly better than Malaysia LVL having higher bending strength with lighter weight and other properties as well. Nevertheless Malaysian LVL still can be used as joist in LCC beam since the LCC beam fundamental natural frequency exceeded the limitation. The mode shapes of simply supported LVL-composite beam were half sine for the first vibration mode and are continues modes with additional half sine shapes for the higher modes. However the natural frequency is not affecting the mode shapes. As this preliminary investigation of the vibration research on LCC was satisfactory. This research can be continued to full scale of T-beam and full scare of flooring system.

Table 2: Comparison of the first six mode shapes of LCC beam using LVL from Malaysia (left) and from New Zealand (right)

LVL Malaysia	LVL New Zealand
f_1 = 8.40 Hz  a)	f_1 = 9.67 Hz 
f_2= 23.04 Hz  b)	f_2= 26.10 Hz 
f_3 = 48.93 Hz	f_3 = 55.96 Hz

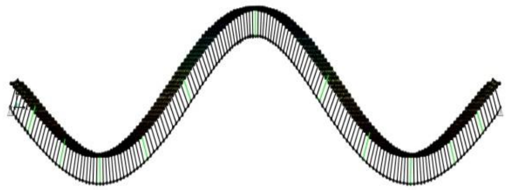
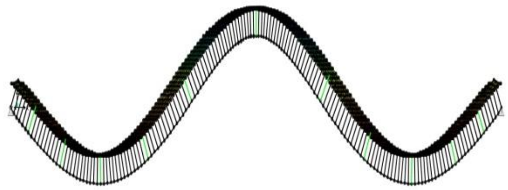
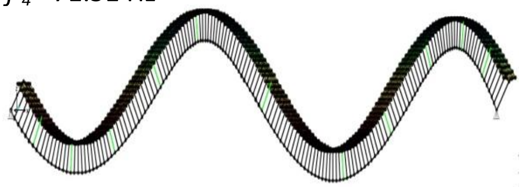
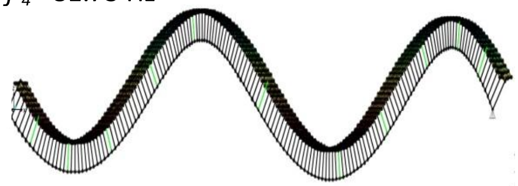
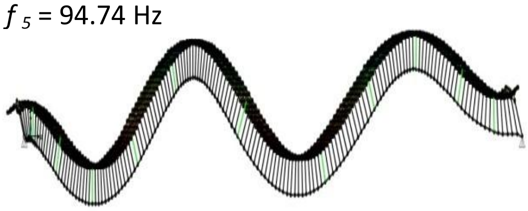
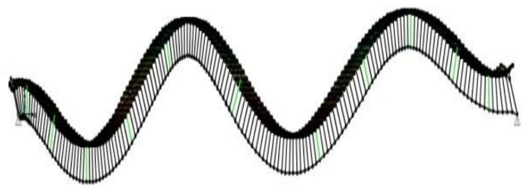
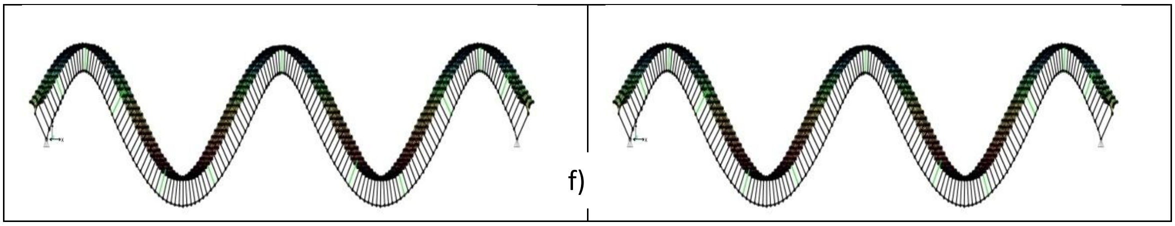
	c)	
f $_4$= 71.51 Hz 	d)	*f* $_4$= 81.73 Hz 

Table 2(cont'): Comparison of the first six mode shapes of LCC beam using LVL from Malaysia (left) and from New Zealand (right)

LVL Malaysia		LVL New Zealand
f $_5$ = 94.74 Hz 	e)	*f* $_5$ = 107.68 Hz 
f $_6$ = 105.68 Hz		*f* $_6$ = 122.03 Hz



6.0 Acknowledgment

The authors would like to acknowledge Universiti Tun Hussein Onn Malaysia (UTHM) for the sponsorship of the article processing fees through the Fundamental Research Grant Scheme vot. 1062 under the Malaysian Ministry of Higher Education.

References

1. Nor Hayati Abd. Ghafar, Bruce Deam, Massimo Fragiacomo and Andy Buchanan (2008), "Susceptibility to vibrations of LVL-concrete composite floors." *VII Workshop Italiano Sulle Strutture Composte*
2. Eric Steinberg, Ricky Selle and Thorsten Faust (2003), "Connectors for Timber-lightweight Concrete Composite Structures." *Journal of Structural Engineering, Vol. 129, No.11, pp 1538-1545*
3. David Yeoh, Massimo Fragiacomo and Bruce Deam (2011), "Experimental behaviour of LVL-concrete composite floor beams at strength limit state." *Engineering Structures 33 (2011) pp 2697-2707*
4. David Yeoh, Massimo Fragiacomo and David Carradine (2013), "Fatigue behaviour of timber-concrete composite connections and floor beams." *Engineering Structure 56 (2013) pp 2240-2248*
5. Nor Hayati Abd. Ghafar (2008). "Forced vibration testing on LVL-Concrete Composite floor systems." *7th fib PhD Symposiumin Stuttgart, Germany*
6. Nor Hayati Abd. Ghafar, Bruce Deam and Massimo Fragiacomo (2009). "Dynamic Measurements of LVL-Concrete Composite Floors" *13th Asia Pacific Vibration Conference, University of Canterbury, New Zealand.*
7. H'ng Paik San, Zakiah Ahmad, and Paridah Md Tahir. Laminated Veneer Lumber from Malaysian Tropical Timber. UiTM Press. 2012
8. Toky O. P. and Arya S. (2005). "Intraspecific Biodiversity in Important Trees of Arid India and Its Conservation." *Bulletin of The National Institute of Ecology 15: 19-24*
9. David Yeoh Eng Chuan (2010). "Behaviour and design of timber-concrete composite floor system." PhD thesis, University of Canterbury, New Zealand
10. A.M.P.G. Dias, J.W. Van de Kuilen, S. Lopes and H. Cruz (2007). "A non-linear 3D FEM model to simulate timber-concrete joints." *Advances in Engineering Software*
11. A. Pavic, Z. Miskovic and P. Reynolds (2007). "Modal Testing and Finite-Element Model Updating of a Lively Open-Plan Composite Building Floor." *Journal of Structural Engineering, Vol. 133, No. 4, pp 550-558*

12. Christopher H. Raebel, Linda M. Hanagan and Martin W. Trethewey (2001). ‘Development of an Experimental Protocol for Floor Vibration Assessment’. *Proceedings of SPIE, the International Society for Optical Engineering* (Vol. 4359, pp. 1126-1132). Society of Photo-Optical Instrumentation Engineers.
13. Emad El-Dardiry, Endah Wahyuni, Tianjian Ji and Brian R. Ellis (2002). “Improving FE models of a long-span flat concrete floor using natural frequency measurement.” *Computers and Structures 80 (2002) pp 2145-2156*
14. Tech Note (2007). Basics of Modal Testing and Analysis. TN-DSA-003
15. Steven R. Alvis (2001). ‘An Experimental and Analytical Investigation of Floor Vibrations’ Master Thesis, Virginia University Institute of Technology.
16. Anil K. Chopra (2007). Dynamics of Structures, Theory and Applications to Earthquake Engineering. Third Edition
17. Massimo Fragiacomo and Ario Ceccotti (2006). “Long-Term behaviour of Timber-Concrete Composite Beams. I: Finite Element Modeling and Validation.” *Journal of Structural Engineering, Vol. 132, No. 1-13-22*
18. Murray, T.M. (1990). “Floor Vibration in Buildings –Design Method”. *Australian Institute of Steel Construction*
19. Arshad A. Al-Foqaha’a *et.al* (1999). “Vibration design criterion for Wood Floors Exposed to Normal Human Activities.” *Journal of Structural Engineering, Vol. 125, No. 12, pp 1401-1406*
20. Smith, I, and Y.H. Chui. (1988). “Design of light-weight wooden floors to avoid human discomfort.” *Canadian Journal of Civil Engineering. Vol. 15, pp 254-262.*
21. Ohlsson S.V. (1988). “A design approach for footstep-induced floor vibration.” *Proceedings of the 1988 International Conference on Timber Engineer Vol. 1, pp. 722-729.*
22. Eurocode 5: EN 1995-1-1: “*Design of timber structures”*
23. Nor Hayati Abd. Ghafar, Bruce Deam, Massimo Fragiacomo and Andy Buchanan (2008). “Vibration Performance of LVL-Concrete Composite Floor Systems.”
24. Australian/New Zealand Standard (ASNZS) 4063 (2010). “Characterization of structural timber”, Part 1: Test methods
25. Engku Abdul Rahman Bin Chik (1988). “Basic and Grade Stresses for Strength Groups of Malaysian Timbers”. Timber Trade Leaflet No.38
26. Fellmoser, P., & Blab, H. J. (2004). Influence of rolling shear modulus on strength and stiffness of structural bonded timber elements. In *CIB-W18 Meeting* (Vol. 37).
27. British Standards Instit., Structural use of timber – Part 2, BS 5268-2, BSI, London, 1996.
28. Eurocode 2 EN 1992-1-1. General Rules and Rules for Buildings
29. Steven R. Alvis (2001). “An Experimental and Analytical Investigation of Floor Vibrations” Master thesis, Virginia Polytechnic Institutue and State University, Blackburg, US.