RESEARCH AND APPLICATION OF TIMBER-STEEL HYBRID STRUCTURES

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ABSTRACT: This paper presents experimental study and numerical modelling of a prototype timber-steel hybrid structure. Such structures are composed of steel moment-resisting frames, timber-steel hybrid diaphragms and infill wood-frame shear walls. The in-plane stiffness and load transferring ability of the hybrid diaphragm was experimentally tested. The lateral performance of timber-steel hybrid lateral load resisting systems with regard to the interaction between the steel frame and the infill wood shear wall was investigated. A user defined element model was developed to model the behaviour of the infill walls, and the numerical model was verified with the test results. The test and modelling results showed the infill walls were very effective in the initial stages of loading and absorbed a substantial part of the lateral load. However, once damage developed in the infill wood-frame shear walls, the lateral load was essentially resisted by the steel moment-resisting frames. In order to ensure the effectiveness of the infill wall, it is also recommended that in practical application, the timber-steel bolted connections between the steel frame and the wood frame wall be designed to act in the elastic range when transferring a shear force equal to the lateral load capacity of the infill wall.

KEYWORDS: Timber-steel hybrid, Lateral performance, In-plane stiffness, Reversed cyclic test, Numerical model

1 INTRODUCTION

As a renewable building material with carbon storage and low embodied energy characteristics, wood is a preferred material choice in green/sustainable building construction. Light wood frame constructions represent the most common method of building single and multi-family residential buildings in North American and European countries. However, it exposes its limitation with the urban population expanding, which has led to greater use of wood in multi-story buildings. As a result, the trend is the expansion of structural application of wood from small single-family low-rise residences to mid-rise/multi-storey buildings. As in [1–6], there has been some research on multi-storey timber buildings over the past two decades, focusing on the structural system, seismic performance, fire safety and non-structural effects. In this paper, a multi-storey timber-steel hybrid building system is proposed and studied. It is composed of steel moment-resisting frames, timber-steel hybrid diaphragms and shear walls. The timber hybrid diaphragm serves as the horizontal system of the structure, and the wood shear walls are used as infill walls in the steel moment-resisting frames as the vertical system of the structure, forming a timber-steel hybrid lateral load resisting system. A series of structural tests and computer modelling were conducted to investigate the lateral performance of this kind of hybrid structure, which aimed to extend the application of timber-steel hybrid structures and similar structural systems.

2 PERFORMANCE OF HORIZONTAL STRUCTURAL SYSTEM

As shown in Figure 1, the timber-steel hybrid diaphragm was composed of C-shaped steel joists and dimension lumber decks, and 30mm thick cement mortar was casted on its top to prevent water and vibration.

Figure 1: Timber-steel hybrid diaphragm

2.1 LATERAL PERFORMANCE OF TIMBER-STEEL HYBRID DIAPHRAGM

Horizontal cyclic pseudo-static tests were conducted separately on parallel and perpendicular to joist direction...
of the timber-steel hybrid diaphragm, and its deformation feature, failure mode, strength, in-plane stiffness, energy dissipation and ductility were obtained. The result showed that shear deformation governed the total in-plane deformation of the diaphragm. Panel nail clipped outside the two loading point was the main failure mode. Moreover, in contrast to the diaphragm loaded parallel to joist, diaphragm loaded perpendicular showed a higher strength, in-plane stiffness, better energy dissipation performance and ductility.

2.2 LOAD TRANSFERRING ABILITY OF THE DIAHPRAGM

The diaphragm’s capacity on transferring horizontal loads in elastic phase was studied by a one-story two-span timber-steel hybrid structure prototype model test. The load transfer ability index $\beta$, and the ratio between the in-plane stiffness of the diaphragm and the lateral stiffness of vertical load resisting system $\alpha$ were defined. Results showed that the hybrid diaphragm without cement mortar was capable of transferring approximately 64% of the unbalanced horizontal load with $\alpha$ in the range of 0.5 to 1. However, $\beta$ increased to around 90% after the casting of the 30mm cement mortar on top of the diaphragm.

3 PERFORMANCE OF VERTICAL STRUCTURAL SYSTEM

Figure 2 shows the timber-steel hybrid lateral load resisting system. The steel moment-resisting frame and the infill wood shear wall served as subsystems in the hybrid system. The shear force was transferred from the steel frame to the infill wall by bolted connections between them, which ensured the two subsystems could work together to resist lateral loads.

The test results showed that the installation of the infill wood-frame shear wall produced a significant increase in the initial lateral stiffness of the bare steel moment-resisting frame. However, once damage developed in the infill wood-frame shear walls, the lateral load was essentially resisted by the steel moment-resisting frames.

4 NUMERICAL MODELLING OF TIMBER-STEEL HYBIRD STRUCTURES

A user-defined element was developed to model the behavior of the infill wood shear walls based on the concept of pseudo-nail model. The element was implemented as a subroutine in the finite element software package ABAQUS, and was verified by test results.

5 CONCLUSIONS

The research project on lateral performance of timber-steel hybrid structures is introduced in this paper. The in-plane stiffness and load transferring ability of the hybrid diaphragm was experimentally tested. The lateral performance of timber-steel hybrid lateral load resisting systems was investigated. For the numerical modelling, a user defined element was developed based on the concept of pseudo-nail model, and the model was verified by test results. This research project aimed to develop a kind of prefabricated timber-steel hybrid structural system, which may also increase the application of timber in multi-storey buildings.

REFERENCES