COMPARISON OF SEISMIC PERFORMANCE ON PLASTERBOARD BRACING WALLS AND PLYWOOD SHEAR WALLS IN THE CONTEXT OF NEW ZEALAND LIGHT TIMBER-FRAMED STRUCTURES

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ABSTRACT

Most residential buildings in New Zealand are low-rise light timber-framed (LTF) buildings in which plasterboard bracing walls form the main lateral load-resisting system to resist wind and seismic forces. Occasionally plywood shear walls are also used in order to provide higher bracing capacity due to limited wall length. Past studies have suggested that the seismic performance of plasterboard bracing walls differs significantly from that of plywood or OSB shear walls which are commonly used in North America. In the 2011 Canterbury earthquakes, LTF houses performed generally well in terms of life safety. However, the total cost incurred to fix all house-related damage was about NZ$12 billion. Although plasterboard bracing walls are the key to the seismic performance of the majority of New Zealand LTF structures, research to quantify their seismic performance is still limited. In this study, seismic performances of plasterboard bracing walls and plywood sheathed walls are compared based on experimental test results. Several factors affecting the wall performance are analyzed. A series of numerical models are developed for plasterboard bracing walls and plywood shear walls based on experimental results from walls of different lengths. Then, a case study of time-history analysis is conducted to compare the seismic performance of LTF structures with plasterboard bracing walls and plywood sheathed walls.

Keywords: plasterboard bracing wall, light timber-framed structure, macro model

1 INTRODUCTION

In general, New Zealand low-rise light timber frame (LTF) residential houses built to the New Zealand modern design codes are considered to have a low risk of collapse. This was verified in the 2010-2011 Canterbury Earthquake Sequence, that includes the 2010 Darfield earthquake (Mw 7.1) and the 2011 (Mw 6.3) Christchurch earthquake. In this earthquake sequence, LTF houses performed generally well and achieved life safety [1]. However, a large number of LTF residential buildings with plasterboard bracing walls suffered from different types of damage, such as cracks on plasterboards in lower story walls or detachment of plasterboards from the wall frames [1][2]. The damage to the LTF houses caused unprecedented economic losses and the total cost to fix all housing-related damage was approximately NZ$12 billion [3].

The majority of residential buildings in New Zealand are low-rise LTF buildings, in which plasterboard sheathed LTF walls are widely used as the gravity and lateral load-resisting systems [4]. Over 90% of LTF proprietary bracing systems are plasterboard bracing walls [5]. A typical plasterboard bracing wall consists of a light timber frame with plasterboards sheathed on both sides or plasterboard on one side and a wood-based panel on the other. The plasterboards for walls are also known as gypsum wallboards (GWB) or drywalls.

LTF residential buildings in New Zealand are unique because they universally rely on LTF walls sheathed by plasterboards for seismic bracing. In other countries, such as the United States and Canada, it is common for wood shear walls in LTF buildings to be sheathed by wood-based sheets, such as plywood or oriented strand board (OSB) [6][7]. And if plasterboard sheathings are used, they are not considered to make a contribution to the bracing capacity of LTF buildings. In general, plasterboards are weaker and more brittle than OSB or plywood sheets, and the fixing method of plasterboard sheets to timber framing (screws) is also different from that of wood-based sheathing (nails). Some studies claimed that plasterboard sheathed walls have different racking responses from bracing walls sheathed with wood-based panels [6][8][9], but research to quantify the difference of their seismic performance is still limited. Meanwhile, little analytical or numerical modelling work has been conducted to assess the performance of New Zealand plasterboard bracing walls, which also limits in-depth studies on the seismic performance and loss assessment of the New Zealand LTF residential buildings.

In this study, seismic performance of plasterboard bracing walls and plywood sheathed walls are compared at the wall component and building system levels. A test database of plasterboard bracing walls and plywood sheathed walls is collected from the Building Research Association of New Zealand (or BRANZ). A series of macro models are developed for plasterboard bracing walls and plywood shear walls based on test data from walls of different lengths. Several factors affecting the wall performance are analyzed. Then, a case study of time-history analysis is conducted to compare the seismic performance of LTF structures with plasterboard bracing walls and plywood sheathed walls.

2 DATA AND METHOD

2.1 BRANZ Bracing Wall Test Database

BRANZ in New Zealand is dedicated to research in building performance and develop better building solutions. Over the years, their research team has conducted many tests to assess performance of LTF bracing walls for building construction. In order to further investigate the seismic performance of plasterboard bracing walls and plywood sheathed walls, three groups of quasi-static test results for these two types of walls were collected from BRANZ. All these tests were conducted following the P21 wall test procedure [10]. The test method is used to determine the seismic bracing capacity of proprietary LTF shear walls that can be used for timber framed buildings in compliance with NZS 3604:2011 [11]. As shown in Figure 1, the P21 test is a cyclic racking test with the loads applied at the top of the wall specimen. Figure 2 shows the P21 displacement-controlled loading protocol with a series of incremental displacement cycle groups. Each group has three identical cycles. The resisting forces of the specimen are measured by a load cell from the actuator.

The following factors affecting wall performance were considered in collecting the wall test data: type of sheathing materials, wall length, presence or absence of hold downs, and single- or double-sided sheathing. Table 1 shows the construction parameters of the walls tested in the collected database. Group 1 contains three types of plasterboard bracing walls without hold downs, with lengths of 0.4 m, 0.6 m and 1.2 m respectively. There are four test specimens for 0.4m and 1.2m plasterboard bracing walls, and one specimen for 0.6m plasterboard bracing wall. Group 2 contains three types of plywood sheathed walls without hold downs, with lengths of 0.4 m, 0.6 m, 1.2 m and 2.4 m respectively. Each type of plywood sheathed wall has three specimens. Group 3 contains four types of 1.2m long LTF wall with hold downs,

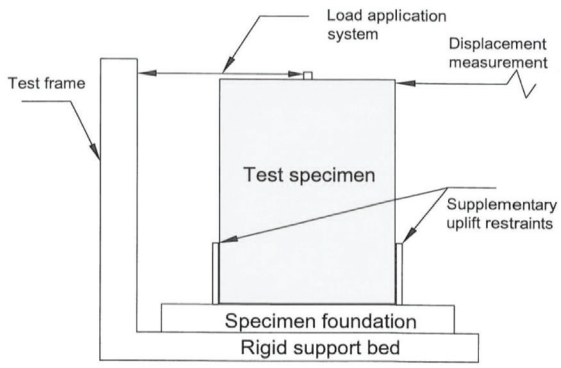

Figure 1. P21 Test arrangement.

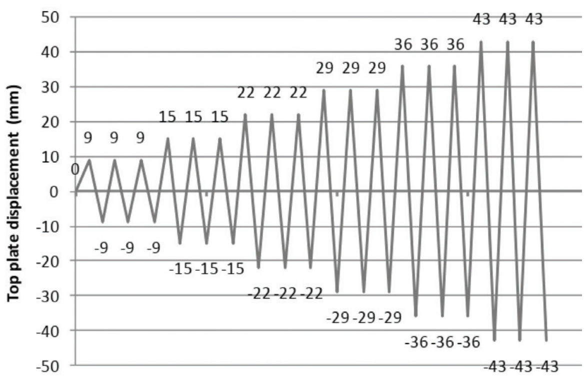

Figure 2. Incremental series of cyclic lateral in-plane displacement set in P21 test.

Table 1. The construction features of the walls tested in the collected database.

Group	Test set	Length (m)	Height (m)	Side 1	Side 2	Hold-Downs?	Number of Replicates	Fastener type
1	G1PB1	0.4	2.4	Bracing Plasterboard	N/A	No	4	Screws
	G1PB2	0.6	2.4	Bracing Plasterboard	N/A	No	1	Screws
	G1PB3	1.2	2.4	Bracing Plasterboard	N/A	No	4	Screws
2	G2PW1	0.4	2.4	7mm Plywood	N/A	No	3	Nails
	G2PW2	0.6	2.4	7mm Plywood	N/A	No	3	Nails
	G2PW3	1.2	2.4	7mm Plywood	N/A	No	3	Nails
	G2PW4	2.4	2.4	7mm Plywood	N/A	No	3	Nails
3	G3PB1	1.2	2.4	Bracing Plasterboard	N/A	Yes	3	Screws
	G3PB2	1.2	2.4	Bracing Plasterboard	Bracing Plasterboard	Yes	3	Screws
	G3PW1	1.2	2.4	7mm Plywood	N/A	Yes	3	Nails
	G3PW2	1.2	2.4	7mm Plywood	Standard Plasterboard	Yes	3	Nails

including single-sided plasterboard bracing wall, double-sided plasterboard bracing wall, single-sided sheathed plywood wall, and double-sided sheathed plywood wall (one side sheathing by plywood sheet and the other side sheathing by standard plasterboard). It should be noted that the plasterboards used in bracing walls are different from standard plasterboards. The bracing plasterboards are stronger and stiffer than standard plasterboards due to different recipes used in manufacturing. Typically, standard plasterboards are used in the inner side of plywood sheathed walls. The plywood sheets in the plywood sheathed walls were all 7mm thick. Plasterboards were fixed to timber frames by screws while plywood sheets were fastened with nails. The construction details of these walls from P21 tests were in accordance with the New Zealand standard NZS3604.

2.2 Macro models for LTF bracing walls

Based on the above wall tests data, numerical models were developed for the plasterboard bracing walls and plywood sheathed walls with different lengths. A search method was used to calibrate the model parameters to match the wall test results. The calibrated wall models were then used to simulate the wall responses under static or dynamic loads. Furthermore, these wall models can be added to the numerical building models for nonlinear time-history analysis of LTF structures.

Timber shear wall models can be classified into two main types: the detailed finite element (FE) model and the macro element model. The detailed FE model explicitly models all components of a timber shear wall and can capture the response of nailed joints and sheathing panels, while the macro element model is highly simplified and aims to capture the global load-drift responses of the wall. In order to balance the computational efficiency and prediction accuracy, this study used a mechanics-based macro model named "pseudo-nail" model. According to the fact that the nail connections and the wood shear wall show similar hysteretic behavior, the "pseudo-nail" model was adapted from a detailed nail connection model called HYST [12], as shown in Figure 3.

The model parameters include the nail length L, nail diameter D and additional six parameters to describe the compressive properties of the wood embedment. The "pseudo-nail" model is computationally efficient and more robust than the empirical curve-fitted models. A revised version of the modified HYST algorithm was developed by [13] which can fully address the strength/stiffness degradation and pinching effect in wood connections. This "pseudo-nail" model has been implemented into a structural analysis tool called "PB3D" [14] which is able to conduct nonlinear time history analysis for timber houses. In this three-dimensional analysis platform, the diaphragms are modelled by beam elements and diagonal truss elements considering the in-plane stiffness, and beams and posts are modelled by elastic beam elements. The shear walls are modelled by the "pseudo-nail" model mentioned above. The uplifting

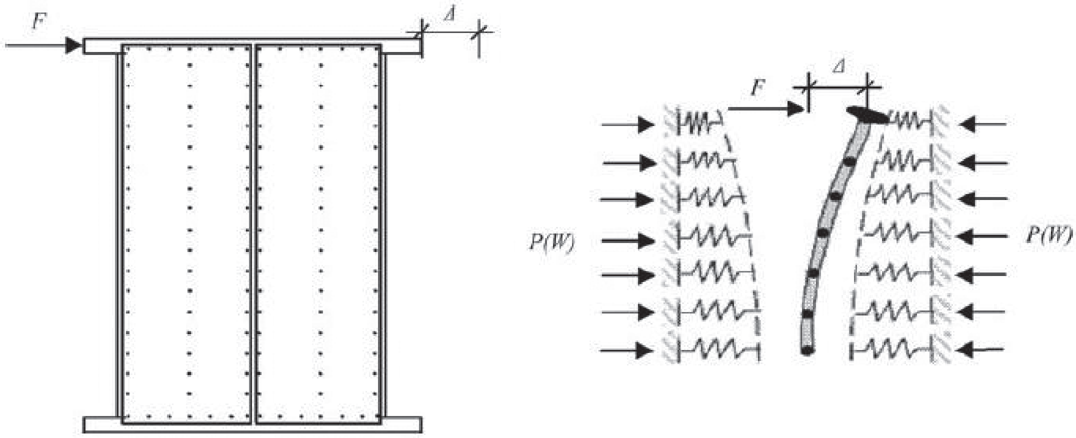

Figure 3. The "pseudo-nail" model [14].

is simply prevented by wall post elements which are fully end-restrained onto the foundation or stories.

3 DATA ANALYSIS ON PERFORMANCE OF PLASTERBOARD BRACING WALLS AND PLYWOOD SHEATHED WALLS

The critical outcomes of the P21 wall tests are the hysteretic load-drift curves of the walls. The skeleton/backbone curves of the hysteretic curves are obtained by connecting the load extreme points of positive or negative loops. Backbone curves are used to characterize wall properties and validate numerical wall models. The average maximum loads and the drifts at the maximum load of all specimens for each type of walls are listed in Table 2. It is noted that the loads of some short walls did not decrease even at the end of the P21 test (displacement up to 43mm). For these cases, the peak loads in the tests were assumed to be the maximum forces that the walls could resist.

3.1 Effect of Type of Sheathing Material

The material of sheathing panels in LTF shear walls is often considered one of the main factors affecting the performance of LTF walls. The collected test results verified that there were significant differences between the plasterboard bracing wall and the plywood sheathed wall. Figure 4 illustrates the average maximum loads of the walls sheathed by different materials. Each pair of two adjacent columns represents the maximum loads of two wall types with the same construction details but different sheathing materials. It can be seen that the maximum loads of plasterboard bracing walls were lower than that of

Table 2. The average maximum loads and drifts at the maximum load of each type of walls.

Group	Test set	Length (m)	Side 1	Side 2	Hold-Downs?	Average Max Load (kN)	Average Drift at Max Load
1	G1PB1	0.4	Bracing Plasterboard	N/A	No	1.26	1.78%
	G1PB2	0.6	Bracing Plasterboard	N/A	No	1.77	1.41%
	G1PB3	1.2	Bracing Plasterboard	N/A	No	3.91	0.90%
2	G2PW1	0.4	7mm Plywood	N/A	No	1.36	1.69%
	G2PW2	0.6	7mm Plywood	N/A	No	2.17	1.73%
	G2PW3	1.2	7mm Plywood	N/A	No	4.95	1.45%
	G2PW4	2.4	7mm Plywood	N/A	No	11.71	1.18%
3	G3PB1	1.2	Bracing Plasterboard	N/A	Yes	7.42	0.81%
	G3PB2	1.2	Bracing Plasterboard	Bracing Plasterboard	Yes	11.19	0.99%
	G3PW1	1.2	7mm Plywood	N/A	Yes	8.96	1.67%
	G3PW2	1.2	7mm Plywood	Standard Plasterboard	Yes	11.32	1.45%

plywood sheathed walls. The difference was more significant for 1.2 m long single-sided sheathed walls with or without hold downs. The average maximum load of 1.2 m long single-sided plasterboard bracing walls without hold downs was 79.0% of that of 1.2 m long single-sided plywood sheathed walls, and the average maximum load of 1.2 m long single-sided plasterboard bracing walls with hold downs was 82.9% of that of 1.2 m long single-sided plywood sheathed walls. However, the double-sided walls with hold downs had similar peak loads. The possible reason was that maybe hold-down failure governed the peak load rather than the sheathing failure.

Figure 5 illustrates the average drift ratios at the maximum loads of the walls. The average drifts of plasterboard bracing walls at the maximum loads were lower than those of the plywood sheathed walls, i.e., 18.7% lower for 0.6 m long single-sided sheathed walls without hold downs, 37.9% lower for 1.2 m long single-sided sheathed walls without hold downs, 51.7% lower for 1.2 m long single-sided sheathed walls with hold downs, and 31.7% lower for 1.2 m long double-sided sheathed walls with hold downs. One exception was that the drifts of 0.4 m long single-sided plasterboard bracing walls at the maximum loads were slightly higher than those of the plywood counterparts. The possible reason was that the maximum drift of the P21 tests was 43 mm and these narrow 0.4 m long walls may not be able to reach the ultimate load at this drift level. If these narrow walls were subjected to sufficiently large displacement, the similar behavior to the wall lengths would likely be overserved.

The difference in energy dissipation capacity of these walls using different sheathing materials can be assessed by calculating the enclosed areas by the hysteretic load-drift curves. As an example, Figure 6 shows the hysteretic load-drift curves and back-bone curves of the 1.2 m long single-sided sheathed walls without hold downs. The hysteretic load-drift curve of the plywood sheathed wall (G1PB3) was fatter and more stable than those of the plasterboard bracing wall (G2PW3). The plasterboard bracing walls had much more pinching, leading to much lower energy dissipation capacity than the plywood sheathed walls.

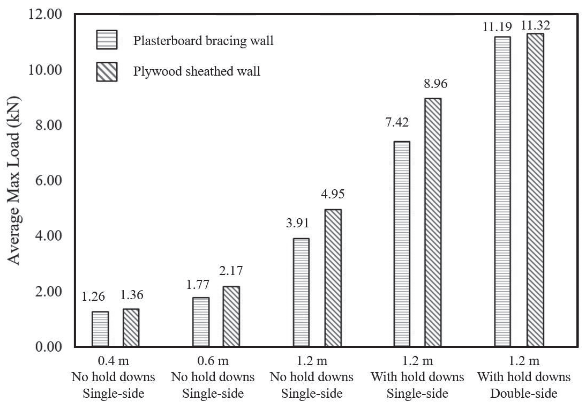

Figure 4. Maximum loads of walls sheathed by different material panels.

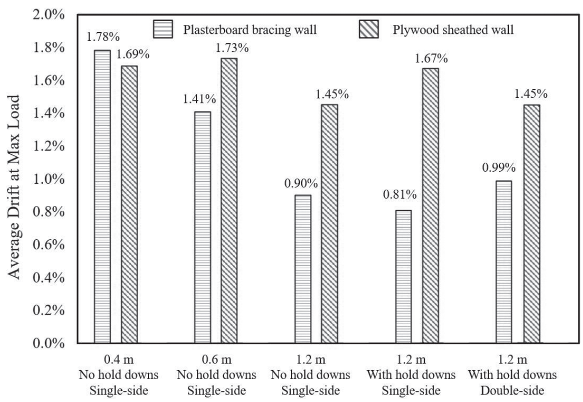

Figure 5. Drifts at the maximum loads of walls sheathed by different material panels.

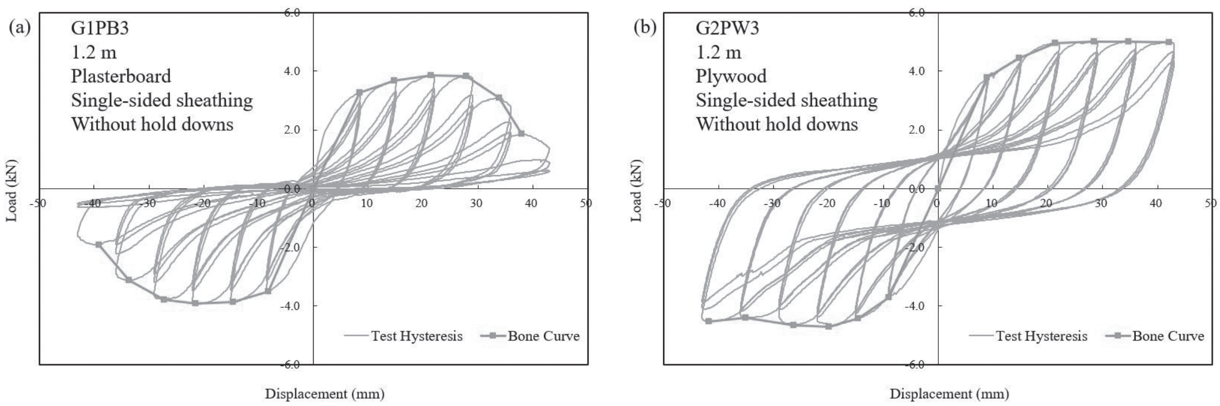

Figure 6. Hysteretic load-drift curves and back-bone curve curves of walls: (a) G1PB3 plasterboard bracing wall; (b) G2PW3 plywood sheathed wall.

The energy dissipation of the plasterboard bracing wall G2PW3 was 1342.19 kN•mm, which was much lower than that of the plywood sheathed wall G1PB3 (3072.69 kN•mm).

3.2 Effect of Wall Length

Wall length is another factor affecting wall performance. Figure 7 illustrates the maximum loads of all single-sided sheathed walls without hold downs. As shown by the trend lines, the maximum loads and wall length had approximately a linear positive correlation. The trend lines fit the data point well with R^2>0.98. This was consistent with the findings in the literature [15].

As per Liu and Carradine [5], the total in-plane deformation of this type of walls was attributed to its flexural deformation, shear deformation, slip deformation and uplift deformation, as follows:

$$\Delta_{total} = \Delta_{flexural} + \Delta_{shear} + \Delta_{slip} + \Delta_{uplift} \qquad (1)$$

The expressions to estimate these sub-displacements were assumed as follows:

$$\Delta_{flexural} = \frac{2VH^3}{3EA_C L^2} \qquad (2)$$

$$\Delta_{shear} = \frac{HV}{GtL} \qquad (3)$$

$$\Delta_{slip} = \frac{C_1 V}{L} \qquad (4)$$

$$\Delta_{uplift} = \frac{C_2 HV}{L} \qquad (5)$$

where V is the racking load at the top of the wall, H is the wall height, L is the wall length, E is the modulus of elasticity of timber studs, A_c is the cross-sectional area of the chord members, G is the shear modulus of plasterboard, t is the total thickness of plasterboard, C_1 and C_2 are two coefficients. As discussed above, the ultimate strength of plasterboard bracing walls has a linear relationship with the wall length, which means V_{max}=C×L. Substituting this relationship into Eq. (1) to

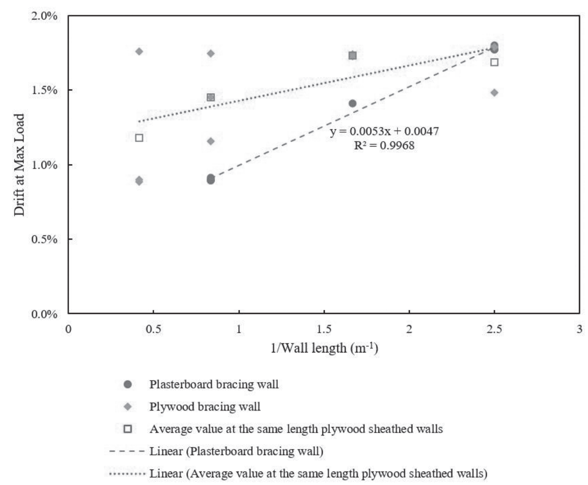

Figure 8. Effect of wall length on drift at maximum load.

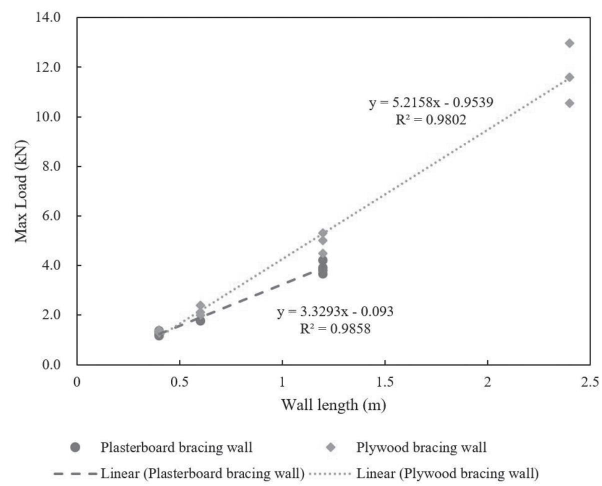

Figure 7. Effect of wall length on maximum load.

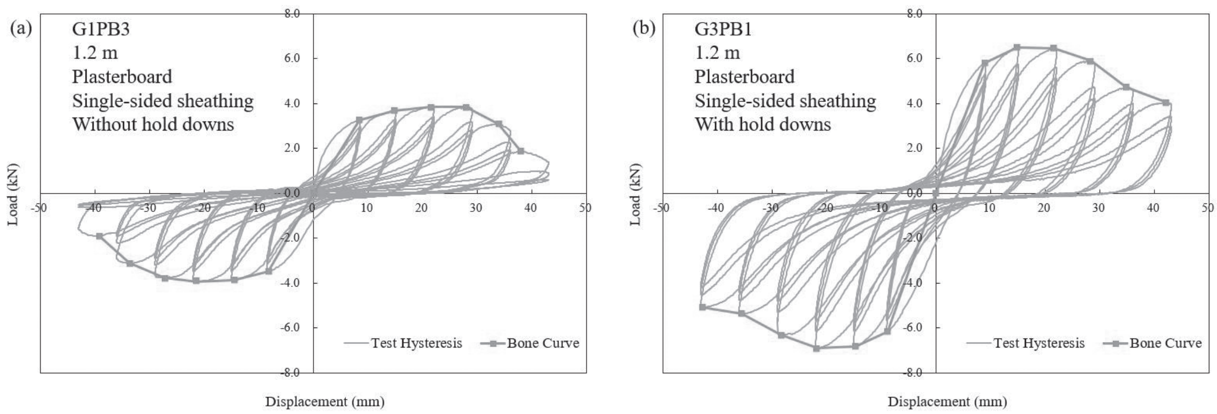

Figure 9. Hysteretic load-drift curves and back-bone curve curves of walls: (a) G1PB3 plasterboard bracing wall without hold downs; (b) G3PB1 plasterboard bracing wall with hold downs.

(5), the total deflection at the maximum load can be expressed as:

$$\Delta_{total} = \frac{C_3}{L} + C_4 \quad (6)$$

where C_3 and C_4 are two new coefficients. This means that the total wall deflection at the maximum load and the inverse of the wall length (1/L) had a linear relationship. Figure 8 illustrates the drifts at the maximum loads of all single-sided sheathed walls without hold downs. It shows that, for the plasterboard wall, the drift at the maximum load increased linearly with the increase of the inverse of the wall length. For plywood sheathed walls, the data points at each length were relatively discrete, but the average value at the same length also had a positive correlation with the inverse of the wall length.

3.3 Effect of Presence of Hold Down and Single- or Double-sided Sheathing

The test results showed hold downs significantly affected the capacity of the walls. With hold downs, the maximum loads increased from 3.91 kN to 7.42 kN and from 4.95 kN to 8.96 kN for the 1.2 m long single-sided plasterboard bracing walls and plywood sheathed walls, respectively. Figure 9 illustrates the hysteretic load-drift curves and skeleton curves of 1.2 m plasterboard walls with and without hold downs. It can be seen that the wall with hold downs had less pinching and the energy dissipation capacity was significantly improved.

The test results also show that double-sided sheathing improved the wall strength and energy dissipation capacity. By adding one more sheathing, the maximum load of the 1.2 m long plasterboard wall with hold downs increased from 7.42 kN to 8.96 kN. However, for the plywood wall, it increased from 11.19 kN to 11.32 kN only. Due to the lack of more detailed information, it is unclear why the increase in plywood walls was minimal. It was likely the hold-down failure governed the ultimate strength of the plywood walls, but it needs further research to confirm.

4 MACRO MODELS FOR PLASTERBOARD WALLS AND PLYWOOD WALLS

Based on the experimental test database, shear wall models for the 11 types of New Zealand plasterboard bracing walls and plywood sheathed walls were developed. As introduced in the method section, the modelling process was to calibrate the parameters in the HYST wall models so that hysteretic load-drift curves of the models match the test results. For each wall type, the result of the wall with median strength was taken as the target for modelling. The model parameters were preliminarily determined based on the back-bone curve. Then the model was subjected to the same displacement protocols in P21 tests to further validate the model accuracy under cyclic loads. The model parameters were iteratively changed to match the experimental hysteretic curves, including pinching and strength degradation.

Using wall G3PB1 as an example, the hysteretic load-drift curve of the test and the HYST model predictions are illustrated in Figure 10. It shows that the overall model predictions agreed well with the test results in terms of the maximum load at each displacement level, pinching and strength degradation. Figure 11 illustrates the comparison of cumulative energy from

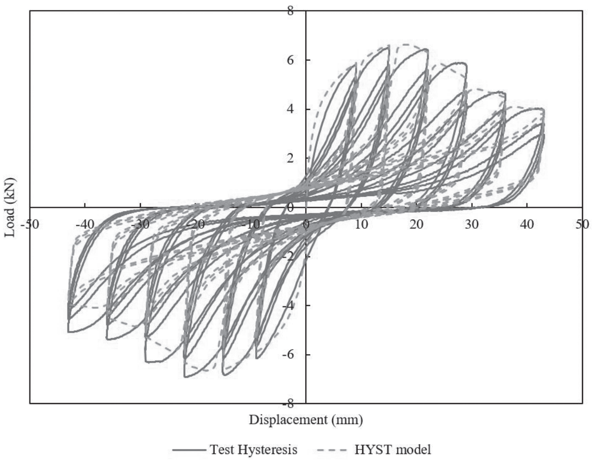

Figure 10. Hysteretic load-drift curves of test result and HYST model for wall G3PB1.

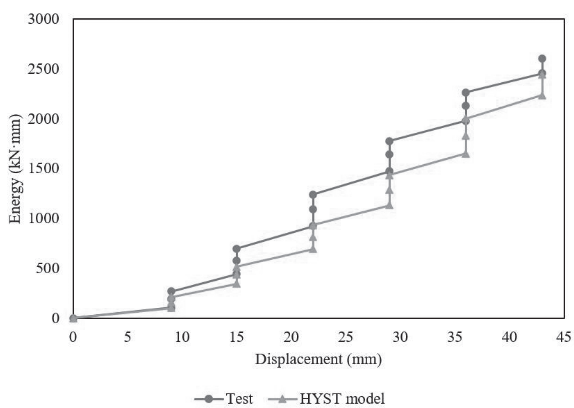

Figure 11. Cumulative energy of test result and HYST model for wall G3PB1.

the test and the HYST model. It further shows that the energy dissipation history was well predicted by the HYST model.

The calibrated HYST wall models can be added into the "PB3D" structural analysis platform. Then, nonlinear time-history analysis can also be conducted to simulate the seismic responses of the New Zealand LTF structures with plasterboard bracing walls or plywood walls. Furthermore, it can provide structural response data for the fragility analysis and seismic loss assessment.

5 A CASE STUDY ON A NEW ZEALAND STRUCTURE

To compare the structural performance of New Zealand houses braced by plasterboard bracing walls or by plywood sheathed walls, 3D numerical models of a one-story LTF structure were developed in the "PB3D" structural analysis platform. Structure A was braced by plasterboard bracing walls while Structure B was braced by plywood sheathed walls, and these two structures had the same layout of walls, as shown in Figure 12. In Structure A, W1 to W4 were 1.2 m long single-sided plasterboard bracing wall with hold downs, 1.2 m long double-sided plasterboard bracing wall with hold downs, 1.2 m long single-sided plasterboard bracing wall without hold downs, and 0.6 m long single-sided plasterboard bracing wall without hold downs respectively. In Structure B, the walls had the same construction details as in Structure A expect the type of sheathing material (changed to the plywood sheathing). The corresponding models developed in the last section were used to build the 3D models for the two structures. The structural mass on the roof was assumed as 454 kg/m^2. It is noted that these two structures were not real existing cases and were mainly designed to compare the building braced by different wall systems.

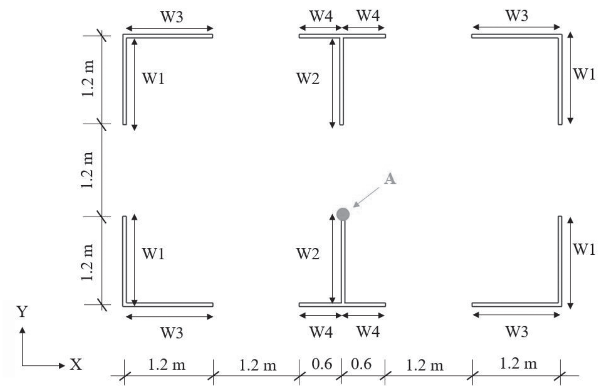

Figure 12. Shear wall layout of the building.

Ten earthquake records in the 2010-2011 Canterbury Earthquake Sequence at Christchurch City were collected for the time-history analysis. These earthquake records were scaled to make the peak ground acceleration (PGA) reaching the ultimate limit states (ULS) in the design standard, which PGA is 0.336g for Christchurch. Then, these records were subjected to the building models in Y direction and the time-history analysis on these two building models were conducted in the "PB3D" platform automatically. Table 3 lists the maximum drifts of the roof and the maximum accelerations at a node on the roof (node A, as shown in Figure 12) of the simulation results. It shows that the structure braced by plasterboard walls had lower maximum drifts than the structure braced by plywood walls, with an average of 16.28% lower. Meanwhile, the structure braced by plasterboard walls had higher maximum accelerations, with

Table 3. Simulation results of time-history analysis.

Earthquake record	Structure A		Structure B		Difference (Δ/ Structure A)	
	Max Drift ratio	Max acceleration (g)	Max Drift ratio	Max acceleration (g)	Max Drift ratio	Max acceleration (g)
1	0.70%	0.6472	0.79%	0.5188	-12.49%	19.84%
2	0.95%	0.6845	1.15%	0.589	-20.79%	13.95%
3	0.39%	0.4535	0.54%	0.3772	-37.14%	16.82%
4	0.69%	0.56	0.86%	0.5	30.44%	31.09%
5	0.86%	0.7224	0.98%	0.5469	-13.46%	24.29%
6	0.38%	0.4667	0.57%	0.416	-48.49%	10.86%
7	0.75%	0.6481	0.75%	0.4756	-0.46%	26.62%
8	1.00%	0.7777	0.85%	0.5184	15.67%	33.34%
9	0.67%	0.6989	0.72%	0.4691	-7.45%	32.88%
10	0.25%	0.3167	0.42%	0.3529	-68.58%	-11.43%
Average					-16.28%	19.83%

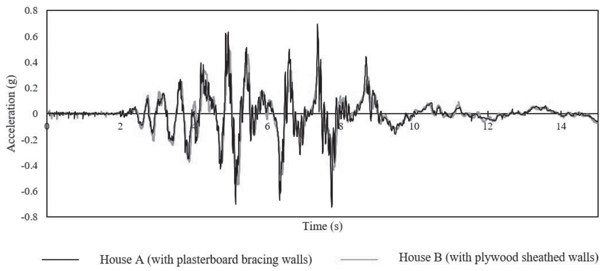

Figure 14. Acceleration response of node A on roof.

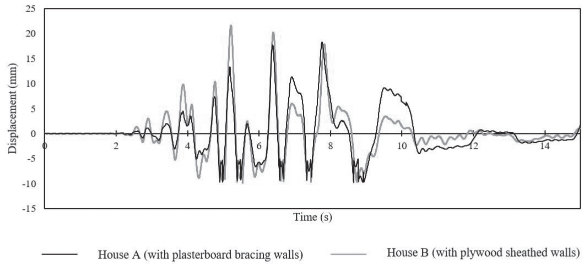

Figure 15. Average displacement response of the roof.

an average of 19.83%. As an example, Figure 14 illustrates the acceleration histories of a node on the roof of these two structures. It shows that these two response history curves overlapped each other in most time ranges. The maximum accelerations of node A were 0.69 g in Structure A and 0.49 g in Structure B. However, the displacement responses of the building models were significantly different. Figure 15 illustrates the average displacement histories of the roof. It shows that the structure with plywood sheathed walls had larger displacements than the structure with plasterboard bracing walls in the first half of the time. After about 8s, Structure A had large displacements than Structure B. That was because most of walls moved to the plastic stages after the peak acceleration record occurred, and plywood walls remained higher stiffness because they were more ductile than plasterboard bracing walls.

6 CONCLUSIONS

In this paper, seismic performance of different types of bracing walls used in New Zealand light timber frame houses was analysed using three groups of P21 wall test data collected from BRANZ. The influencing factors, such as sheathing types (plasterboard vs. plywood), with/without hold downs, wall length, that may affect the wall performance were studied. The main findings are listed as follows:

(1) The New Zealand plasterboard bracing walls have very different racking performance compared to plywood sheathed walls. Compared to the plywood sheathed walls, the plasterboard bracing walls are generally weaker and less ductile with lower energy dissipation capacity.

(2) Wall length significantly affects the performance of plasterboard bracing walls and plywood sheathed walls. For the single-sided sheathed wall without hold downs, wall length and the maximum wall strength have a linear positive relationship. However, the wall drift at the maximum load decreases approximately linearly.

(3) The hold downs and double-sided sheathing can improve the ultimate resisting load and energy dissipation capacity of walls.

A series of macro shear wall models using the HYST algorithm was developed for plasterboard bracing walls and plywood shear walls based on the collected test data. The model predictions agreed well with the test results in terms of load-drift hysteresis and energy dissipation. The developed HYST wall models were then implemented into a structural analysis platform, "PB3D" to conduct seismic simulations of the LTF houses. A case study of a single-story regular structure was conducted to compare the seismic performance of LTF structures with plasterboard bracing walls and plywood sheathed walls. The simulation results showed that the structure braced by plasterboard walls had lower maximum drifts than the structure braced by plywood walls, while the structure with plasterboard walls had higher peak accelerations.

This study is our first attempt to compare the structural performance of different LTF shear walls. Further studies will focus on real typical residential houses and more time history analysis will be constructed to assess their seismic performance at different earthquake intensity levels.

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