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NONLINEAR DYNAMIC ANALYSES OF NOVEL TIMBER-STEEL HYBRID SYSTEM

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ABSTRACT: Although the benefits of using timber in mid- and high-rise construction are undisputed, there are perceived shortcomings with respect to the ductility needed to provide seismic resistance and a corresponding lack of appropriate design guidance. Overcoming these perceived shortcomings will allow timber, and its wood product derivatives, to further expand into the multi-storey construction sector, also in the context of hybrid structures that integrate different materials. The “Finding the Forest Through the Trees” (FFTT) system is a new hybrid system for high rise structures which combines the advantages of timber and steel as building materials. This paper presents research utilizing finite element models to capture the seismic response of the FFTT system and help developing design guidance. From the results presented herein, it appears that the FFTT system can meet the design performance requirements required for seismic loading: inter-storey drifts were lower than required and local plastic deformations were within a reasonable range for life safety performance.

KEYWORDS: FFTT System, Finite Element Models, Seismic Response, Nonlinear Dynamic Analyses

1 INTRODUCTION

The innovative hybrid system “Finding the Forest Through the Trees” (FFTT) is a proposed structural system for mid- and high-rise buildings [1]. The system utilizes engineered timber products to resist gravity and lateral loads with interconnecting steel members to provide the necessary ductility for seismic demands. The system reaps the light-weight, strength, stiffness, and environmental benefits of engineered timber, and exploits the ability of steel to dissipate energy and provide a ductile failure mechanism. Four different options for lateral force resisting systems (LFRS) are proposed for heights up to 30 stories; For a novel hybrid system, such as the FFTT, to gain recognition, experimental data must be gathered and supported by computational modelling and analysis to predict its structural performance. This paper presents nonlinear dynamic analyses utilizing finite element models to capture the seismic response of the FFTT system.

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2 NONLINEAR DYNAMIC ANALYSES

2.1 MODEL DEVELOPMENT

The FFTT system was numerically modelled using SAP2000 and OpenSees. Preliminary analyses using SAP models showed that the dynamic properties of the system were insensitive to whether or not the slabs were explicitly modelled with shell elements or simply captured through multi-point diaphragm constraints at each storey height. Thus, rigid diaphragm constraints were used in the OpenSees models to reduce modelling complexity and analysis time.

2.2 Timber Members

Accurate nonlinear modelling of any structure or material is a difficult task, even more so when dealing with an anisotropic material as timber. Timber when loaded in tension or shear is a brittle material, with failure occurring suddenly and almost without warning. To avoid sudden failure, timber structures are typically designed to fail in their connections, which are usually made using steel to provide a ductile failure mechanism and large amount of energy dissipation. The FFTT system considered in this study follows a similar design philosophy, in which steel beams that connect the main timber components are designed to yield before the timber members can fracture or crush. Consequentially, it is reasonable to model the timber components as purely elastic, as long as the complete nonlinear behaviour of the connections and the steel members are accurately captured.

2.3 STEEL MEMBERS

In the FFTT system, steel beams connect the timber wall elements and control the failure mechanism of the structure; therefore, it is quintessential to the accuracy of the models to capture the yielding, hardening, and degradation properties of steel-timber connections. The hinges were calibrated to test results performed at the University of British Columbia by Bhat [2]. The result moment-rotation relationship of a hinge calibrated to one of the test results is illustrated in Figure 1.

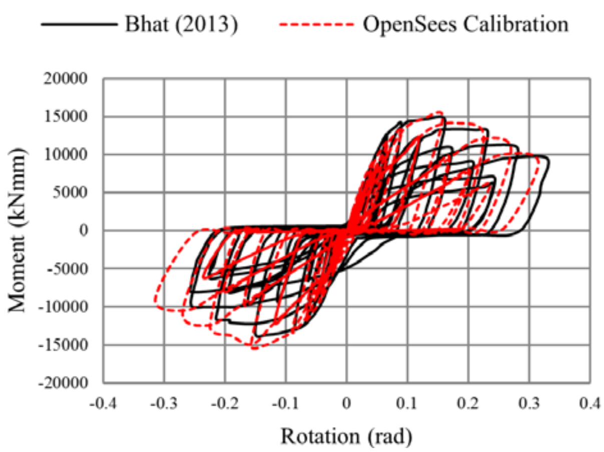

Figure 1: *With OpenSees calibrated test results on embedded HSS profile*

2.4 ANALYSIS

For each considered model and bi-directional ground motion, two analyses were run for – one for each of the two main ground motion orientations (orientation of the primary component of the motion). The ground motions were always applied parallel to the primary axes of the structure. Then, for each scenario (a particular height of a particular building plan option subjected to a particular ground motion) the results were taken as the maximum of the two ground motion orientations.

2.5 INTERSTOREY DRIFT RESULTS

The stress state in each component was recorded during each analysis, to ensure that all timber members did not reach their ultimate strength. This was to make sure that the elastic modelling assumptions used for the timber members were valid. This assumption held true throughout all of the analyses. The differential movement between adjacent floors, called interstorey drift, was selected as the main predictor of seismic performance for this study. The mean interstorey drift for each model of each of the four options is illustrated in Figure 2. The mean interstorey drift is calculated as the mean of the maximum responses observed from each of the ten ground motions. It may be noted that the interstorey drift tends to decrease with the height of the building, meaning that as the structures become taller, they become be less governed by earthquake load, in part due to their high flexibility.

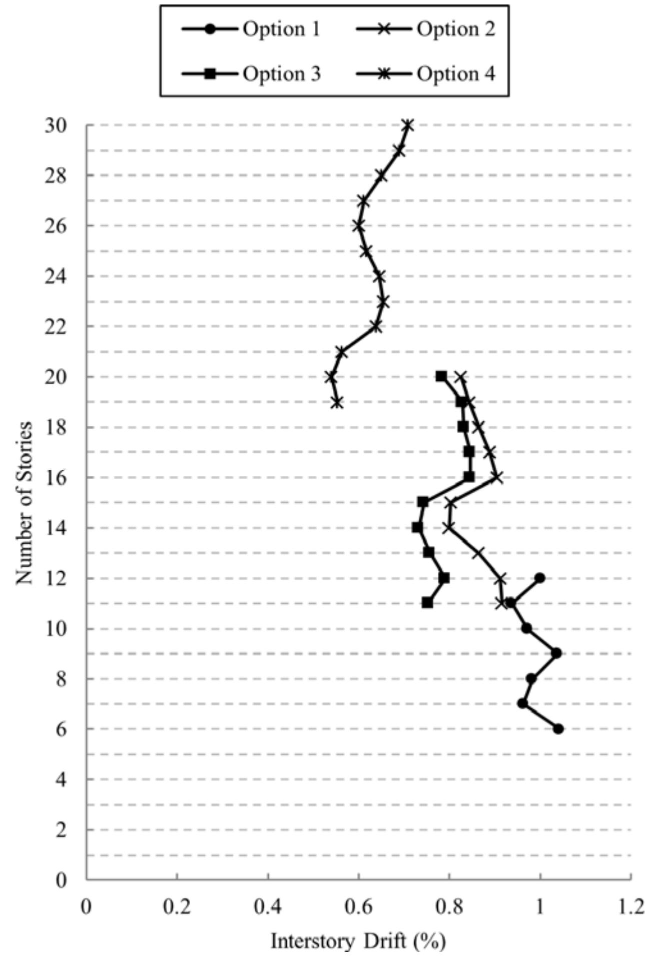

Figure 2: *Inter-storey drifts*

3 DISCUSSION

From the results presented herein, it appears that the FFTT systems, as they were designed for this study, meet the performance required under design seismic loading. Interstorey drifts were lower than required and local plastic deformations were within a reasonable range for life safety performance. Maximum drifts and plastic deformations tended to decrease as the height of the structures was increased, as the taller, more flexible structures were less impacted by the seismic excitations. However, these characteristics, which made the taller structures less susceptible to damage induced by ground shaking, may cause serviceability issues under wind loads. Additional studies are currently being conducted to assess this issue.

4 REFERENCES

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