

Connection performance for LVL-Concrete Composite Floor System

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Abstract. The LVL-concrete composite (LCC) structure is a hybrid in system which the LVL member is well connected to the concrete slab by a connector to produce composite action. Various types of connector with different stiffness and shear capacity are available in the market currently. The stiffness of the connector is identified through the push-out experiment. The notch connections for LVL concrete composite beams have higher stiffness and strength compared to mechanical fasteners. This paper discusses the experimental results of symmetrical push-out tests on 3 different types of connector, 150 mm rectangular notch with 10 mm diameter screw, 100 mm rectangular notch with 8 mm diameter screw and 100 mm triangular notch with 8 mm diameter screw. The experimental test was shear push out to failure and the type of failure was discussed. The 150mm rectangular notch was found to be strongest among all and low cost. The 100 mm rectangular notch was found to be slightly stiffer than 100 mm triangular notch but 100 mm triangular notch is easier to construct with only 2 cut. The maximum strength and stiffness at ultimate limit states and serviceability limit states of each type of connection were discussed in this paper.

Introduction

Timber-concrete composite (TCC) is an upgrade of traditional timber floors to improve the dynamic and static behavior at serviceability limit state. The combination of timber and concrete provide higher strength and stiffness, better thermal mass and better acoustic separation than traditional timber [4]. TCC structures primarily consist of a concrete slab mechanically connected to a timber joist through the use of connectors [5]. 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 [5, 6, 7].

Timber-concrete composite (TCC) systems are used both to upgrade existing timber floors and for new construction [6]. Traditionally, the timber joist for TCC was produced from sawn or Glulam timber to increase the TCC strength, the traditionally joist timber was replaced by engineering timber, Laminated Veneer Lumber (LVL) timber. LVL is an engineered wood material laminated from rotary peeled timber veneers parallel to grain by adhesive glue for each layer. LVL is specifically produced to reduce the wide variation in timber strength even within the same log. Figure 1 shows a sample of LVL produced in Malaysia from local wood. This product can be produced in billets up to 18 m long and 1.2 m wide. The advantages of LVL include 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 [1, 2, 3].



Figure 1 : Sample of LVL produced in Malaysia

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. According to Yeoh [8], 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. To ensure complete composite action with little or no slip at the interface and small deflection, very stiff connections are needed [6]. Therefore, the choice of the mechanical connection is crucial to ensure an effective behaviour of the composite structures both at ultimate and serviceability limit states [9].

The aim of this study to carry out the push-out tests to determine the connector stiffness of LCC, which the LVL was produced by local manufacturer. The types of the connectors were selected as suggested by previous study (Yeoh, 2010). The push-out test specimen consists of concrete, LVL and shear connectors. Wide range of shear connector types were developed in the world mostly in Europe. However, 3 types of connectors were chosen due to the ease of construction and materials availability in market. The function of shear connector is to transmit the shear force between the concrete and LVL.

Previous study on push-out test

There are two chosen push-out types specimen done by Kulhmann and Aldi [10] as presented in Figure 2. Figure 2a) consist of notch meanwhile Figure 2b) consist of rebar. It was concluded that both connection types seem to be suitable for application in TCC structures for road bridges. Besides, both connection types showed high load capacity and notch connection showed high connection stiffness whereas rebar connection only showed 50% of the connection stiffness [10].

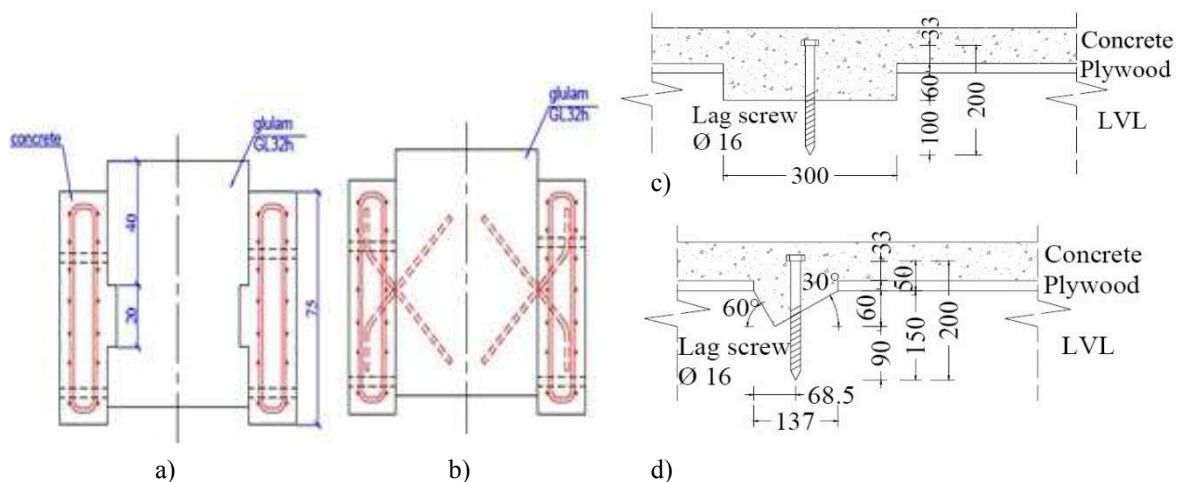


Figure 2: (a) specimen with notch (b) specimen with rebar [10] (c) specimen with rectangular notch and screw (d) specimen with triangular notch and screw [8]

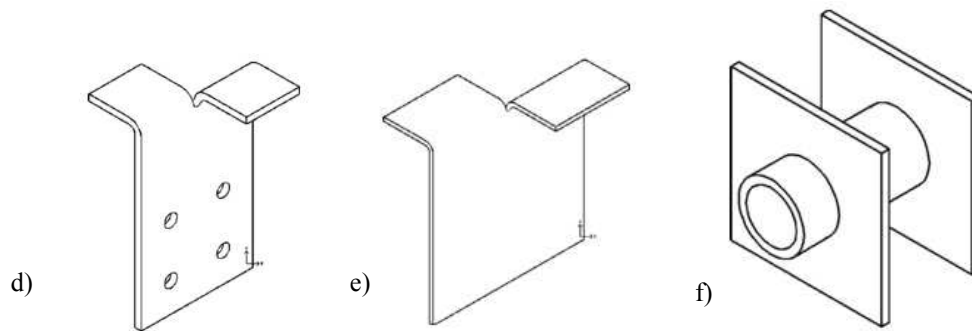


Figure 4: (a) SNP: toothed metal plate folded at 90° (b) SM: steel mesh embedded by epoxy glued (c) SST+S: a long steel tube with a hexagon head coach screw (d) SP + N: two folded steel plates embedded by nail (e) GSP: wide folded steel plate, embedded by epoxy glued (f) ST+S+N: long steel tube with one hexagon coach screw and a notch [16]

GSP connectors is difficult to achieve was proven due to it required to be placed in correct position in the moulding form thus the accuracy required during the prefabrication of the slab. The ST+S+N connector proved it is the strongest among all, however for pre-cast slab, it must be cropped a square to install the connector and fill the square with concrete. The SNP connector only half of the strength compared to ST+S+N connector. The drawback of this system is the complexity of moulding forms and concrete placement during the prefabrication process, no leaking concrete on the teeth plate. The SST+S is the lowest stiffness but using longer screw can lead to higher stiffness. The connector type SP+N is the most simple, economical and moderately stiff. The GSP connector strength is only two-third of the SP+N since they are quite similar and somehow GSP complexity cause it pricey than SP+N. Therefore it can be concluded that SST+S and SP+N are the most suitable connectors for prefabricated timber-concrete composite systems [16].

Push-Out Test specimen

A total of 9 specimens which consists of 3 types of connections were built for the short term symmetrical push out test. The details can be viewed in Fig. 6 (a) to (c). There are 300 mm rectangular notch with coach screw, 150 mm rectangular notch with coach screw and 100 mm rectangular notch with coach screw. The depth of each coach screw embedded in LVL is 100 mm respectively and each type consists of 3 specimens. All the specimens are estimated to be done within 2 months. The purpose of short term symmetrical push out test is to obtain the stiffness of the connection between LVL and concrete. The experiment is carried out by using universal testing machine. All the activities were performed in University Tun Hussein Onn Malaysia (UTHM)'s Structures and Materials laboratory.

Based on the results of the push out tests that had been done by Yeoh [11], among the 15 types of connection system which includes rectangular notched, triangular notched and toothed steel plate, the rectangular and triangular notches embedded with coach screw were an excellent connection system. There are four types of connectors that Yeoh recommended, among those connectors consists of rectangular, triangular and toothed steel plate. However, only two (2) types of connectors that been selected in this study, the rectangular and triangular notches. This is due the difficulty to compress the toothed steel plate between two (LVL) as the equipment is not available in the laboratory. Hence the specimen only focus on rectangular and triangular notch and the only different are length and shape of the notch as shown in Figure 5.

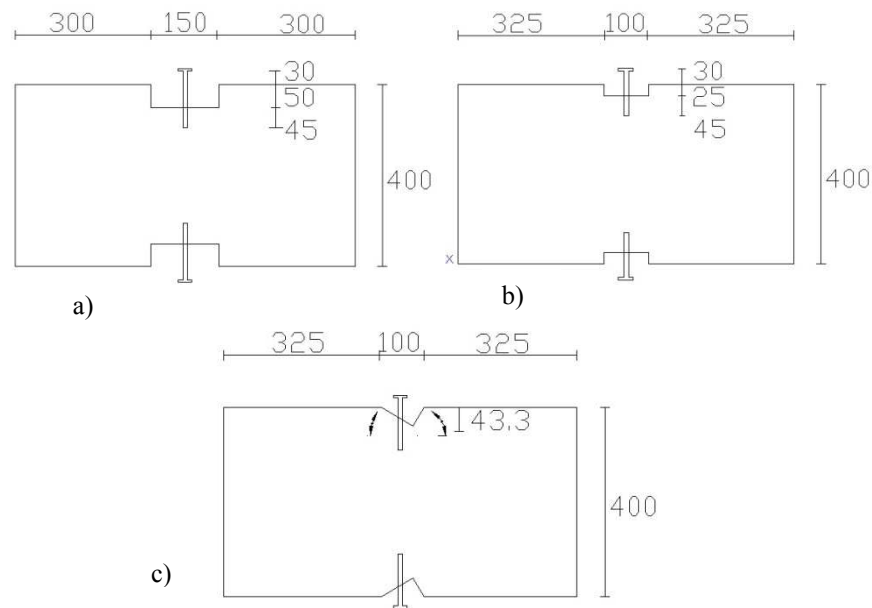


Figure 5: (a) Rectangular notch 150 x 50 x 40 mm with coach screw dia. 10mm (b) Rectangular notch 100 x 25 x 40 mm with coach screw dia. 8mm (c) Triangular notch 100 x 43.3 x 40 mm with coach screw dia. 8mm

The plywood was used as slab formwork base, two pieces of plywood connected perpendicular to the LVL. Notches were cut by portable jigsaw, whereas the predrilled need to be done before insert screw into the notch. Figure 8 presented the reinforcement bars were installed before concreting. According to Valente and Cruz [16], the reinforcement to reduce and control the crack development during the test. In addition, as the reinforcement area increased, the ultimate load increased as well. Concreting notches required extra precaution to allow specimen to achieve higher stiffness.



Figure 6: (a) 8mm reinforcement bar installed (b) Front side of push-out specimen (c) Push-out specimen placed on magnus frame machine

Push-out test set-up

The push-out test experiment was performed in the structures laboratory of UTHM. Each specimen was predrilled with two holes on each side and epoxied with steel rods parallel to LVL. Four Linear Variable Displacement Transducer (LVDT) were mounted on these steel rods at LVL, 2 on each side with the purpose of displacement measurement. Each specimens were located under the 1000 kN capacity Magnus Frame testing machine as illustrated in Figure 7 (a). Two steel strap were installed as shown in Figure 10 to prevent the separation from LVL with concrete and to ensure only slip horizontal occur during the push-out test. The steel plate was placed at the middle of the LVL and the vertical monotonic load was applied at the steel plate.

The loading protocol was according to EN 26891 [17] as illustrated in Figure 7. The estimation maximum load, F_{est} , for each type of the connection was determined by using the previous results of push-out test by Yeoh [8]. The estimation of maximum load only used for first test of each type of connection. The subsequent same type of connection was using the same estimation maximum load if the maximum load is not more than 20% difference. The protocol loading as shown in Figure 7 involved a semi cyclic load whereby the loading is applying until 40% of the estimated ultimate load, paused, reduced to 10% of the estimated ultimate load, paused, and then loading until failure. The purpose of the initial loading and unloading was to eliminate the friction in the connection.

The connections were loaded in shear, the load-slip relationship was recorded using load cell and LVDT 1, 2, 3 and 4. The load cell and LVDT were all connected to the data logger and convert into excel format. The LVDT 1 and 3 were located at same side as left and right shown in Figure 6 (b) where LVDT 2 and 4 at the opposite side of the specimen. The LVDT was checked for functional before the protocol loading start.

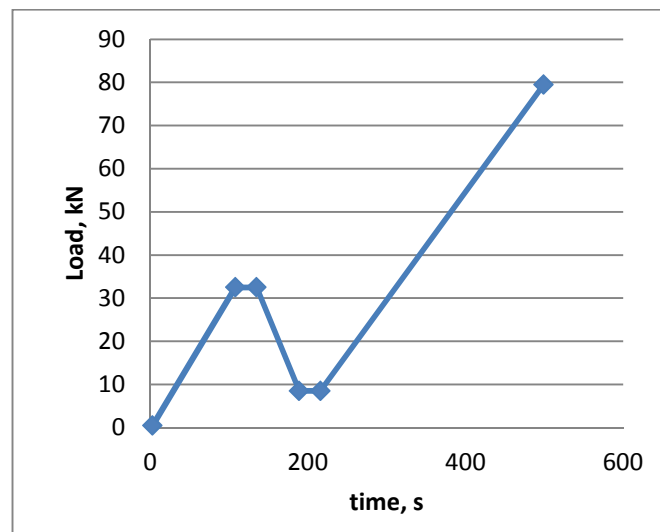


Figure 7: Loading protocol

Push out test data analysis

During the push-out test, the mode of failures and behaviour were observed. All the failure mechanisms were similar. The specimen started to crack on middle region of the concrete slab and the crack continued as the load increased. The cracks location was close to the notch area as presented in Figure 8(c). The concrete in the notches were crushed as well during the test and the gaps between concrete and LVL become visible as shown in Figure 8(a). It can be noticed that the notches were resisting the slip between concrete and LVL. All the screws were bent as displayed in Figure 8(b). This showed that the screws were doing their work to receive the shear load from concrete slab.



Figure 8: (a) The failure of concrete crushing and gap (b) The dowel was bent (c) The concrete slab cracking

The load-slip curve of 100 mm rectangular notch length, 100 mm triangle notch length and the load-slip curve of 150 mm rectangular notch length. The beginning of the test of each specimen exhibited linear-elastic behaviour followed by some degree of plasticity. In general, the 100 mm and 150 mm rectangular notch connections performed well in plastic behaviour as shown in Figure 10 and Figure 12. The plastic behaviour demonstrated the ductile capacity of such connections which is contributed by the presence of the screw.

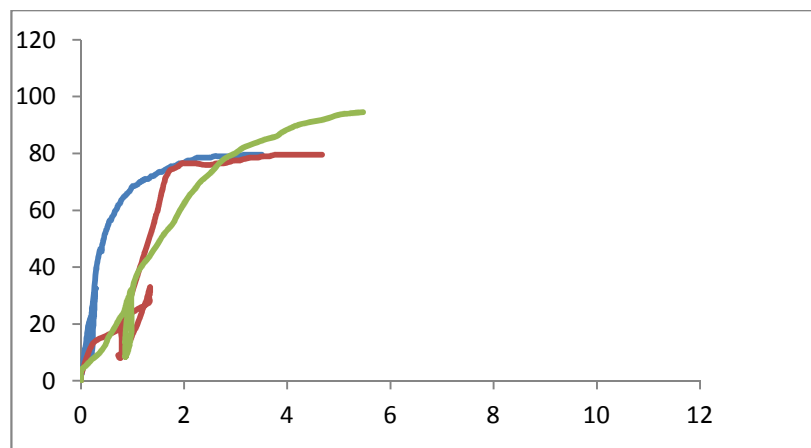


Figure 10 (a): Load-slip curve of 100mm rectangular notch length

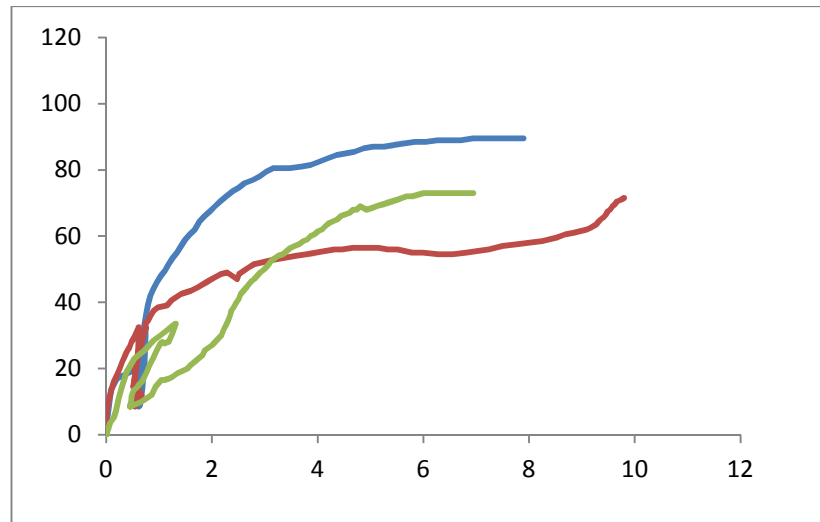


Figure 10 (b): Load-slip curve of 100mm triangle notch length

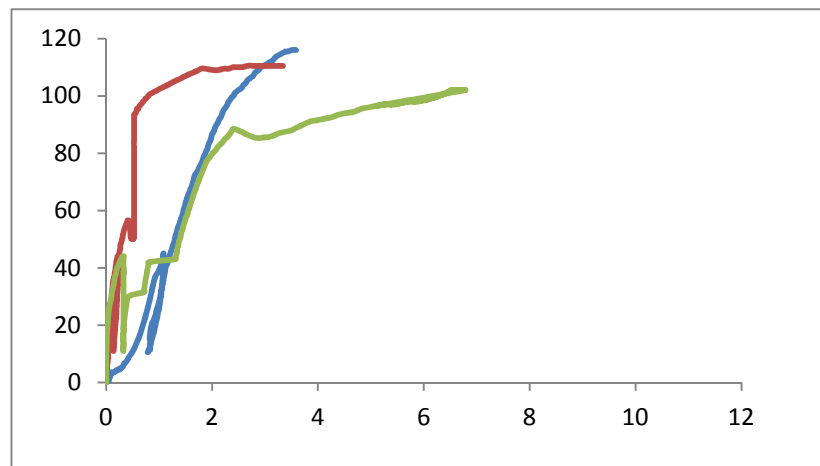


Figure 10 (c): Load-slip curve of 150mm rectangular notch length

Figure 11(a) show the specimens 150R achieved the highest stiffness and ultimate load, but the slip for 150R shown in Figure 11(a) perform excellent as the lowest among all. The specimens of 100R and 100T fall to second and last as it is depend on the area of the notch, respectively. The average slip modulus of connector 150R was almost as high as the connector 100R but connector 100T has a significantly highest slip modulus.

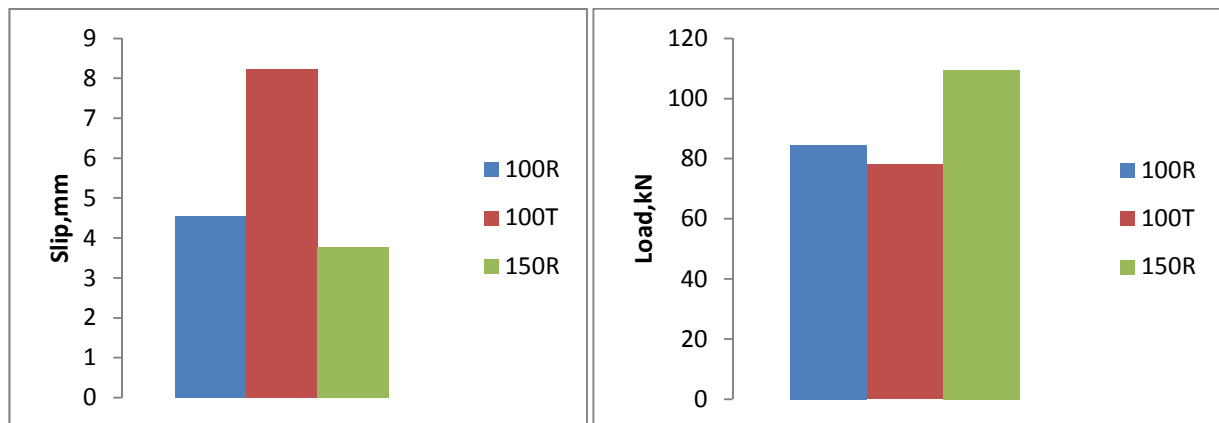


Figure 11: (a) Average slip of each type connector (b) Average max load of each type connector

Table 1 presented the result summary of single notch with screw. According to the slip modulus at serviceability limit state ($K_{s,0.4}$), the larger 150 mm rectangular notch with larger screw dia.10 mm

rank as winner with 39.36 kN/mm, the 100 mm rectangular notch with dia. 8mm rank as silver with 15.9 kN/mm and the triangular notch with dia. 8 mm rank the last with 15.54 kN/mm which the silver only slightly better than the last. It showed that 100T is better than 100R in term of ease of construction with two cut profile.

Table 1: Summary of the push-out test results

			Notch D10 50x150 150R	Notch D8 25x100 100R	Notch D8 100 (30° & 60°) 100T
Maximum strength	F_{max}	kN	54.75	42.25	37.08
SLS Stiffness	$K_{s,0.4}$	kN/mm	39.36	15.9	15.54
ULS Stiffness	$K_{s,0.6}$	kN/mm	24.71	17.34	13.78
Collapse Stiffness	$K_{s,0.8}$	kN/mm	22.58	16.81	14.49

Conclusion and recommendation

This paper presented an experimental study on three (3) different connector types for LVL –concrete composite structure. All the specimens were tested until failure. The shear strength and slip modulus results were presented and discussed. Although the push-out specimens in this investigation differ from Yeoh's specimens [11] in terms of LVL timber species, LVL size, smaller concrete thickness and smaller diameter of screw, the findings of this investigation are consistent with Yeoh's [11] in that longer notches resulted in greater shear strength, and similar mode of failure were observed. Based on the consideration reported above, the 150mm rectangular notch was recommended for greater strength and 100 mm triangular notch was recommended for fast production due to its two cut profile. The shear strength of 100 mm triangular notch and 100 mm rectangular notch does not vary considerably. Therefore, 150 mm triangular notch is recommended for use and for future experimental studies.

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