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Hysteretic behavior of timber framed shear wall with openings

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HIGHLIGHTS

- Hysteretic responses of timber framed walls are experimentally investigated.
- The variables are presence of openings, and aspect ratios of timber framed walls.
- The varying dimensions of openings significantly affect the strength and stiffness.
- The ultimate loads resisted by the timber framed walls are calculated Eurocode 5.
- The analytical results are not in good agreement with the experimental results.

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ABSTRACT

Hysteretic responses of timber framed shear walls are experimentally investigated in this study. The variables considered in the study are presence of openings with varying dimensions, presence of horizontal retrofitting elements and aspect ratios of timber framed shear walls. The data obtained from the tests conducted on timber framed shear walls are used to deduce conclusions about the behavior of such type panels in terms of load–displacement relationships, strengths, stiffnesses, displacement ductilities, energy dissipation capacities and failure modes. Furthermore, the ultimate loads resisted by the timber framed shear walls are also calculated as per Eurocode 5. Then the analytical and experimental results are comparatively presented. From the test results, it is observed that the aspect ratio of a timber framed shear wall is a significant factor on the load–displacement relationship and failure mode. The varying dimensions of openings on the timber framed shear walls significantly affect the strength and stiffness of the panels. The increasing opening dimensions reduced the strength and stiffness values of the panels. Besides, from the comparison of analytical and experimental results, it is observed that the analytical results are not in good agreement with the experimental results.

1. Introduction

Timber structures have been gaining popularity all over the world significantly in the regions that under severe risk of seismic excitations. The construction of timber structures have increased since last 15 years. However, from the literature review, it is observed that the number of comprehensive studies focused on the behavior of timber structures under ground motion excitations is limited relative to those conducted on the hysteretic behavior of masonry, reinforced concrete and steel structures [1].

The timber framed panel walls are the main load resisting elements providing strength, stiffness and energy dissipation to timber structures under lateral loads such as ground motion excitations. Timber structures are structures constructed by the combination of timber framed panel walls designed according to architectural plans [2]. The lateral loads acting on timber structures such as ground motion excitations are mainly resisted by the timber framed panel walls. Timber framed panel walls are similar to the shear walls in reinforced concrete or load bearing walls in the masonry structures in terms of providing strength, stiffness and energy dissipation capacity to the structure [3]. In relation, it is believed that the earthquake behavior and performance of timber framed panel walls should be examined to determine the overall performance of timber structures under ground motion excitations. Consequently, an experimental study on the behavior of timber framed panel walls under the effect of ground motion excitations is conducted.

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Timber framed panel walls are load resisting elements composed of two main components. These components are; (i) timber frame elements and (ii) Oriented Strand Board (OSB) plates that are composed of pressurized timber parts used to cover the surface of the wall [2,3]. These components are tied together with appropriate connector links and form up the whole panel wall. Major advantages of timber structures compared to traditional buildings are sound physical properties, reduced power consumption, increased construction speed and factory production of prefabricated elements. Timber is used as the main construction material for assembling walls, ceilings, roof and beams, etc. [4]. According to Thelandersson and Larsen (2003), experiences from earthquake-prone areas indicate that timber structures generally exhibit good seismic performance [2]. Their advantages lie mainly in the low weight of the structure, ductile joints and regularity of the structure. Timber structures represent a significant part of the construction industry in many countries around the world. One of the commonly used solutions for both single- and multi-story buildings is the prefabricated timber structures with timber-framed wall elements as the main vertical load-bearing members. The wall elements are composed of a timber frame and the sheathing boards, which are usually made of either a wood-based or the fiber-plaster material. In general, the load-bearing capacity of the timber frame resists most of the vertical loads, while the sheathing boards provide the horizontal stability (i.e., their main function is in resisting loads such as wind and earthquake). Using adequate shear connection between the components, the wall elements may be considered as composite systems taking advantage of the favorable properties of both materials [5].

Prefabrication of timber framed panel walls significantly reduces the construction times and enhances the earthquake performance of structures [3]. Increase in the number of structures that are built using elements such as timber framed shear panels also increased the number of studies conducted on these topics. The parameters affecting the strength of the panels are investigated in the experimental studies conducted on the performance of timber framed panel walls under lateral loads [6–10]. In such studies, generally the experiments are conducted using the timber framed panels with unit length. Moreover, the analytical and numerical finite element studies focused on the lateral load resisting capacities of the timber framed shear panels also exist [11,12]. These studies are also conducted on the timber framed shear panels with unit dimensions. In conventional buildings (i.e., residential, office, etc.) a significant part of the wall elements may have one or more openings for functional reasons, such as doors or windows. The openings reduce the stiffness of the structure, while additional problems may occur due stress concentrations at the corners. Several research studies have been published in the past discussing the influence of the openings on the load-bearing capacity of different structures, e.g., reinforced concrete shear walls [13], and plywood-sheathed timber-frame wall elements [14,15]. In the literature, it was observed that there were a limited number of studies on this subject [6–8,16]. The observations from the conducted studies showed that generally, timber framed shear panels with widely used geometrical properties are used in the experimental and analytical studies. In relation to that an experimental study is designed to consider the effect of reversal cyclic loading of (i) panels walls composed of several timber units and (ii) panel walls with varying aspect ratios (width/length). The main variables considered in the study are (i) the aspect ratios of timber framed panel walls, (ii) presence of lateral retrofitting elements distributed along the height of the panel and (iii) the dimensions of the openings located on the panel walls. Studies in the literature generally consist of experiments conducted on single timber framed panel walls with unit width. In addition, in these studies the specimens were subjected to unidirectional lateral monotonic loading until failure. The specimens test in this study were designed to represent real panels constructed by the combination two or more panels with variable aspect ratios. Furthermore, in the study, the ground motion loading was applied in a reverse cyclic manner in contrary to the studies in the literature. In the literature, the authors cannot find a comprehensive study focused on the performance of timber framed panel walls with or without openings under lateral loading. In relation to that this experimental study was designed and conducted. A significant contribution of the study to the literature is the investigation of aspect ratio, which is very effective on the strength, of timber framed panel walls. Also the investigation of the effect of openings, with variable dimensions and locations, on the performance of timber framed panel wall is another contribution of the conducted study. Application of reverse cyclic, which was not applied before, loading to the timber framed panel walls, is another contribution to the literature. In scope of the experimental study, 11 specimens are tested under the reversal cyclic loadings to simulate the ground motion excitations. The data obtained from the tests are used to deduce conclusions about the behavior of such type panels in terms of load–displacement relationships, strengths, stiffnesses, displacement ductilities, energy dissipation capacities and failure modes. Furthermore, strain measurements are used to observe the lateral load resisting mechanism of the timber frames. The ultimate loads resisted by the timber framed shear walls are also calculated as per Eurocode 5 [17]. Then the analytical and experimental results are comparatively presented to observe the accuracy of the analytical procedure in terms of ultimate loads resisted by the test specimens.

2. Experimental program

2.1. Test specimens and material

In scope of the experimental study, the main load resisting mechanisms of timber structures, timber framed panel walls are tested under lateral, reversal cyclic loading to simulate the ground motion excitations. 11 timber framed panel walls are tested in scope of the study. Test specimens are manufactured in real dimensions without introducing any scaling. Main variables considered in the study are the aspect ratios of timber framed panel walls, presence of lateral retrofitting elements distributed along the height of the panel and dimensions of the openings located on the panel walls. Properties of the test specimens are presented in Table 1. From Table 1, it is clear that a wide range of aspect ratios (0.24–1.12) is considered in the study. This range of aspect ratios is selected to observe the effects of aspect ratio on the general load–displacement relationships and failure mechanisms of timber framed shear walls. Test specimens 3, 4 and 6, 7 are manufactured with same aspect ratio and geometrical properties. However, these test specimens differ in the timber framing systems. Timber frames of test specimens 4 and 7 are retrofitted with lateral strengthening elements along the height of the frame. In contrary to that, in test specimens 3 and 6, these retrofitting elements are not used. Another variable considered in the study is the presence of openings in the panels. The ratio of areas of openings to the surface of the panel ranges in between 3% and 33%. The effect of opening area on the significant parameters such as load–displacement behavior, strength, energy dissipation capacity, displacement ductility and failure mechanisms are investigated in this study.

Timber framed panel walls are composed of timber frame elements and OSB plates used to cover the surface of the wall. The production of test elements is started by bringing together the pieces of spruce material in a manner that would form a frame in the dimensions of 38×140 mm. In the joining of the spruce frame elements, 2 (each No. 10) wood screws (5×100 mm) are used for the lower and upper horizontal pieces and 2 (each No. 10) wood screws (5×100 mm) are used in the joining of the vertical side and central pieces, whereas, nails (3.1×80 mm) are used in the joining of the OSB surface sheathing material with the timber frame elements. A pneumatic nail driving machine is used in the nail driving process. The production of timber completed on both surfaces by using OSB materials with a standard 11 mm thickness. The tested timber framed panel walls have varying aspect ratios. OSB plates have standard dimensions of 1220×2440 mm. In the market, OSB plates with larger dimension are not available. Due to this fact, the panel walls cannot be manufactured using a single OSB plate. Accordingly, OSB plate parts are used in the manufacturing of panel walls. In the manufacturing of test specimens with openings, the panel parts at the sides of the openings were used as monolithic parts. However, in the manufacturing of specimens without any open-