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EXPERIMENTAL STUDY ON THE CONTRIBUTION OF GWB TO THE LATERAL PERFORMANCE OF WOOD SHEARWALLS

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ABSTRACT: It is well known that gypsum wall board (GWB) affects the structural performance of light wood frame buildings (LWFBs) constructed with wood-based shearwalls. However, there have been limited studies on the behaviour of the LWFBs with GWB in combination with wood-based sheathing under earthquake actions. As the first step to investigate the seismic response of LWFBs with GWB, the structural behaviour of shearwalls and the contribution of GWB were studied experimentally. Twelve (12) shearwalls sheathed with oriented strand board (OSB) or GWB alone, or in combination were tested under static monotonic or reversed cyclic lateral load. The structural performance of shearwalls in terms of lateral stiffness, strength, ductility, failure modes, load distribution between OSB and GWB were analyzed. Based on the tests, the influences of panel orientation, panel joint taping and double-layer GWB on the shearwalls were investigated. This test series provided essential information for the development of a super macro-element model to simulate the behaviour of shearwalls sheathed with OSB and GWB, and the simulation of the seismic behaviour of LWFBs considering the contribution of GWB.

KEYWORDS: Wood Structures, Shearwalls, Gypsum wall boards, Ductility, Seismic response

1 INTRODUCTION

In light wood frame buildings (LWFBs), shearwalls which provide the lateral resistance are constructed with dimension lumber and wood-based panels, such as oriented strand board (OSB). Nails are often used to fasten these components together which generally leads to ductile and energy absorbing capability. For fire resistant purpose, gypsum wall boards (GWBs) are commonly found on the interior face of the wood shearwalls.

It is well known that GWB contributes to the structural performance of the LWFBs [1-2]. However, the influence of GWB on the ductility, failure mechanism and load-transferring path of the LWFBs is still unknown. A study was undertaken to investigate the influence of GWB on the seismic response of the LWFBs.

The effect of single-layer GWB on the structural performance, in terms of load-carrying capacity and stiffness, of shearwalls has been studied by Wolfe [3], Ceccotti and Karacabeyli [4], Sinha and Gupta [5] and Zhu et al. [6] . It has been reported that the lateral resistance of walls sheathed with OSB and GWB appeared to be equal to the sum of the resistances of shearwalls sheathed with OSB or GWB only. However, the influence of GWB on ductility, which is used to determine an important seismic force modification factor, R_d, [7] of shearwalls concluded by Ceccotti and Karacabeyli [4] is different from that derived by Sinha and Gupta [5].

Hence, as the first step towards investigating and understanding the seismic response of LWFBs with GWB, the structural behaviour of shearwalls and the contribution of GWB were studied experimentally. The parameters studied were panel orientation, taping of panel joints and double-layer GWB.

2 TEST PROGRAM

2.1 MATERIALS

Spruce-pine-fir (SPF) dimension lumber of stud grade and dimensions 38 mm × 89 mm was used to build the frame of the shearwall test specimens. The density of SPF stud was about 480 kg/m^3. The lumber pieces were stored in the laboratory which had an environment that would provide about 12% moisture content in the lumber. Wood-based

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sheathing was 12.5mm thick sheathing grade OSB. Drywall panel was 15.9mm thick Type X grade GWB. Sheathing panel dimensions were 1220 mm × 2440 mm.

Fastening for the frame itself included 10d (φ3.8 × 76 mm) and 16d (φ4.1 × 89 mm) common wire nails which were used to connect together the framing members. The smaller nail was used when nailing thought double stud members. OSB panel was attached to the frame using 8d (φ3.5 × 63.5 mm) common wire nails. Drying wall screws, #6 (φ2.87 × 50.8 mm) and #10 (φ3.25 × 63.5 mm), were employed to fasten the GWB to the wood frame. Simpson HD3B hold-down and 15.9 mm diameter A307 anchor bolts were used. Drywall paper tape and compound were used to tape the GWB joints.

2.2 SHEARWALL TEST SPECIMENS

Twelve assemblies were fabricated, see Table 1. Two shearwalls with OSB (SW-M1) or GWB (SW-M2) only were tested under static monotonic load to derive the maximum loads and ultimate displacements; while the other ten shearwalls (SW-01,…, -10) were tested under reversed cyclic load.

Table 1: *List of shearwall test specimens*

No.	Sheathing	Fastener	Orientation*	Loading
SW-M1	OSB	8d	V	Monotonic
SW-M2	GWB	#6	V	Monotonic
SW-01	OSB	8d	V	Cyclic
SW-02	OSB	8d	H	Cyclic
SW-03	GWB	#6	V	Cyclic
SW-04	GWB	#6	V(Taping)	Cyclic
SW-05	2×GWB	#6, #10	V	Cyclic
SW-06	GWB	#6	H	Cyclic
SW-07	OSB + GWB	8d + #6	V	Cyclic
SW-08	OSB + GWB	8d + #6	V(Taping)	Cyclic
SW-09	OSB + 2×GWB	8d + #6, #10	V	Cyclic
SW-10	OSB + GWB	8d + #6	H	Cyclic

Note: * - H and V stand for 'Vertical' and 'Horizontal' panel orientation, respectively.

All shearwalls had the same dimensions of 2440 mm × 2440 mm (8 × 8 ft) and different types of sheathing panels (OSB, GWB, and OSB + GWB), GWB panel joint taping cases (with or without) and panel orientations (vertical and horizontal). Stud members were spaced at 406 mm on centre. The top plate and the end stud consisted of double members, while the bottom plate and the interior stud were built with single member only. The sheathing panels were connected to the framing members with common nails or drywall screws spaced at 150 mm around the panel perimeter and 300 mm elsewhere.

The taping of the GWB was achieved with drywall paper tape and compound using the taper edge treatment technique, as shown in Fig. 1. For double-layer of GWB cases, the seam in the upper layer was offset 406 mm from the seam in the base layer.

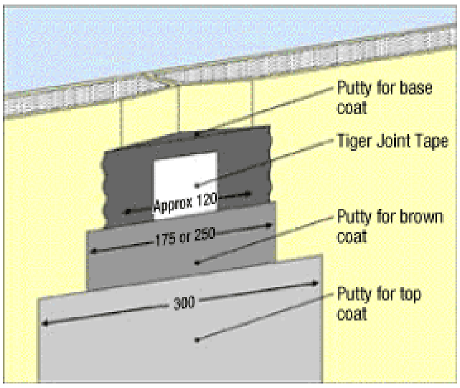


Figure 1: *GWB taping*

Prior to testing, assemblies were stored in the laboratory for at least two weeks to allow for wood relaxation around fasteners.

2.3 TEST SETUP

The shearwall test setup is shown in Figure 2. The end studs of each shearwall were fastened to the foundation beam by mechanical hold-down (Simpson HD3B) devices, and the bottom plate was attached to the foundation beam by 15.9 mm diameter A307 anchor bolts at 610 mm on centre. Similarly, the top plates were connected to the load beam with the same bolts and spacing. The lateral load was applied to the test specimen through a hydraulic actuator.

Figure 2: *Test setup and specimen SW-03*

All data were collected using electronic sensors. These included a load cell (89kN) with an accuracy of ± 1% of the full range, and several linear variable differential transformers (LVDT's) with an accuracy of ± 0.5% of their full ranges. All the data were recorded automatically by a data-acquisition system.

2.4 LOADING REGIMES

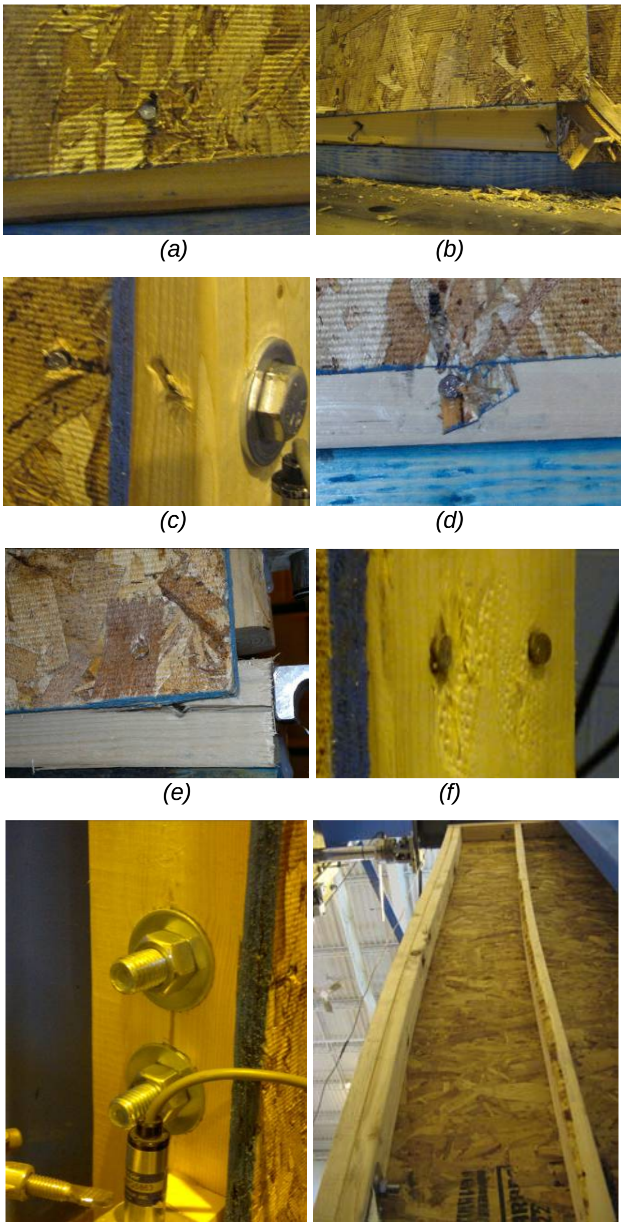
Two shearwall assemblies (SW-M1 and -M2) sheathed with OSB or GWB alone were tested under static monotonic load according to ASTM E564 [8] to derive the maximum loads and ultimate displacements which were used in establishing the loading regimes in the reversed cyclic loading tests. The lateral load was applied at a constant rate of displacement to reach the target (that is, limiting displacement) in no less than 5 min: 12mm/min for shearwalls sheathed with OSB only, 3mm/min for shearwalls sheathed with GWB only. At load levels approximately one-third and two-thirds of the estimated ultimate load, the load was removed and the recovery of the wall after 5 min was recorded. Reloaded the wall to the next higher load level above the back-off load. Continued loading and unloading in this manner until ultimate load was reached. In order to derive the ductility, the specimens were unloaded once the applied load decreased to 50% ultimate load.

The other ten shearwall assemblies were tested under reversed cyclic load in accordance with ASTM E2126 [9] to investigate the influence of the panel orientation, the panel joint taping and double-layer GWB on the structural performance of shearwalls. The ISO displacement schedule was employed as the load regime of this test. Displacement-controlled loading procedure that involves displacement cycles grouped in phases at incrementally increasing displacemnt levels was used. The ISO loading schedule consisted of two displacemnet patterns. The first displacement pattern consists of five single fully reversed cycles at displacement of 1.25%, 2.5%, 5%, 7.5% and 10% of the ultimated displacement Δ_m which was obtained from matched specimens in the monotonic test according to ASTM E564 [8]. The second displacement pattern consists of phases, each containing three fully reversed cycles of equal amplitude, at displacements of 20%, 40%, 60%, 80%, 100% and 120% of the ultimate displacement Δ_m. Loading rate was 60 mm/min.

3 RESULTS

3.1 FAILURE MODES

For the specimens sheathed with OSB only, SW-M1, -01 and -02, there are eight observed failure modes. As shown in Figure 3, they involve (1) panel-frame nail connections: (a) nails yielding with head embedding in OSB under shear, (b) nail head pull-through, (c) nail withdrawal from the framing member, (d) sheathing edges and (e) framing members torn by nails; (2) framing connections: (f) nail yielding between end studs; (3) hold-down connections: (g) washers embedment into studs; and (4) studs: (h) studs bending. In addition, nail withdrawal at bottom plate from studs happened to SW-M1 and 01, and stud failure at knots was found for SW-01 only, as shown in Figure 4.



(a) *(b)* *(c)* *(d)* *(e)* *(f)* *(g)* *(h)*

Figure 3: *Failure modes of shearwalls sheathed with OSB*

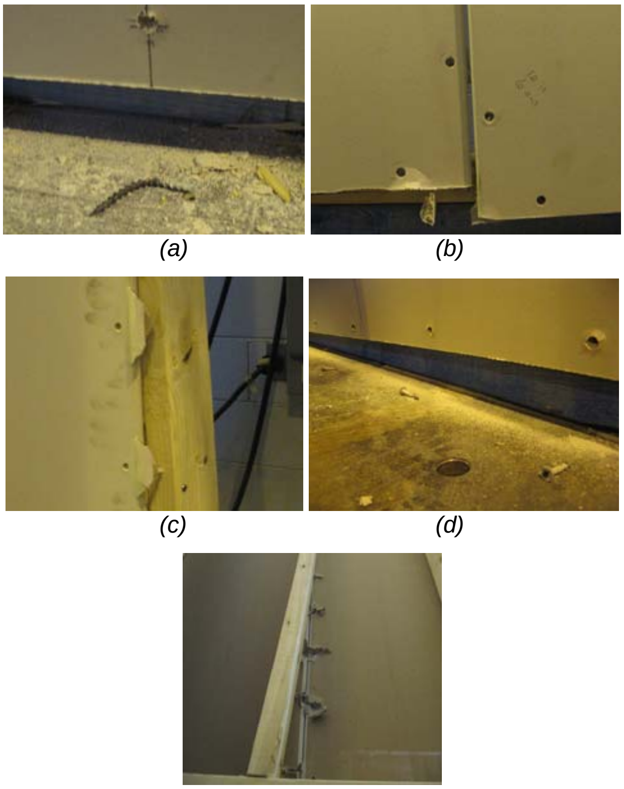
Note: (a) nail yielding with nail head embedding into OSB; (b) nail head pull-through the panel; (c) nail withdrawal from framing member; (d) OSB torn off by nail; (e) framing member torn off by nail; (f) yielding of nails between studs plus pull-out; (g) washers of hold-down connection embedment into studs; and (h) studs bending.

(a) (b)

Figure 4: *Failure modes of shearwalls sheathed with OSB*

Note: (a) nails between studs and bottom plate pull out; and (b) stud failure at knot.

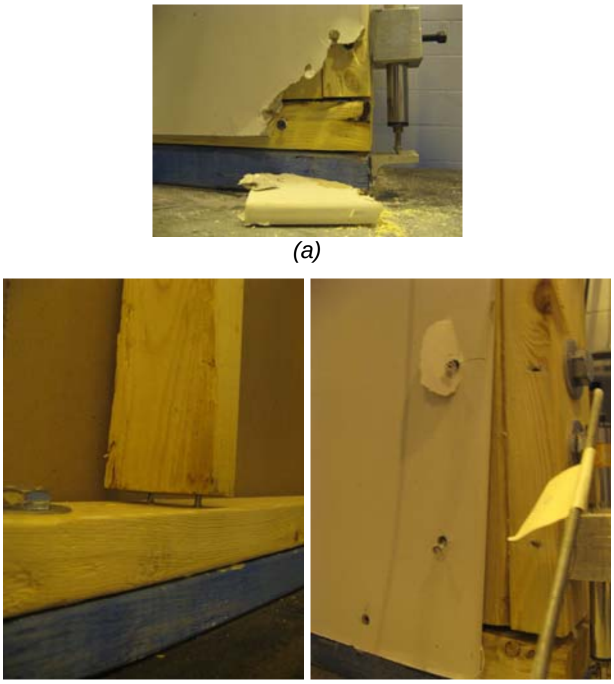
Regarding the specimens sheathed with GWB only, SW-M2, -03 to 06, five common failure modes were observed. As shown in Figure 5, they involve (1) panel-frame screw connections: (a) screw yielding under shear, (b) screw-head pull-through, (c) sheathing edges torn by screw, and (d) screw complete sheared off; and (2) stud: (e) stud bending. The tearing out of GWB corners and nails between bottom plate and studs pull out from studs occurred in most of the specimens except SW-06, whereas screw withdrawal from framing member happened in SW-05 only, as shown in Figure 6.



(a) (b) (c) (d) (e)

Figure 5: *Failure modes of shearwalls sheathed with GWB*

Note: (a) screw yielding; (b) screw head pull-through; (c) GWB torn off by nails; (d) screw sheared off; and (e) stud bending.



(a) (b) (c)

Figure 6: *Failure modes of shearwalls sheathed with GWB*

Note: (a) the corner of GWB torn off; (b) nails between studs and bottom plate pull-out; and (c) screw withdrawal from framing member.

With regard to the specimens sheathed with OSB and GWB, SW-07 to 10, similar failure modes of shear walls sheathed with OSB or GWB were evident on OSB and GWB face, respectively. To the specimens with panel joint taping, SW-04 and 08, there was no failure in the tapping joints.

3.2 TEST RESULTS

The load-displacement curves of shearwalls under static monotonic loading and the typical hysteresis loops of specimens under reversed cyclic loading are shown in Figures 7 and 8.

Analysis of test results was carried out in accordance with the equivalent energy elastic-perfectly-plastic (EEEP) curve given in ASTM Standard E2126 [8]. The yield load, F_y, as defined in ASTM 2126 can be determined as follows, see Figures 7 and 8.

$$F_y = \left(\Delta_u - \sqrt{\Delta_u^{\,2} - \frac{2E}{K_y}} \right) K_y \tag{1}$$

where K_y is the initial (yield) stiffness, which is the secant stiffness between zero and 40% of the ultimate load; E is the energy dissipated at the ultimate displacement; and Δ_u

is the ultimate displacement in post maximum load region where the load dropped to 80% of the maximum load, F_{max}.

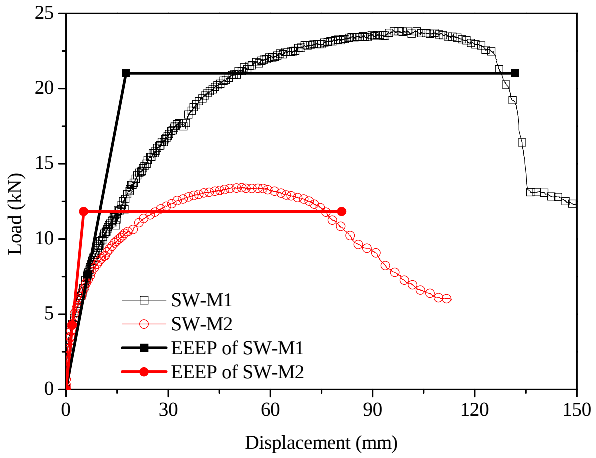
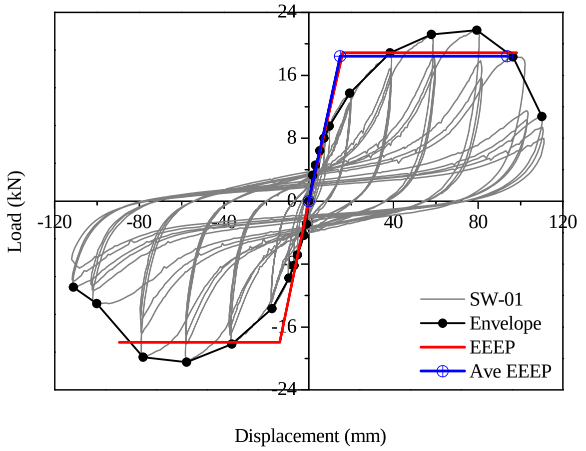
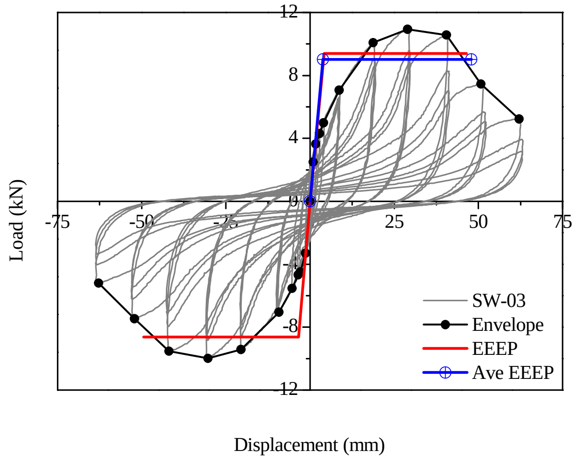


Figure 7: *Load-displacement curves of shearwalls under static monotonic loading*



(a) Shearwall sheathed with OSB only (SW-01)



(b) Shearwall sheathed with GWB only (SW-03)

Figure 8: *Load-displacement curves of shear walls under reversed cyclic loading*

A summary of the test results under static monotonic and reversed cyclic loading is provided in Table 2. In the table, the values for specimens under reversed cyclic loading, SW-01 to 10, are the average of positive and negative envelope curves (Figure 6).

Table 2: *Test results of shearwalls under monotonic and cyclic loading*

No.	K_y (kN/mm)	F_y (kN)	Δ_y (mm)	$F_{\max}$ (kN)	Δ_{Fmax} (mm)	Δ_u (mm)	μ
SW-M1	1.19	21.0	17.6	23.9	96.1	131.8	7.5
SW-M2	2.26	11.8	5.2	13.4	51.4	80.9	15.5
SW-01	1.24	18.4	14.9	21.1	68.5	93.8	6.3
SW-02	2.43	12.2	5.4	14.2	41.0	70.7	13.9
SW-03	2.39	9.0	3.8	10.5	29.6	47.9	12.8
SW-04	2.19	10.2	4.6	12.2	28.8	37.2	8.0
SW-05	2.95	22.4	7.6	25.3	35.3	64.7	8.5
SW-06	1.87	6.7	3.6	7.6	25.1	45.4	12.6
SW-07	2.67	25.8	9.7	29.7	53.3	82.0	8.5
SW-08	2.01	22.4	11.2	26.6	43.7	60.8	5.4
SW-09	3.19	33.1	10.5	38.3	44.3	61.5	5.9
SW-10	2.83	17.9	6.3	20.7	38.8	88.8	14.0

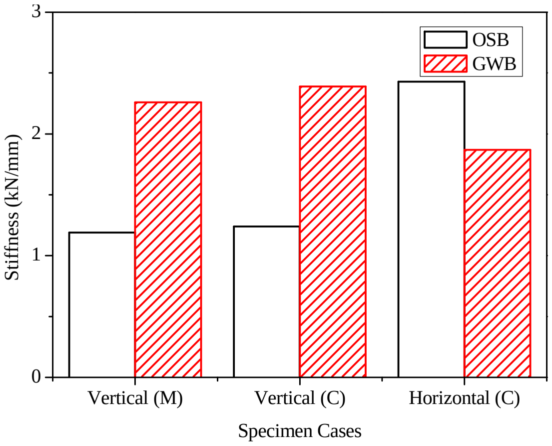
Note: μ is the ductility ratio, which is Δ_u divided by Δ_y.

4 DISCUSSIONS

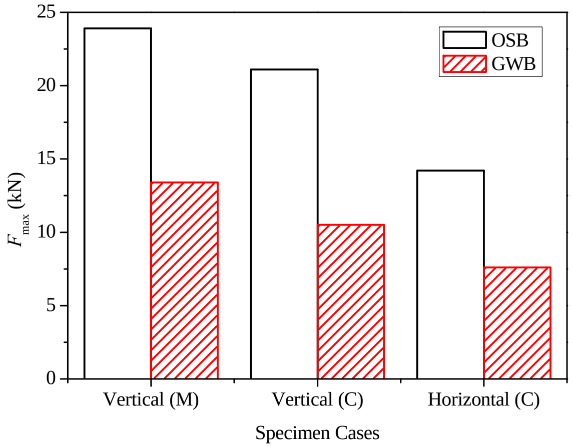
4.1 PERFORMANCE OF SHEARWALLS

Specimens SW-M1 and 01 were sheathed with single OSB only, while SW-M2 and 03 were sheathed with single GWB without taping. These specimens were sheathed with panels oriented vertically. The specimens SW-M1 and M2 were loaded monotonically, and specimens SW-01 and 03 were tested under reversed cyclic loading. The structural performance, in terms of stiffness, strength and ductility ratio, of these specimens is compared in Figure 9.

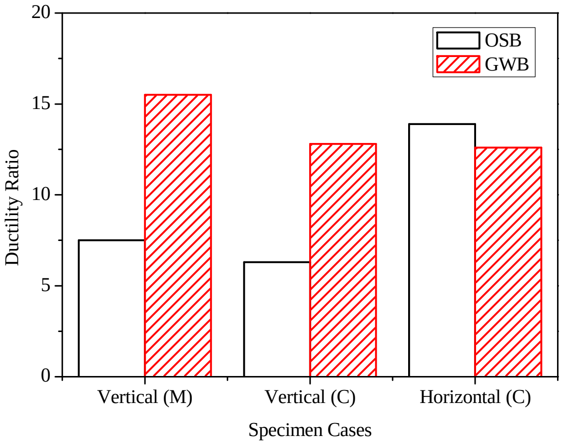
It shows that, the reversed cyclic loading increases the stiffness but decreases the strength and ductility ratio of shear wall regardless of OSB and GWB; and within the range of parameters studied here, the shearwalls with OSB possess higher strength and lower stiffness and ductility ratio by comparison with shearwalls with GWB. The effect of reversed cyclic loading and the relationships of stiffness and strength between OSB and GWB are expected. However, that of ductility ratio deviates from common understanding. The lateral performance of shearwall with wood-based sheathing is usually regarded as ductile, whereas that of shearwall with GWB is considered non-ductile because of the brittle nature of the gypsum material. The hysteresis loops and the EEEP curves shown in Figure 8 confirm this finding. Although the ductility ratio of shearwalls with OSB is less than that of shearwalls with GWB due to the latter's higher stiffness, it possesses larger deformation capability, Figure 7.



(a) Stiffness



(b) Strength



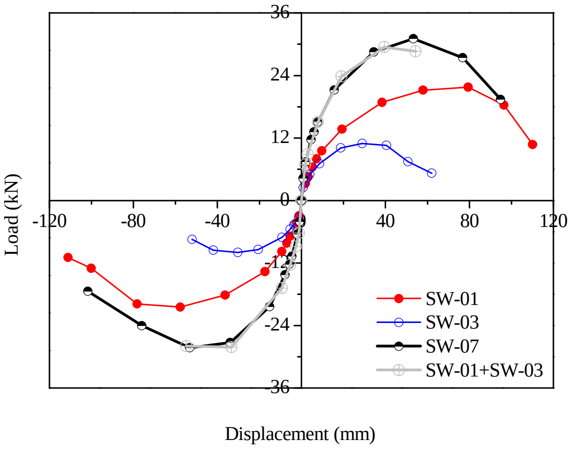
(c) Ductility ratio

***Figure 9:** Performance comparison of shearwalls*

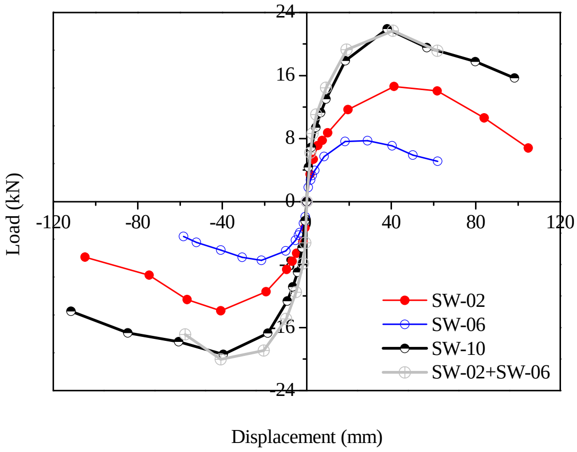
4.2 EFFECT OF PANEL ORIENTATION

Of particular interests in this paper is the influence of panel orientation on the structural behaviour of the shearwalls sheathed with OSB and GWB. The structural performance of specimens SW-02 and 06, which were sheathed with single horizontal OSB or GWB without taping alone, are also shown in Figure 9 as well. It shows that the specimens sheathed with OSB oriented vertically possess higher strength and lower stiffness and ductility ratio than those with OSB oriented horizontally. For shearwalls with GWB, those with vertical panel orientation possess higher lateral strength and stiffness than those with horizontal panel orientation. Ductility ratios, however, are similar for the two orientations.

Another point of interest in this project is whether the lateral strength of OSB and GWB on opposite faces of a shearwall is cumulative. The load-displacement envelope curves of specimens, SW-01, 03 and 07, with vertical sheathing panels are shown in Figure 10a, along with a response curve developed by summing curves of SW-01 and 03. It is noted that the combined curve matches the curve of SW-07 well. It indicates that the lateral resistance of shearwall sheathed with OSB and GWB on each face can be estimated by summing those of shearwalls with OSB and GWB only. A similar conclusion can be drawn for shearwalls with horizontal sheathing panels, Figure 10b.



(a) Specimens sheathed vertically



(b) Specimens sheathed horizontally

***Figure 10:** Envelope curves of specimens with single GWB without taping*

4.3 EFFECT OF PANEL JOINT TAPING

Comparing the load-displacement response of GWB shearwalls without (SW-03) and with (SW-04) panel joint taping, it can be noticed that taping increases the strength but decreases the stiffness and ductility ratio, as shown in Table 2 and Figure 11.

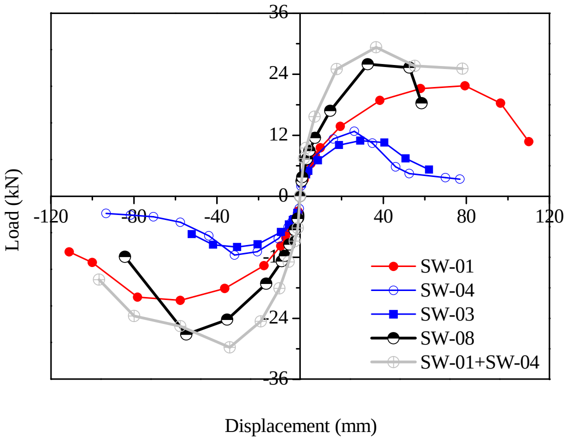


Figure 11: *Effect of panel joint taping*

The envelope curves of specimens sheathed with OSB (SW-01) and GWB without (SW-03) and with (SW-04) taping alone, and in combination (SW-08), and a load-displacement curve developed by summing curves of SW-01 and 04 are shown in Figure 11. It shows that the curve of SW-08 dose not go with the combined curve. The combined curve exhibits slightly higher lateral strength and stiffness than the test curve of SW-08. It means that, unlike that for shearwall with untapped joint, the lateral resistance of shearwall sheathed with OSB and GWB with panel joint taping on each side cannot be estimated by summing those of shearwalls with OSB and GWB alone.

4.4 EFFECT OF DOUBLE-LAYER OF GWB

The use of double-layer GWB increases the stiffness and strength but decreases the ductility ratio of shearwalls, as shown in Table 2 and Figure 12, comparing the structural performance between specimens sheathed with single-layer (SW-03) and double-layer (SW-05) GWB with the panel oriented vertically.

The envelope curves of specimens sheathed with OSB (SW-01), single- (SW-03) and double-layers GWB (SW-05) alone, and in combination (SW-09), and a load-displacement curve developed by summing curves of SW-01 and 05 are shown in Figure 12. It is interesting to note that the lateral strength of double-layer GWB shearwall (SW-05) is about 2.5 times that of single-layer GWB shearwall. Similar to results shown for tapped panel joints, the combined curve does not match the curve of SW-09, indicating that the lateral resistance of shearwalls sheathed with OSB and double-layer GWB on each face cannot be estimated by summing those of shearwalls with OSB and double-layer GWB alone.

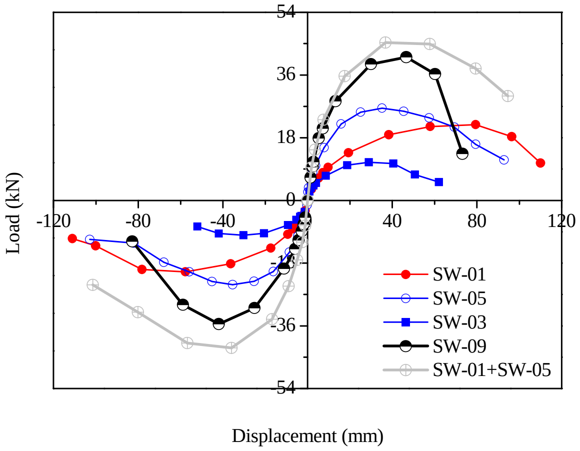


Figure 4: *Effect of double-layer GWB*

5 CONCLUSIONS

In total, 10 shearwalls were tested under reversed cyclic lateral load to investigate the structural behaviour of shearwalls sheathed with OSB or GWB only, or in combination. Two reference shearwall specimens were also tested under monotonic loading to help define the reversed cyclic loading regime. Based on these tests, the influence of panel orientation, panel joint taping and double-layer GWB on the shearwalls was researched, and the following conclusions can be drawn.

- Contrary to common belief, there is evidence to indicate that shearwalls sheathed with GWB provide ductility ratios similar to that of OSB sheathed shearwalls, although OSB sheathed shearwalls exhibit larger ultimate deformation.
- Shearwalls sheathed with OSB oriented vertically possess higher strength and lower stiffness and ductility ratio, while shearwalls sheathed with vertically oriented GWB have higher or similar structural performance, in comparison with parallel shearwalls with sheathing panels oriented horizontally.
- Irrespective of panel orientation, the lateral resistance of shearwalls sheathed with OSB and GWB on opposite faces can be estimated by summing those of shearwalls with OSB or GWB alone.
- Either panel joint taping or double-layer GWB increases the strength and decreases the ductility ratio of shearwalls. However, double-layer GWB increases the stiffness of shearwalls whereas taping of panel joint do the opposite.
- For shearwalls with panel joint taping on GWB or double-layer GWB, the lateral resistance cannot be

estimated by summing those of shearwalls with OSB and single- or double-layer GWB alone.

For further investigation, a super macro-element model for simulating the dynamic behaviour of the shearwalls sheathed with OSB and GWB will be developed. These will be implemented in a system finite element (FE) models which can be used to investigate the contribution of the GWB to the LWFBs under earthquake actions. Further work will also include testing of screw joint specimens with practical edge and end spacing [10] and different GWB thicknesses, screw sizes and lumber properties to help explain the shearwall test observations, and expand the findings to other construction parameters.

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