World Conference on
Timber Engineering
Oslo 2023

HIGH CAPACITY SHEAR CONNECTORS AND APPLICATION FOR TIMBER-CONCRETE BRIDGES

Raitis Lacis[1], **Maris Karlsons**[2]

ABSTRACT: This paper describes the experimental study of a new hybrid type shear connector for timber-concrete composite systems. The main emphasis of the study is the development and testing of high capacity shear connectors and their use in timber-concrete systems associated with high structural demand for composite interaction such as vehicular and pedestrian bridge structures. Experimental pushout test data of a hybrid shear connector is presented along with the full-scale bridge design and testing using this shear connection system. Shear connection consists of two main parts welded together: a circular hollow section (CHS) and a common steel nail plate. The first part is considered a rigid dowel, but the addition of the nail plate considerably improves the redistribution of the shear forces to a larger area of the timber body, thus minimizing the risks of high concentration shear-induced damage locally if only dowel is used. Based on the test results, a single span timber-concrete vehicular bridge design and load-proof aspects are briefly discussed, including factors of different loading effects and construction methods.

KEYWORDS: Bridge, Timber-concrete composite, Shear connection, Circular hollow section, Nail plate

1 INTRODUCTION

Appropriate choice of the shear connector configuration is crucial in order to provide effective degree of composite action between timber and concrete structural parts such as beams and slabs. Vehicular bridges have to sustain relatively high concentrated loads both in the ultimate state as well as at the service level. As a result, timber-concrete systems require special attention to the shear connection used because of it directly depends the vertical deformations and overall stress state of timber/concrete components.

In order to level up the ability of timber-concrete systems to compete with other structural formulas, it requires to develop shear connectors, that both have high stiffness and high strength so that they not limit the overall design of the structure.

Many types of timber-concrete shear connectors have been tested during the last two decades [1]. These include different combinations of notched, screwed, dowel-type and adhesion based connections generally subtyped as continuous or discrete shear connectors [2]. The purpose of this paper is to present a hybrid type of connection, that employs two of the aforementioned principles by using a large diameter dowel in the form of a circular hollow section (CHS) filled with concrete [3] in combination with a widely known industrial product, punched nail plate (see Figure 1 and 3) representing the semi-continuous part of the connector.

The proposed connector's experimental push-out testing results are presented, including shear stiffness, ultimate strength, failure character, and specific sample preparation aspects that were taken into account to achieve failure, particularly in the shear mode along the wood grain. Particular investigation results were directly used in the design, construction and proof loading of a single span vehicular timber-concrete bridge. A quantitative discussion is given to demonstrate the importance of chosen construction method for the timber-concrete composite bridge, which is already at the design stage. For instance, temporary construction propping or no propping affect the magnitude of shear forces in the connectors, the permanent self weight induced stresses of beams/slabs and overall structural stiffness.

2 MATERIALS AND TEST SETUP

2.1 CONFIGURATION OF THE CONNECTOR

Hybrid connector consists of the steel nail plate and circular hollow section (steel CHS), which are welded together in 90° configuration (Figure 1). Connector is pressed into the predrilled slot of the timber beam and hollow section is consequently filled with the concrete during the deck construction process in such a manner that no steel parts are exposed to the direct environmental impacts. Timber and concrete penetrating part of CHS dowel serves well for the transfer of shear force in the concrete deck and provides stiffness due to its volume and relatively large contact area, but the nail plate effectively distributes these forces in the timber with the help of many small sized but high number of nails. Besides, as the steel CHS element extends also in the timber then it functions as a circular notch and thus providing extra stiffness. (Figure 2b).

---

[1] Raitis Lacis, Inzenierbuve LTD., Latvia, raitis.lacis@inzenierbuve.lv
[2] Maris Karlsons, JMR-Frame LTD., Latvia, maris.karlsons@jmr-frame.lv

https://doi.org/10.52202/069179-0436

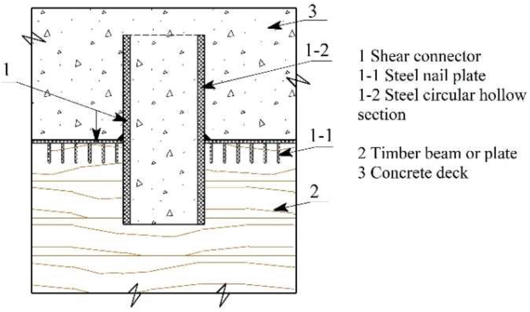

Figure 1: *Cross section of the nail plate/CHS shear connector*

Figure 2: *a) single connector; b) predrilled slots in the timber; c) timber beams with pressed-in shear connectors*

For less demanding shear systems a variation presented in Figure 2 appears to be more practical due to its simpler application, however, research of this layout is outside the scope of this publication and is reserved for future investigations [3].

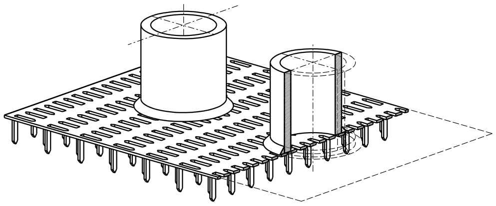

Figure 3: *Variation of shear connector without CHS extension to the wood*

2.2 PREPARATION OF THE SAMPLES AND TESTING PROCEDURE

Samples for the laboratory push-out testing in shear were prepared using symmetrical test layout depicted in Figure 4 and 5. This employs two identical slip surfaces constituting two shear planes each of which characterizes individual shear connector. Shear connectors and sample dimensions were chosen to represent the design of full-scale bridge, which was intended following the current research.

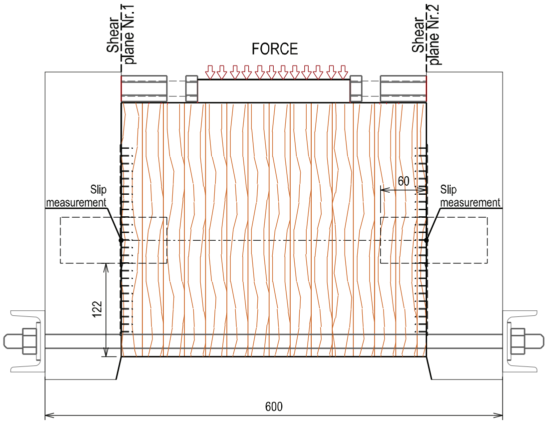

Figure 4: *Layout of the sample*

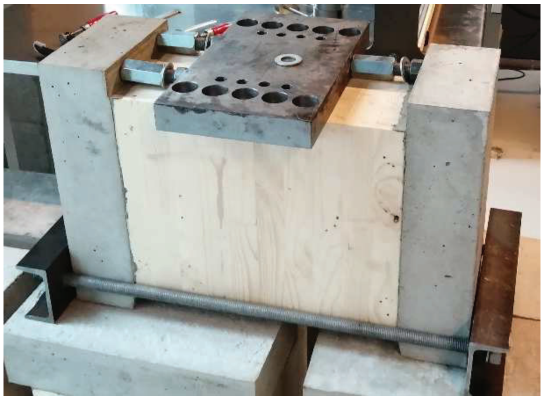

Figure 5: *Setup of the sample*

General characteristics of the materials used:

Timber class GL24h according to [5], moisture content 8-11%;

Concrete class C35/45 [6];

Steel class of circular hollow section S355, diameter 60mm, wall thickness=3mm;

Nail plate Wolf 15N [7], steel class S280, size 175×250mm.

The test timeline and loading schedule followed the routine of EN 26891 [8], see time-load history in Figure 6. Loading machine Zwick/Roell Z600.

Number of specimens: seven (one of which were predamaged).

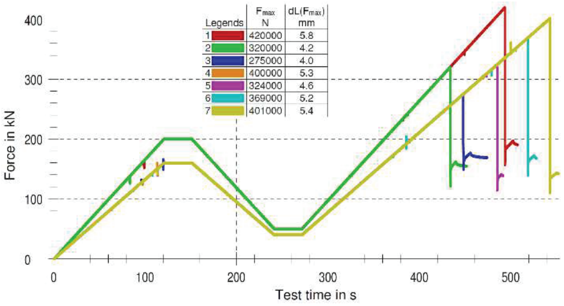

Figure 5: *Time-load history of the samples tested*

Special attention was paid in the sample preparation process in order to avoid unnecessary mechanical restraining effects during the loading. When applying vertical force to the timber upper face, horizontal reactions at the top and bottom of the sample develops, which tend to split the sample at the bottom and push it together at the upper part. As a result, compression fixings were used at the top level and tension rods at the bottom. Steel plate for the force distribution at the top was chosen such that expected failure of the shear plane is not crossed over and failure in pure shear could be objectively expected.

3 RESULTS OF PUSH-OUT TESTS

3.1 Ultimate shear capacity and stiffness

Values of ultimate shear capacity varied from 275kN to 420kN (see Table 1). The lowest value 275kN represents the sample Nr.3, which was predamaged, but still tested for the sake of interest. All of the seven samples failed in a brittle manner (Figure 6).

Table 1: *Shear capacity, slip and stiffness results of push-out tests*

#	F_{max} * [kN]	Slip at 0,6F_{max} [mm]	Slip at 0,8F_{max} [mm]	Stiffness at 0,6F_{max} [kN/mm]	Stiffness at 0,8F_{max} [kN/mm]
1	419,8	0,9	1,4	134,7	117,8
2	319,6	0,8	1,1	125,7	119,4
3	274,9	0,6	0,9	134,1	125,5
4	400,0	1,1	1,4	114,3	111,1
5	324,3	0,7	1,1	130,1	115,8
6	369,1	0,8	1,2	138,4	127,3
7	401,0	0,9	1,3	133,7	122,4

*F_{max} results are presented for the symmetric sample layout (two connectors per sample)

**Slip and stiffness values calculated as an average from two of the connectors forming one test sample. In all tests only one side failed

For each sample, the slip values between timber and concrete were measured during the loading. Due to the minor geometrical and material variation the slip values always differed for the two shear connectors of the sample (example in the Figure 6), therefore for all the samples a complete failure only occurred in one of the shear plane, the other in all cases remained intact.

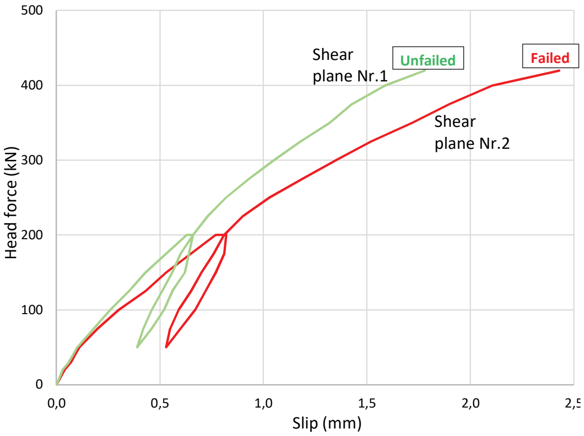

Figure 6: *Slip - load values (example of one sample)*

Failure mechanism observed was in pure shear by the block shear failure in wood depicted in Figure 7 and 8. Extension of the CHS element in the wood demonstrates provision of extra stiffness and strength as the line of the failure copies CHS profile in all of the samples. Physical deconstruction (Figure 9 and 10) of the failed sample indicates some plastic deformation in front of the CHS profile (compression perpendicular to the grain) before wood failure in shear along and mostly between the annual rings takes place. Notably that CHS element is relatively intact and only outer nails of the plate are visibly deformed after the ultimate slip of the shear surface in the wood.

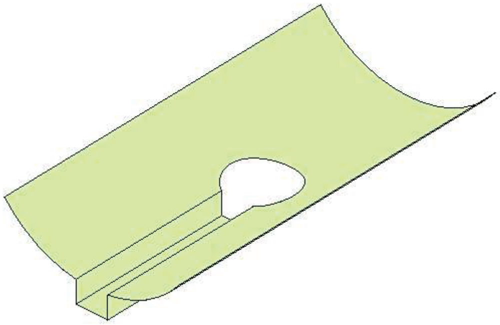

Figure 7: *Typical shear failure plane*

https://doi.org/10.52202/069179-0436

Figure 8: *Top and bottom surface after the failure*

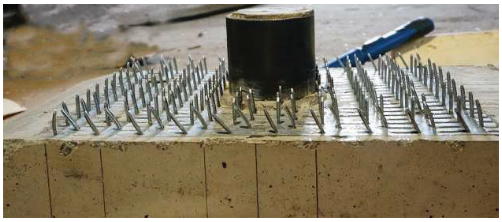

Figure 9: *Condition of the connector after the failure (wood part removed)*

Figure 10: *Compression by the CHS element perpendicular to the grain*

4 APPLICATION OF TEST RESULTS IN THE DESIGN OF TIMBER-CONCRETE BRIDGE

Laboratory tests of the shear connectors were preliminary part of the timber-concrete bridge design process during which all of the necessary data in terms of connectors stiffness and strength were acquired. Once these were established a design of the the full-scale bridge could be carried out. Structural model was build using 2D beam elements following the grillage modelling principles. Timber and concrete cross sectional parts were placed by appropriate eccentricities and interconnected with spring elements [12] characterised by the stiffness values established from the connector's push-out tests.

Figure 11: *Jecupe bridge in a construction stage and in a finished state*

The bridge consists of ten individual laterally braced glulam beams (GL28h 750×220mm) and cast-in situ concrete deck (C35/45). Length of theoretical span is 12,80m (Figure 11, 12); minimal design load is heavy-duty forestry vehicles up to 60t. Concreting of the deck was done using temporary propping beneath the glulam beams. Bridge is named after the river it is crossing (*Jecupe bridge*) - it was successfully built and load-proofed in 2020, location Nica parish, Latvia) proving to a client (Latvia's State Forests) that rationally approached timber-concrete systems can be a competitive option for the bridge inventory.

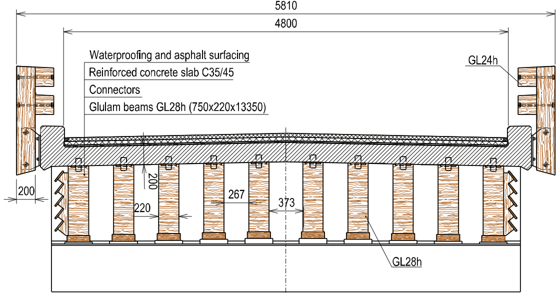

Figure 12: *Cross section of the bridge*

Load-proofing procedure included symmetrical and asymmetrical quasi-static load schemes using 40t five axle vehicle. Load effects were controlled by vertical deformation measurements and strain gage system installed on the lower face of the timber beams at midspan. Beam stresses were calculated based on the continuous strain measurements (Figure 13), which approved satisfactory load distribution and stiffness across the beams.

Figure 7: *Load-proof with 40t vehicle*

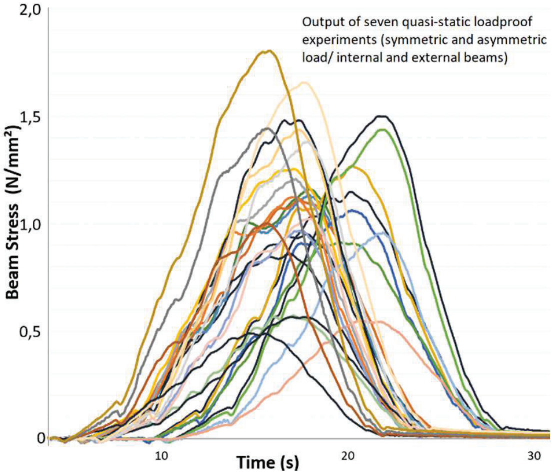

Figure 13: *Calculated beam stresses (based on recordings of strain gages)*

Figures 14, 15, 16, 17 summarises main load effects for different design and load-proof situations. Main differentiation is made between different construction methods (temporary propping and no propping) and different load models including Load model 1 (α=0,8). Also load effects of theoretical non-composite situation is given in order to emphasize the importance of shear connectors in timber-concrete composite systems.

Maximum shear (Figure 14) force in the connectors according to the design model were purposefully kept low due to the brittle character of the connection region as established in the laboratory tests. For instance, maximum value of Eurocode ultimate limit state shear force in the connectors zone using Load model 1 (α=0,8; γ_{LM1}=1,5) did not exceed 56 kN. However, at everyday service levels (60t wood harvester and 40t five axis vehicle) as demonstrated in the calculations and load-proof situation the total self weight and live load connectors shear force maximal range is 14 kN to 28kN depending on the vehicle and live load placement relatively to the longitudinal axis. Highest beam stresses registered in asymmetric load-proofing did not exceed 1,8 MPa. According to the design model stresses of similar category are in the range of 2 MPa.

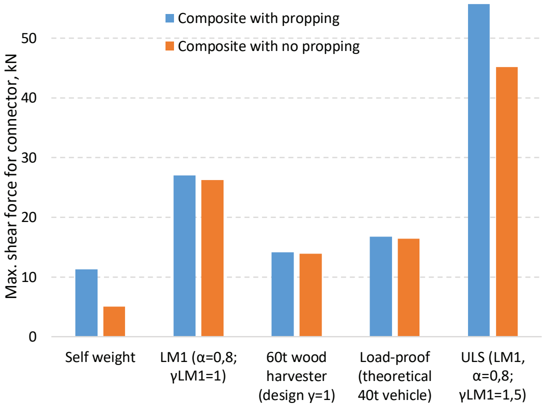

Figure 13: *Comparison of maximal shear forces of connectors*

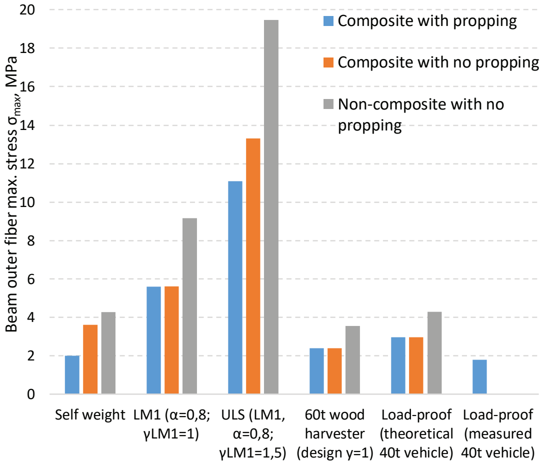

Figure 14: *Maximal beam bending+tension stresses*

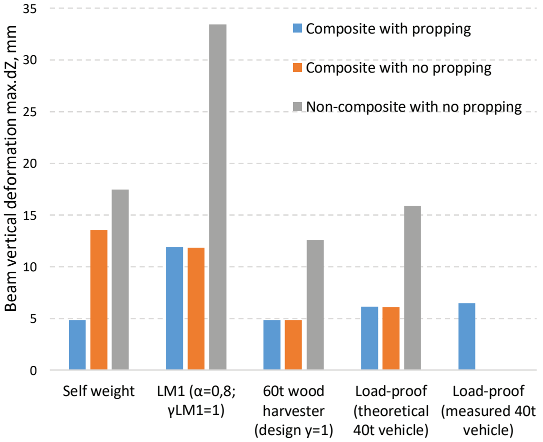

Figure 15: *Comparison of vertical deformations*

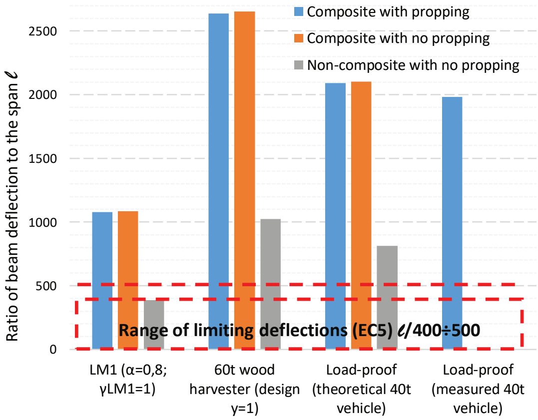

Figure 16: *Serviceability criteria of vertical deformations*

As for the deflection category, the lowest vertical deformations (Figure 15) are achievable using temporary propping construction method naturally on the expense of increased shear forces. Figure 16 represents levels of serviceability for different live load situations. For this shear connection and bridge design a deflection criteria of EC5 serviceability is fully satisfied ranging from 1/1080 for the LM1 and 1/1983 for the load-proof 40t vehicle (Figure 16).

5 CONCLUSIONS

Experimental testing demonstrated high strength and stiffness of the proposed hybrid shear connectors. Their applicability to the road bridges with design loads of up to the Load Model 1 (α=0,8) has been presented. Different construction methods and impact on the shear connectors utilisation and general stress state of the timber-concrete bridge was quantitatively discussed acknowledging potential use of the hybrid shear connectors in other bridge design situations.

REFERENCES

[1] Rodrigues J., Dias A.; Providencia, P.: Timber-Concrete Composite Bridges: State-of-the-Art Review. Bioresources. Vol.8, No.4. 6630-6649. 10.15376/biores.8.4.6630-6649, 2013.

[2] Riestra F.S., Cimadevila J.E., E. Martín-Gutiérrez E.M., Chans D.O.: Perforated shear + reinforcement bar connectors in a timber-concrete composite solution. Analytical and numerical approach. Composites Part B Engineering. 10.1016/j.compositesb.2018.08.074, 2018.

[3] Lacis R.: Shear connector of the timber-concrete composite systems consisting of punched metal nail plate and steel hollow section. Patent office Republic of Latvia. Application Nr.LVP2021000008, 2020.

[4] EN 14080:2013. Timber structures - Glued laminated timber and glued solid timber, 2014.

[5] EN 1992-1-1:2004 Eurocode 2: Design of concrete structures, 2015.

[6] Deutsches Institut für Bautechnik (DIBt): Technical approval Z-9.1-210. Wolf-Nagelplatten Typ15N, 15 NE,15Z und 15 ZE als Holzverbindungsmittel, 1997.

[7] EN 26891:1992 Timber structures - Joints made with mechanical fasteners. General principles for the determination of strength and deformation characteristics, 1992.

[8] EN 1995-2:2005 Eurocode 5: Design of timber structures - Part 2: Bridges

[9] Girhammar U. A.: Nail-plates as shear connectors in composite timber and concrete structures. IABSE 12th Congress, Vancouver, Final Report,pp. 961-968, 1984

[10] [10] Van der Linden M.:. Timber-concrete composite beams. HERON. Vol. 44. No.3 (1999) ISSN0046-7316

[11] [11] Aicher S., Klöck W, Dill-Langer G., Radovic B.: Nails and nailplates as shear connectors for timber-concrete composite constructions, Otto-Graf-Journal Vol. 14, 2003

[12] Midas Civil software manual, 2023