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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF NOVEL STEEL-TIMBER-HYBRID SYSTEM

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ABSTRACT: This paper summarises the experimental and numerical investigation conducted on the main connection of a novel steel-timber hybrid system called FFTT. The component behaviour of the hybrid system was investigated using quasi-static monotonic and reversed cyclic tests. Different steel profiles (wide flange I-sections and hollow rectangular sections) and embedment approaches for the steel profiles (partial and full embedment) were tested. The results demonstrated that when using an appropriate connection layout, the desired strong-column weak-beam failure mechanism was initiated and excessive wood crushing was avoided. A numerical model was developed that reasonably reflected the real component behaviour and can subsequently be used for numerical sensitivity studies and parameter optimization. The research presented herein serves as a precursor for providing design guidance for the FFTT system as an option for tall wood-hybrid buildings in seismic regions.

KEYWORDS: Strong-column weak-beam failure mechanism, cross-laminated-timber, energy dissipation

1 INTRODUCTION

According to the objective-based design approach in the 2010 version of the National Building Code of Canada, new structural systems that are not defined in the code can be used as "alternative solutions", provided that the alternative solution provides the same level of performance as the "acceptable solution" specified in the code. The adoption of this objective based approach can favour large-scale wood construction if equivalent performance design can be demonstrated.

Over the last decade, several innovative hybrid systems were developed. One such system is '*Finding Forest Through Trees*', abbreviated as FFTT [1]. It consists of mass timber wall panels such as CLT as the vertical system that are anchored down using ductile hold downs or dampers and rigid (elastic) shear connectors. Steel beams are partially embedded into the panel faces that hold the walls together and also act as the ductile weak links for seismic design, thus providing the desired "Strong-Column Weak-Beam" failure mechanism.

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2 EXPERIMENTAL AND NUMERCIAL INVESTIGATIONS

2.1 SPECIMEN DESCRIPTION

Two 7-ply Spruce-Pine-Fir CLT panels, 3.9m long and 0.9m wide in combination with two beam profiles: i) wide flange I-section (150 x 100mm) and ii) hollow rectangular tube section (HSS 100 x 50 x 3.1mm) were used in the tests. The beams were embedded into pre-cut slots in the panels and held in place using lag bolts. The main parameters of the five test series are presented in Table 1.

Table 1: *Summary of Test Series Configuration*

No.	Section	Embedment Length [mm]	Embedment Depth [mm]
1	I	900	50
2	I	900	100
3	Reduced I	900	100
4	HSS	900	50
5	HSS	600; 300	50

2.2 METHODS

The CLT panels were bolted to the floor at both ends to restrain them from translation, rotation or uplift (Figure 1). The load was applied by means of a hydraulic actuator at the end of the projecting steel beam. Six sensors along the steel beam allowed for measurement of the relative horizontal displacement between the beam and panel and the rotation of the steel beam.

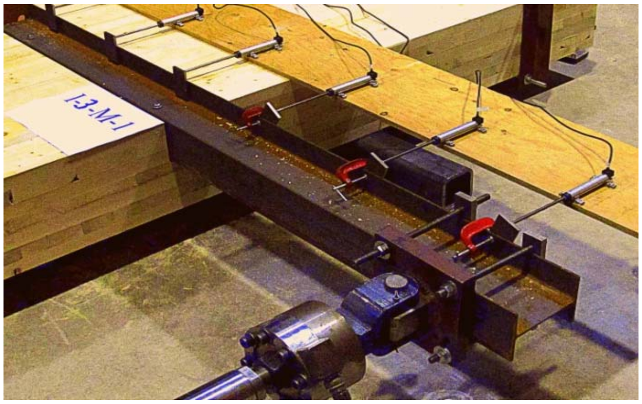

Figure 1: *Typical experimental setup*

Two replicates for each series were tested under quasi-static monotonic loading, while one specimen was tested under reversed cyclic loading. The static load was applied at a constant displacement rate according to EN-26891; the reversed cyclic tests followed the CUREE protocol.

2.3 RESULTS

The static tests were used to develop the cyclic loading protocol. Recommendations on optimum beam profile and placement (embedment length) to maximize energy dissipation under seismic loads were provided. The obtained hysteresis loops were typical of a steel component, implying a connection with adequate ductility for the desired seismic application.

In all series, the failure mode was ductile steel yielding. Rectangular hollow sections proved to be the better solution for achieving ductile failure mechanisms without any significant wood crushing even at partial embedment lengths, without out-of-plane buckling that was characteristic for the I-section beams.

Main parameters from monotonic and cyclic tests are summarized in Table 2.

Table 2: *Summary of Monotonic and Cyclic Test Results*

No.	Yield load [kN]	Ultimate displ. [mm]	Load cycles	Dissipated energy [J]
1	40.0	76.2	34	4,066
2	41.0	64.7	38	19,228
3	44.5	72.6	36	5,326
4	17.0	126.0	42	21,086
5	17.1	174.5	42	27,844

2.4 NUMERICAL MODEL

To complement the experimental results, a numerical investigation was carried out using ANSYS. All properties were assigned in such a manner so as to represent the actual behaviour. CLT was modelled a linear elastic orthotropic material, steel as bilinear isotropic elasto-plastic material. Contact elements were used to represent the gap and contact between the components.

The computed load deformation curves of the joint were compared to the experimental results. The five different test configurations were modelled and a static pushover analysis for each test series was performed. For each configuration, the load-displacement curves at the locations of the six LVDTs were recorded and compared to those of the experimental results. The results for Series 1 are exemplarily shown in Figure 2.

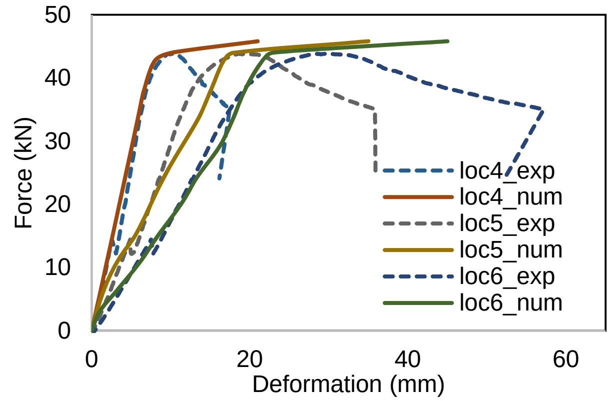

Figure 2: *Load-deformation plots comparing experimental and numerical results for cantilever portion from series 1*

3 CONCLUSIONS

The research presented herein focused on the component level performance of the proposed wood-hybrid FFTT system. A full-size connection assembly, consisting of a 7-ply CLT panel and a steel beam, subjected to static and cyclic loads, demonstrated high connection strength while maintaining ductile performance. The combination of hollow profiles with a minimum embedment length provided best results. The experimental and numerical investigations provided input data that can be used to develop preliminary design guidance for the FFTT system to be used in mid- and high-rise timber buildings.

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