Shear Connection of Cross Laminated Timber to Steel Beams with Gangnail Plates

Christopher Jarvis, Buick Davison, Kwesi Okutu

Abstract

Timber is seen as a "green" material as it can be a sustainable material, therefore in recent years it has been in increased demand. Recently the technology and design philosophies behind the use of Cross-Laminated Timber (CLT) have made it an alternative building material. The hybridisation of structures using Cross-Laminated Timber and a steel or concrete frame has become an area of interest due to the "green" aspect and the total weight of the structure will likely be less than a comparable steel-concrete composite frame.

A poorly researched area is that of composite action between a steel beam and CLT flooring where at present only non-composite action is considered. Therefore this research will investigate the level of composite interaction achieved between a steel beam and Cross-Laminated Timber flooring using a Gangnail plate (GNP) shear connection as commonly used in trusses. The research undertaken is in the form of experimental results that will explore the basic principles of this idea and a theoretical design will be used to establish the amount of composite interaction possible from the experimental data.

The experimental results show that the failure mechanisms are semi-ductile and the shear capacity of the GNPs are considerable. Using relevant sections from the Eurocodes relating to steel, timber and composite design, a design method was established. Theoretical results show that partial composite interaction is possible for the case investigated, however further research is required to establish the relationship when increasing the amount of GNPs. Practical issues were highlighted that could limit the use in the construction industry, such as the substantial force required to press the CLT on to the GNPs.

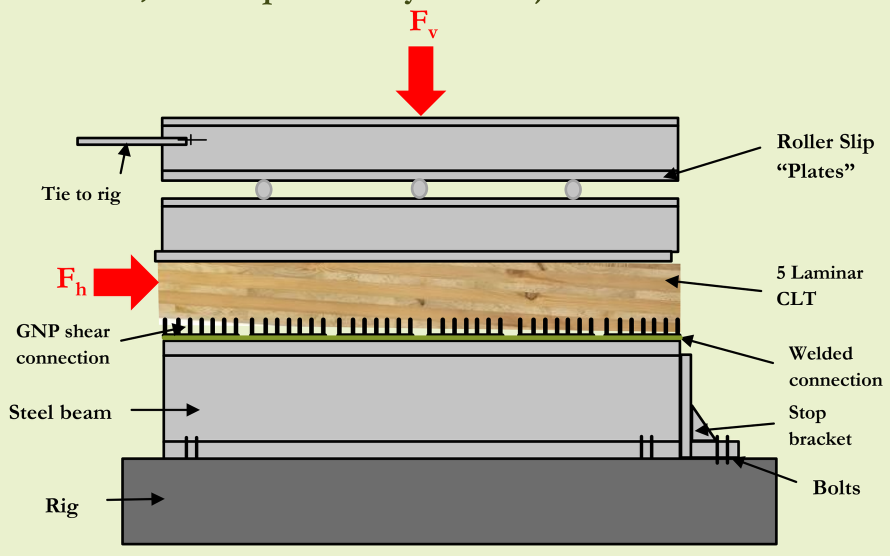
Aims

To obtain a defined level of composite interaction between a CLT floor slab and a steel flange experimentally using a GNP as the shear connector.
To determine the nature of the shear interaction, if achievable, whether it is a ductile or brittle failure mode.

Methodology

Set-up

To simulate structural behaviour accurately and to enable comprehensive data collection, the following structural set-up was used. LVDTs were used to measure the displacements at both ends of the CLT, and on both sides to measure any rotation of the specimen. To apply the forces shown, hand operated hydraulic jacks were used.



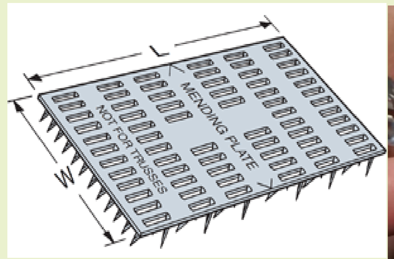
Procedure

The vertical load (F_v) was the independent variable whereby there would be 3 repetitions for each F_v. The horizontal load F_h was the dependant variable. F_v was calculated using different floor imposed loadings from EC1 and the self-weight of the CLT if it were a 3x1m panel. A thorough risk assessment was undertaken before the commencement of the experiments and a safe working procedure developed.

Materials

5 laminar CLT were with dimensions, 0.3m x 1m.

The GNPs were marked "not for structural use" but were of similar dimensions and steel grade as a similar product that could not be sourced. Each plate measured, 75mm x 150mm. There were 4 GNPs along 1m length of CLT that were welded to the steel beam with the CLT panel pressed on to the GNPs before the start of the experiment.



	$F_{v,1}$	$F_{v,2}$	$F_{v,3}$
Imposed Floor load kN/m²	1.5	2.5	2.2
Self-weight kN/m²	0.2	0.2	0.2
Total Pressure kN/m²	1.7	2.7	4.2
Force, 3x1m panel kN	5.1	8.1	12.6

Background

Why is there a return of timber construction?

Timber is a an environmentally friendly construction material and, if sourced from a trusted certified source such as the FSC (www.fsc-uk.org/), it can be sustainable. Timber has a lower embodied energy compared to concrete. CLT has 0.9 t/m³ of CO^2 (J.W.G.VAN DE KUILEN, A. X. H., 2011) (when including sequestered carbon) less than concrete. CLT is also a lighter material with the density almost 5 times less than normal weight concrete.

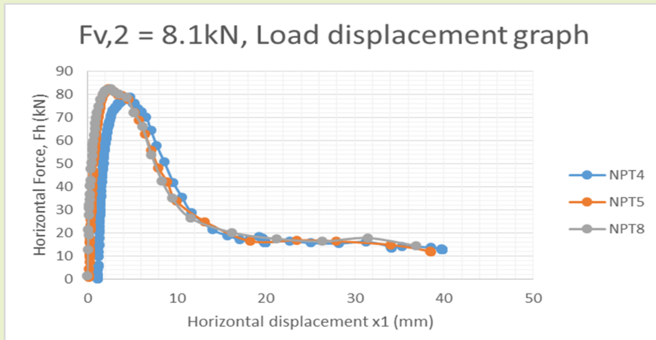
What would the benefits of Timber-Steel composite structures?

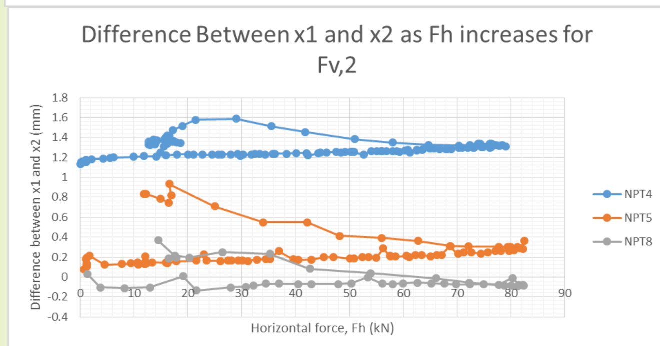
Composite construction enhances the structural efficiency compared to a non-composite structure. The main method of composite construction is between a steel frame and a concrete floor slab with a shear stud shear connection cast into the concrete and welded to the steel frame. However, if the concrete floor slab was replaced by a CLT flooring panel the embodied energy and the self-weight of the structure would be reduced significantly.

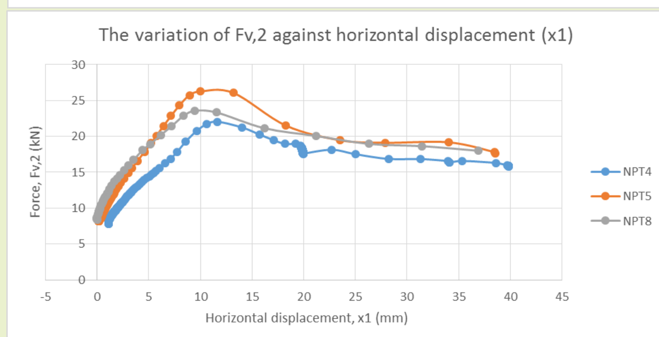
There has not been any previous research in this area of composite interaction. Previous research and practice of concrete and timber composite construction, with the use of a similar product to the GNP cast into the concrete, was successful (Fragiacomo, E. L. Æ. H. J. Æ. M., 2008.).

The use of CLT in a structure is relatively new for multi-storey buildings. The Stadthaus, London, is the tallest structure (10 storeys) and is built entirely from timber, with the use of CLT floors and walls (TRADA, 2009. *Case Study: Stadthaus*). There are similar proposed buildings that would break this record, and also the proposed new Google offices in London are to use a steel-CLT hybrid structure. CLT is therefore growing in demand.

Experimental Results







These graphs show a typical set of collected data.

The load displacement graph shows semi-ductile failure - the load increasing linearly to the peak value followed by a reduction of load with a larger increase in displacement until the GNP has failed and there is horizontal displacement occurring at a constant level of applied horizontal force. There is a very strong correlation between all results suggesting a reliable set of results. The peak F_h is reached at around 3mm displacement.

The compression of the CLT is shown in this graph by the increasing difference between the 2 LVDTs measuring displacement. In general it shows that there is very little compression in the CLT until after the peak F_h has been reached.

The vertical pressure was seen to increase despite the jack being fixed at the starting value. This can be explained by the vertical displacement (not measured) causing an increase in pressure inside the closed-off hydraulic system. The peak value of F_v occurs at about 10mm which is around the height of the individual nails of the GNP.

Photographic Results

Understanding how the materials failed was a key aspect to the research as during the experiment not everything can be seen.

This photograph shows the 4 GNPs after failure, where they have been positioned equally along the beam.

The GNP after failure often has large splinters trapped underneath the flattened nails. Some individual nails have been torn from the plate.

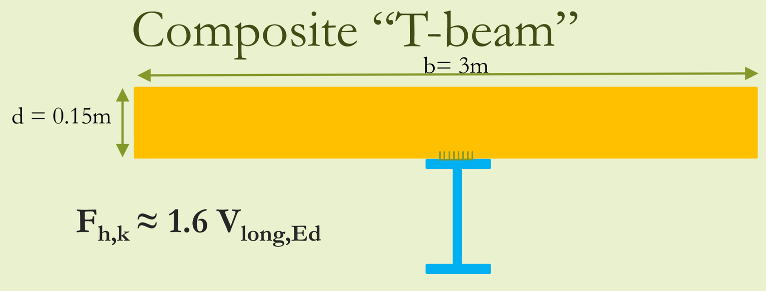
This CLT panel was from a low vertical load experiment. It shows high destruction and splintering with little amount of torn off nails suggesting a tear out failure mechanism.

When a high vertical load is applied there is less destruction of the CLT and more torn off nails present, with many still embedded in the CLT. This suggests a tear-out failure mechanism.

Theoretical Design

Using the relevant sections of the Eurocodes, a design method was used similar to that of partial interaction according to EC4 with the included factors from EC5 where strengths were determined from using the normal distribution method in EC0. The steel beams have also been designed as non-composite to directly compare the increase in deflection. It can be seen that both configurations can be considered to have partial composite interaction with the use of 4 GNPs per metre with the "T-beam" being the more efficient.

Composite "T-beam"

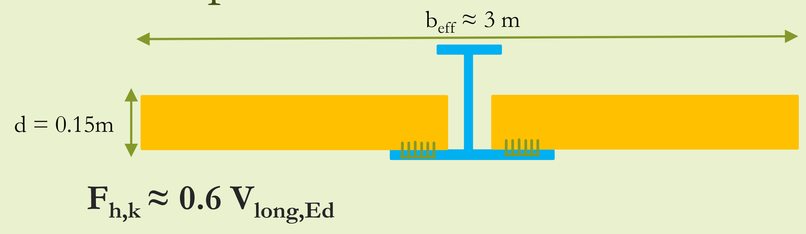


$F_{h,k} \approx 1.6\ V_{long,Ed}$

$F_{h,d} \approx 0.6\ V_{long,Ed}$

27.4% decrease in deflection compared to non-composite case.

Composite "T-beam"



$F_{h,k} \approx 0.6\ V_{long,Ed}$

$F_{h,d} \approx 0.2\ V_{long,Ed}$

10% decrease in deflection compared to non-composite case.

Conclusion

Partial interaction is possible for the conditions that have been investigated, whereby 4 GNPs per metre length of beam have been equally spaced and substantially welded to the steel beam and the CLT has been pressed on to the GNPs before testing. This partial interaction is considerable and would lead to smaller steel sections being used. However there are practical issues that have arisen, whereby the pressing of the CLT to the GNPs required a much larger pressure than thought, about 35 kN; this would make it difficult to do in-situ on a construction site. Also the welding of the GNPs to the steel beam had to be made more substantial to stop the welds from failing during the testing but if the welding was done off-site then this would save time.

The failure mechanisms are semi-ductile pull-out or tear out of the GNPs depending on the level of vertical loading. However there is no data to show that tear-out is less preferential than pull-out failure, all results show similar semi-ductile nature irrespective of the mode of failure.

With further research, including using different numbers of GNPs and different types of GNPs, Finite Element modelling and full-scale bending tests, this area of composite construction could lead to many more timber buildings being constructed which will help lower the embodied energy of future structures.

Acknowledgements

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