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Structural behaviour of prefabricated load bearing braced composite timber wall system

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ABSTRACT

Timber is gaining its popularity in the construction of low to the mid-rise buildings and sometimes in high-rises due to its sustainability, cost-effectiveness, and availability all around the world. In addition, the prefabricated building is getting popular due to advances in the automation industry, reduction in resources including time, labour, and waste; and cost-effectiveness in mass production. Due to higher capacity demands for mid-rises and convenience in design for manufacturing and assembly (DfMA) in prefabrication, a new development of prefabricated load bearing closed panel composite timber (CPCT) wall system made of oriented strand boards (OSBs) stiffened by sawn-cut timber stud and sometimes with additional steel stud to increase its load carrying capacity has been considered in this research. Five full-scale CPCT walls have been tested subjected to axial compression. The results showed that the mid-height lateral deflection governs the maximum allowable force acting to this wall. Moreover, finite element analysis (FEA) has been done and compared to the experimental results. Once a good agreement between the experimental results and FEA results has been obtained, parametric studies have been performed to comprehensively understand the sensitive parameters affecting the axial behaviour of this system. The parameters studied in this research include the material, the size and the arrangement of the stud, the spacing of the nail, and type of adhesive. Moreover, the possible issue in the practice and the effect of the additional steel stud have also been discussed.

1. Introduction

Timber is gaining its popularity in the construction of low to the mid-rise building due to its sustainability, cost-effectiveness, ability to use in an advanced manufacturing environment and availability all around the world [1]. In Australia, there is an increase in the demand for using engineered timber product and the demand for taller timber structures [2]. Engineered timber is usually more preferred than the solid timber due to its higher thermal performance, higher moisture resistance, uniformity, and lower expense. There are several engineered timber products commercially available, such as plywood, cross-laminated timber (CLT), laminated veneer lumber (LVL), glue-laminated timber (Glulam), oriented strand board (OSB), and wood I-joists [3]. This study includes a 38 mm thick oriented strand board (OSB) timber panel created from multiple layers of strand board. The primary mechanical material properties of the material have been tested and found to be significantly lower than that of solid sawn timber, however, it was selected to provide a level of performance proportional to its cost.

The combination of studs and engineered timber panel can be termed a diaphragm wall [4]. This approach of combining sawn cut timber with engineered timber is termed as a method hybridization, the results of doing so is a maximisation of benefits in which individual building components offer [5]. Diaphragms are efficient structural systems which can counter lateral shear forces such as those induced by wind or earthquakes [6], they can be single sheathed or double sheathed either both on one side of the studs or on both sides [7]. However, this research proposes utilisation of the diaphragm to transfer the gravity load.

The prefabricated building is getting popular due to advances in the automation industry, reduction in resources including time, labour, and waste; and cost-effectiveness in mass production. Due to higher capacity demands for mid-rises and convenience in design for manufacturing and assembly (DfMA) in prefabrication, a new development of prefabricated load bearing closed panel composite timber (CPCT) wall system made of oriented strand boards (OSBs) stiffened by sawn-cut timber stud and sometimes with additional steel stud to increase its load carrying capacity has been considered in this research. There is very limited research observing the axial behaviour of the CPCT wall as

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a gravity load transferring element though experimental and analytical approaches are available for the lateral behaviour of timber wall in the literature [8–10]. For instance, there is one previous research observing the axial behaviour of the OSB panel [11]. However, the dimension of this OSB panel was quite small and there was no stiffener attached to the panel. These conditions do not reflect the CPCT wall considered in this research which has the OSBs stiffened with the studs and pinned only along two opposite edges. In addition, the axial behaviour of CPCT wall with OSB and timber studs are not covered in popular guidelines such as AS 1720.1 [12] and Eurocode 5 [13].

In general, wood behaves differently in each direction due to its heterogeneity and orthotropic material which increases the difficulty level of predicting the behaviour of the timber under loading condition [11,14]. Abaqus 6.13 [15] was used in this research to simulate the axial behaviour of the full-scale closed panel composite timber (CPCT) wall system made of oriented strand boards (OSBs) stiffened by sawn-cut timber stud and sometimes with additional steel stud. Abaqus 6.13 [15] is used since it is proven to be able to predict the behaviour of the timber under the various conditions, such as delamination [16], timber with flaws [17] and cracks [18], steel dowel connections [14], nailed joint [19] and timber pegs connections [20], moisture variations [1], buckling of oriented strand board webbed wood I-joists [21].

Fig. 1 shows the isometric view of the CPCT wall considered in this research. It is designed such that the gravity load is transferred through the three layers of OSB wall in order to keep the continuity of the timber studs (MGP10) and steel studs (SHS). Having the gravity load applied to the wall, there will be an eccentricity between the centroid of the CPCT wall and the applied load which can increase the lateral deformation of the system due to second order effect. Moreover, due to the low Young's modulus of the timber, eccentric loading conditions due to tolerance limits in computer numerical control (CNC) machines and thin wall, the excessive lateral deflection due to buckling may govern the allowable gravity load that can be transferred to the wood panel and therefore, it is worth to be further studied.

In order to comprehensively understand the behaviour of the wall under gravity load, both experimental work and finite element analysis (FEA) have been utilised in this paper. Five typical full-scale CPCT wall sections including 2 MGP10 studs are subjected to compressive load until failure. Once the FEA results have a good agreement with the experimental result, parametric studies were conducted to obtain the sensitive parameters affecting the axial behaviour of the CPCT wall. These include several different variables such as the material and

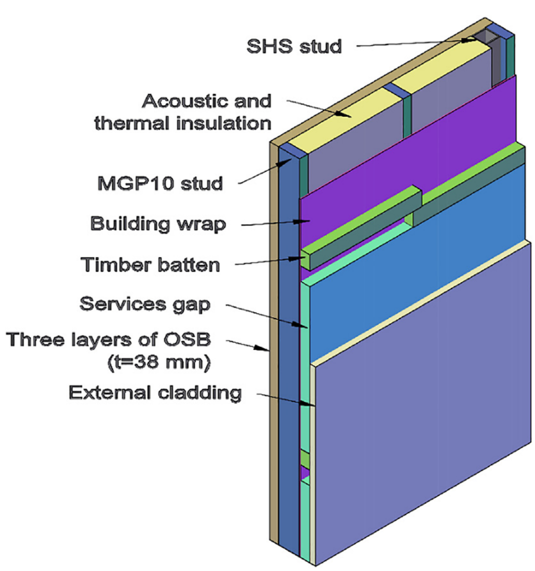

Fig. 1. The isometric view of the closed panel timber wall system considered in this research.

geometry of the stud, the strength of the adhesive, the spacing of the nail, and the presence of the steel stud. The results showed that the arrangement of the studs governs the behaviour significantly. Moreover, a minimum strength of the adhesive and maximum spacing of the nails were also derived to prevent the premature stiffness degradation. In addition, it is recommended for further research to quantify the effect of different moisture content as well as the creep on the structural behaviour of the proposed wall.

2. Experimental work

2.1. Experimental setup

A total of five CPCT walls were tested in pure compression with pinned supports at both ends restrained against both vertical and lateral movement. Fig. 2 shows the details of the specimen. Two 70 × 35 MGP10 studs were used to simulate the frame in only one side of the wall. There were no studs at the other side of the wall because this side will be the interior side of the structure. In the construction, the gravity load is transferred through the three layers of OSB wall only. Therefore, a notched section was made at each end of the stud as shown in Fig. 2(b). The studs were attached to the wall by both nails and polyurethane adhesive. Moreover, the nails have a diameter of 3.75 mm, length of 90 mm, and spacing of 200 mm.

Fig. 3 shows the layout of the test rig. Each end of the CPCT wall was supported inside 200 PFC (parallel flange channel). This PFC is then connected to the actuator at one end by using two 200 PFC bolted back to back as an "I" configuration which provides a stiff support for distributing the load equally from actuator to the wall. The PFC sections are all 1250 mm in length which is a bit larger than the width of the specimen. At the other end of the wall, the specimen was supported by two 150 SHS at the stud end. By adding the studs to the OSB wall, the neutral axis of the stiffened wall has moved towards the studs and hence the buckling will occur towards the studs since the axial loading is applied to the OSB wall. The specimen was allowed to have a maximum rotation of approximately 20 degrees upward. A displacement loading was applied with a rate of 5 mm/min (which is equivalent to a strain rate of 0.0018 min^{-1}) to ensure that there was no dynamic effect.

A hydraulic actuator with an axial force of 250 kN and accuracy of 0.01 kN and 0.01 mm was used and mounted horizontally. For each specimen, both force and displacement were measured axially by using the data logger every 0.01 s. Moreover, for specimen 3 to 5, a lateral deflection at 50 mm from both sides of the mid-height of the wall was also measured by using a laser transducer with a precision of 0.01 mm.

2.2. Experimental results

Fig. 4 shows the axial force versus axial deflection obtained from the experimental work. It is shown that there is a variation between the results in terms of the initial stiffness and the maximum axial force and its corresponding deflection. For instance, if the initial axial stiffness was calculated at 1 mm axial deflection (within the linear elastic range), the average initial axial stiffness is approximately equal to 38.35 kN/mm with a standard deviation of 6.5 kN/mm. Moreover, the maximum axial compression capacity is equal to 107.5 kN which occurs in Test 3 which has a combined failure mode, i.e. stud flexural failure accompanied by the delamination of the stud from the wall as shown in Fig. 5. However, the minimum axial compression capacity is equal to 85.2 kN which occurs in Test 2. This is due to the failure of the adhesive and the insufficient embedded depth of the nails which caused the delamination between the stud and the surface of the OSB wall as shown in Fig. 6. The adhesive and the nails support each other and hence, failure of one of these leads to the failure of the other. In specimen 2, it was observed that the nail only penetrated the OSB wall approximately 15 mm. This may be due to the misalignment when driving the nail to the stud. Moreover, it may also due to the surface of