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Testing and modelling of shearwalls studded with small-diameter round timber under cyclic lateral load

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HIGHLIGHTS

- Utilising small-diameter round timber in the light wood frame construction.
- Firsthand test data of shearwalls with the built-up studs under cyclic lateral load.
- FE simulation and prediction of the structural behaviour of the shearwalls.
- The newly developed shearwalls can be used as a substitute of the conventional ones.

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ABSTRACT

As a forestry by-product mainly from thinning of the artificial forests, small-diameter round timber is not suitable for structural members due to its low quality. For use in structural applications, a kind of shearwall utilising small-diameter round timber in the form of built-up studs was developed. To investigate the structural behaviour of the shearwalls, 15 full size specimens with different configurations were manufactured and tested under cyclic lateral loading. The failure modes of the shearwalls were observed and the hysteresis curves obtained. The lateral resistance, stiffness and displacement capacity were evaluated. An FE model of the shearwalls was then developed using ABAQUS, and the structural behaviour simulated. FE modelling and testing of the shearwalls correlated closely. The results of this study showed that the developed shearwalls performed quite well under cyclic lateral load, with sufficient lateral resistance for use in light wood frame construction.

1. Introduction

Light wood frame construction is widely used in North America and is becoming more and more popular in China. It is resistant to seismic actions due to the light weight and the sufficient energy-dissipation capacity of its shearwalls. Conventional shearwalls consist of a dimension lumber frame and sheathing materials like OSB, plywood and gypsum panels (GWB). In the past two decades or so, the light wood frame construction has been extensively investigated by means of experimental testing or FE modelling, with an emphasis on performance of the shearwalls. Notably among the studies were the CUREE-Caltech Project [1], in which 25 shearwalls under cyclic lateral load were tested to evaluate the effect of various parameters, and the NEESWood Project [2], in which a series of “Capstone” tests were conducted on a full-scale six-story light wood frame building to compare the actual response of the building in shake table tests to the performance expectations set out by the design. With a background of well-developed North American light wood frame construction, researchers around the world have also been trying to modify the conventional shearwalls by replacing the dimensional lumber or conventional sheathing panels with materials that may be more available or efficient from local resources. Manalo [3] investigated the structural behaviour of shearwalls, of which the frame was made of glass fiber reinforced polyurethane foam and sheathed with Magnesium Oxide Corp Boards. Xiao et al. [4] developed a type of light frame construction using glued laminated bamboo as the framing members and ply-bamboo as the sheathing panels. Correal and Varela [5] investigated the performance of shearwalls sheathed with glued laminated bamboo panels. Sulistyono et al. [6] investigated the structural performance of shearwalls made from mangium wood whilst Du [7] modified the frame of shearwalls by applying

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cross-braces and using mortise and tenon joints between framing members.

In this study, to reduce the cost of shearwalls and enhance the efficiency of engineering application of the small-diameter round timber, a built-up stud made of the timber of Northeast China larch was developed and used as a substitute for the conventional dimension lumber stud in the shearwalls. Small-diameter round timber refers to logs with a diameter between 40 mm and 160 mm [8]. It is a forestry by-product mainly from thinning of artificial forests, of which the main species suitable for structural use are fir and larch. A large quantity of small-diameter round timber is produced every year in China, accounting for up to 44% of the total wood supply [9]. Small-diameter round timber is fast-growing and inexpensive, with a harvest age of 10–15 years. Much economic and environmental benefit can be derived from proper use of the timber. Some studies involving use of small-diameter round timber were reported. Wang et al. [10] investigated the performance of a kind of glued beams made from small-diameter round timber. He et al. [11] studied the performance of small-diameter round timber posts for falsework. Chrisp et al. [12] applied small-diameter round timber to the structural frame of a single story residential center. However, small-diameter round timber is not suitable for direct use as structural members due to the small size and serious natural defects, there are few effective ways to utilise it in structural members. Most of the round timber is used as a raw material for products other than building materials, *e.g.* used for paper-making and furniture panels. The objective of this study is thus to propose a simple, economical and efficient way to make use of this kind of timber in the form of built-up studs for shearwalls.

The built-up studs were developed and tested under axial and eccentric compression also by the authors of this paper [13]. In this present study, the structural performance of shearwalls with the built-up studs was investigated by experiment and FE modelling. A total of 15 full-size shearwalls with different stud spacing, end studs and sheathing panels were manufactured and tested under cyclic lateral load. An FE model of the shearwalls was developed, the performance of the shearwalls including the test specimens and those covering more parameter variations was then simulated. The results predicted by the FE model correlated with the test closely. This paper presents the observations and results from the tests and FE simulations.

2. Test of the shearwalls

2.1. Shearwall configurations

As shown in Fig. 1, the built-up stud comprised of two limbs of small-diameter round timber, U-shaped nails were used to link the two limbs. A piece of small-diameter round timber was sawn into two halves to form two semicircular limbs, or to form one limb if the size was small. The U-shaped nails were applied to both sides of the limbs. The angle between the stud and the U-shaped nail was about 45 degrees.

Also shown in Fig. 1, the shearwalls consisted of bottom and top plates, studs and sheathing panels, and were 2.44 × 2.44 m in size. The wall system was primarily intended to be used in cold places like Northeast China, therefore for heat insulation reasons, the framing thickness was taken as 140 mm, rather than 89 mm as in a conventional shearwall. Thus the dimension lumber for top and bottom plates and for end studs of some shearwalls was SPF of Grade No. 2 and 38 × 140 mm (nominally 2 × 6 in) in cross-sectional size. The built-up studs were made from small-diameter round timber of Northeast China larch. The average diameter of the smaller end of the timber used in this study was 75.8 mm, with a coefficient of variation in the diameter of about 0.20. The average moisture content of the timber during test was 12%. The framing members were nailed together with four 3.8 mm(φ) × 80 mm hand-driven nails at each end of stud. The sheathing-to-frame connecting method was the same as in a conventional shearwall, *i.e.* the OSB panels of 9.5 mm thick were connected to the frame with 2.8 mm(φ) × 50 mm hand-driven nails, whilst the gypsum panels of 12 mm thick were attached to the frame with 3.5 mm(φ) × 38 mm wood screws. Blocking was not used within the frame of the shearwalls.

A total of 15 shearwalls were manufactured and were classified into 7 test groups with different stud spacing, type of end stud and sheathing panel. The details of each shearwall are listed in Table 1.

2.2. Test procedure

Fig. 2 shows the test arrangement diagrammatically. The bottom plate of the shearwall was connected to the base beam of the test frame with six 12 mm-diameter bolts spaced at 400 mm. A loading beam was installed on the top plate of the wall, also fixed with six 12 mm-diameter bolts. Load was applied to the loading beam via a hydraulically-driven jack and was measured with a load cell. Lateral restraints were provided at the two ends of the loading beam, so that the loading beam can only move along a direction parallel to the wall. A through-height anchorage bolt 8 mm in diameter was applied to each end of the shearwall. The horizontal displacement at the top and bottom of the wall and the uplift at the base of the wall were measured with LVDT's. The shearwall was loaded at a rate of 1 mm/s, according to the prescribed cyclic displacement procedure following the ISO 16670 Protocol [14,15]. Since the monotonic tests were not conducted, the reference ultimate displacement Δ_m was chosen as 80 mm, based on tests of conventional shearwalls conducted by Chen [16]. The information of load and displacement was collected with the computer-controlled data acquisition system WS3811 at a frequency of 1 Hz. A shearwall undergoing test is shown in Fig. 3.

2.3. Test results

2.3.1. Test observations

For shearwalls sheathed with OSB panels on both sides in Groups II, IV and V and shearwalls sheathed with OSB panels on one side only in Groups VI and VII, as the walls were racked, the nail connections at the panel corners failed first, followed by failure of nail connections along the edges of the panel. For shearwalls sheathed with OSB panels on one side and gypsum panels on the other side in Groups I and III, the overall performance was similar. However, the nail connections of the two kinds of sheathings failed in sequence and not simultaneously. The nail connections of the gypsum panels failed earlier than those of the OSB panels. For all shearwalls, there were neither signs of fracture of the built-up studs nor slippage or withdrawal of the U-shaped nails that connected the two limbs and there were no signs of failure of the nail connections between the framing members, either. For shearwalls sheathed with OSB panels on one side only, no twisting of the studs was observed.

All shearwalls failed due to failure of the sheathing-to-frame nail connections. Four failure modes of the nail connections were identified. As shown in Fig. 4, the failure modes were pull-out of the nail from the stud, penetration of the panel, failure of sheathing panels (slotting and tearing-off) and failure of the nails and wood screws.

2.3.2. Summary of the test results

The recorded deflection was corrected by removing the effect of any rigid-body translations and rotations caused by slipping of the