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THE LENGTH OF PLYWOOD SHEAR WALLS MATTERS

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ABSTRACT: Timber-framed construction is the predominant method used for the construction of residential dwellings in Australia. In this method, lateral forces caused by wind and earthquakes can be resisted by shear wall systems with various sheathing types. The plywood shear wall systems in AS 1684, which typically allow builders to achieve full racking capacity with walls as short as 600 mm, were validated in experimental testing of walls having a standard length of 2400 mm. This study performs 27 shear wall panel tests with length ranges from 450 mm to 2700 mm to examine the effect of wall length on the strength and stiffness of plywood shear wall systems. Variables of the study include two bracing details from AS 1684, two types of plywood, and two timber species. The findings show that the unit strength and stiffness of timber-framed plywood shear walls varies linearly with respect to the shear wall length. This finding raises concerns that an over-reliance on many short-length bracing walls in a building may be problematic.

KEYWORDS: shear walls, short walls, aspect ratio, bracing, plywood, framing

1 – INTRODUCTION

People prefer homes with open plan living spaces filled with natural light and ventilation. Houses that are designed to suit these preferences have many windows in external walls and a relatively small number of internal walls. This creates a problem for designers and builders who must brace the building against wind and earthquake loads. External walls are typically built with many short lengths of bracing walls placed between windows and doors and at corners.

Bracing provisions in AS 1684.2 [1] currently allow builders to achieve full racking capacity (measured in kN per metre of wall length) for plywood sheathed shear walls from a minimum wall length of 900 mm (Detail (g) and Method B, Detail (h), Table 8.18) or 600 mm (Detail (i) and Method A, Detail (h), Table 8.18). Detail (g) allows a reduced design load for wall lengths between 600 mm and 900 mm. Unfortunately, the bracing capacities for the systems in AS 1684.2 [1] were based on experimental testing of a standard test panel of 2.4 m to 3.0 m in length [2]. Considering that Dhonju et al. [3] found that unit shear wall strength (kN/m) varied linearly with respect to wall length for shear walls with oriented strand board (OSB) sheathing, further work was needed to test whether this relationship holds true for plywood shear wall systems in AS 1684.2 [1]. The Dhonju et al. [3] study showed that the unit strength of a standard OSB shear wall increased by approximately 50% when the wall length was doubled and that the unit strength of an OSB shear wall with double end studs and double bottom plates increased by more than 20% when the wall length was doubled. If this length-of-wall effect was confirmed for plywood shear walls, it could provide technical support for improving the design method for bracing in AS 1684.2 [1].

Here, we report on our experimental test plan to quantify the length-of-wall effect on timber-framed shear walls with plywood sheathing attached in accordance with AS 1684.2 [1].

2 – LITERATURE REVIEW

Ni and Karacabeyli [4] reported on testing of 22 full-scale plywood braced shear walls with lengths of 1.22 m, 2.44 m, and 4.88 m. Other variables in their study included loading protocol (monotonic vs. cyclic) and boundary conditions (with hold-downs vs. without hold-downs). Their results (reproduced in Fig. 1) showed that wall length had no effect on the strength of walls with tie-downs (blue and black boxes), but that wall length shows a positive linear relationship with the strength of walls without hold-downs (red and green boxes) and a positive nonlinear relationship with stiffness for all groups (circles and crosses).

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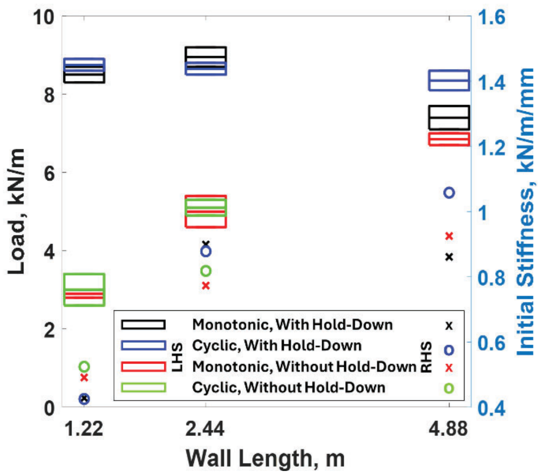

Figure 1. Unit Strength (LHS) (kN/m) and Unit Initial Stiffness (RHS) (kN/m/mm) vs Wall Length (m) from [4].

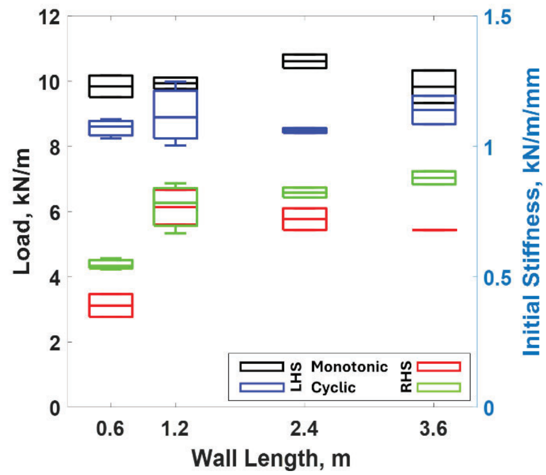

Figure 3. Unit Strength (LHS) (kN/m) and Unit Initial Stiffness (RHS) (kN/m/mm) vs Wall Length (m) from [5,6].

Dhonju et al. [3] reported on testing of 11 full-scale OSB braced shear walls with lengths of 300, 600, 900, 1200, 1800, and 2400 mm. Other variables in their study included a standard frame vs. a frame with double end studs and double bottom plate. Their results (reproduced in Fig. 2) showed that both unit strength and unit initial stiffness vary in a roughly linear fashion as the length of the wall increases.

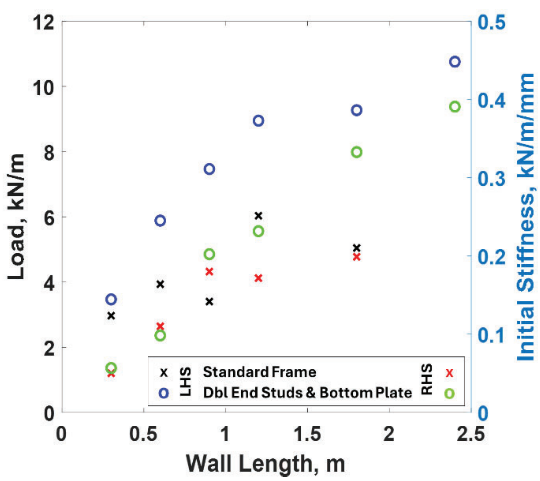

Figure 2. Unit Strength (LHS) (kN/m) and Unit Initial Stiffness (RHS) (kN/m/mm) vs Wall Length (m) from [3].

Salenikovich and Dolan [5,6] reported on testing of 18 full-scale OSB braced shear walls with lengths of 600, 1200, 2400, and 3600 mm. They reported results from monotonic testing in [5] and cyclic testing in [6]. Their results (reproduced in Fig. 3) are very similar to those of Ni and Karacabeyli [4] who showed that wall length had no effect on the strength of walls with hold-downs; however, their findings on stiffness differ. They found that unit initial stiffness was unaffected by wall length for wall lengths greater than 1200 mm. The stiffness of 600 mm walls was 30% to 50% lower than the stiffness of 1200 mm walls.

Guíñez et al. [7] reported on testing of 17 high strength full-scale OSB braced shear walls with lengths of 1200, 2400, and 3600 mm. Other variables in their study included loading protocol (monotonic vs. cyclic) and nail spacings (50 mm vs. 100 mm). Their results (reproduced in Fig. 4) are rather unique among the literature reviewed here. They found that short walls (1200 mm long) had higher unit strength than longer walls. Although the authors do not discuss why their results are so unique, it is likely that the hold-downs had a significant influence. In this study, unit initial stiffness appears to vary linearly as the length of the wall increases. Each test panel in the Guíñez et al. [7] study had five end studs at each end of the panel and heavy-duty hold-down anchors.

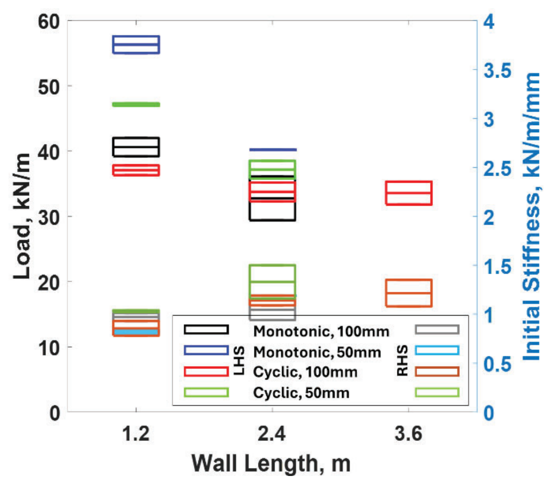

Figure 4. Unit Strength (LHS) (kN/m) and Unit Initial Stiffness (RHS) (kN/m/mm) vs Wall Length (m) from [7].

Crofton [8] reported on testing of 5 full-scale plywood braced shear walls with lengths of 300, 450, 600, 900, and 2700 mm. Notably, the short walls in his study were tested as multiple short walls with gaps in between. For example, the test panel for the 300 mm long walls was 2700 mm long and comprised 6 sheets of plywood with

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180 mm gaps in between each sheet. His results (reproduced in Fig. 5) show that wall length has a clear nonlinear effect on unit strength. Following these results, Crofton [8] improved the design of the shear wall by tripling the number of nails in the top and bottom plates (TP6, wall length = 0.9 m, $P_{ULT} = 6.19$ kN/m), and using M10 coach screws in the corners of the plywood (TP7, wall length = 0.6 m, $P_{ULT} = 6.59$ kN/m). Stiffness was not reported by Crofton [8].

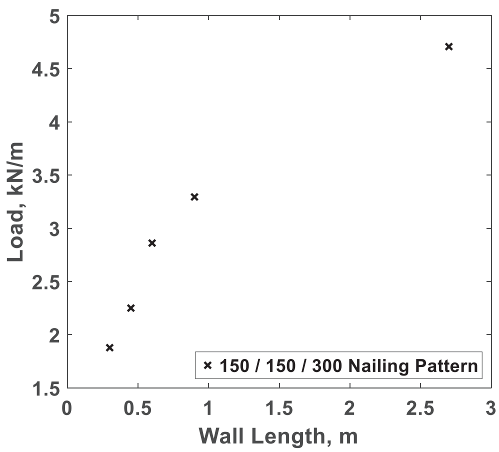

Figure 5. Unit Strength (kN/m) vs Wall Length (m) from [8].

The key finding from this literature review is that hold-downs have a significant influence on the strength of timber-framed shear walls sheathed with wood-based panel products. Without hold-downs the unit strength of walls varies linearly with wall length [3,4]. With hold-downs the unit strength of walls does not vary with wall length [4-6] or may decrease as wall length increases beyond 1200 mm [7]. Unit initial stiffness increases with wall length [3,4,6,7]; however, this relationship was not observed in [5] for walls longer than 1200 mm.

3 –DESCRIPTION OF TEST PANEL

Test panels (Fig. 6) are 2700 mm high with plywood sheathing fixed to one side of the panel and 10 mm thick plasterboard fixed to the other side of the panel. Timber framing is kiln dried (KD) MGP10 with 90 × 35 mm studs and 90 × 45 mm top and bottom plates. Timber is sorted by density into three groups (i.e., high, medium, and low density). Each group of test panels includes one panel made with high density timber, one panel made with medium density timber, and one panel made with low density timber. Plywood sheets are connected to the timber framing with 2.8 (ϕ) × 30 mm (l) galvanised clouts fixed according to one of the nailing patterns specified in Detail (h) of Table 8.18 in AS 1684.2 [1]. Some short walls of 450 mm length include 4M10 × 70 mm (l) coach screws fixed through the plywood into the top and bottom plates at the corners (i.e., one coach screw in each corner). This is colloquially known in Australia as the 'Kevin' connection, presumably after Kevin Lyngcoln who wrote a commentary [9] on the Crofton study [8]. Perhaps, the 'Kevin' connection should better be known as the 'Kelvin' connection since Kelvin Crofton [8] appears to have been the first to use this detail, as noted by his comment that "[c]oach screws have never been used before for fastening plywood to timber frames."

Additional details are provided in Table 1.

For reasons outlined in [10], each test panel has 10 mm thick standard grade plasterboard fixed on one side with 6g × 25 mm (l) screws (i.e., 3.5 mm (ϕ)) at 270 mm spacings and no adhesive (Fig. 6b).

To resist sliding, the test panels were anchored to a steel floor beam with M12 bolts through the bottom plate at 1200 mm maximum spacings. Test panels in group P1 and P9 include an M12 tiedown rod at the end nearest the hydraulic ram (see Method A, Detail (h), Table 8.18, AS 1684.2 [1]).

The loading mechanism and loading protocol used in this study is identical to that used on test group M1 in [11]. Test groups P1, P9, P4, P7, and P8 have been previously reported in [12].

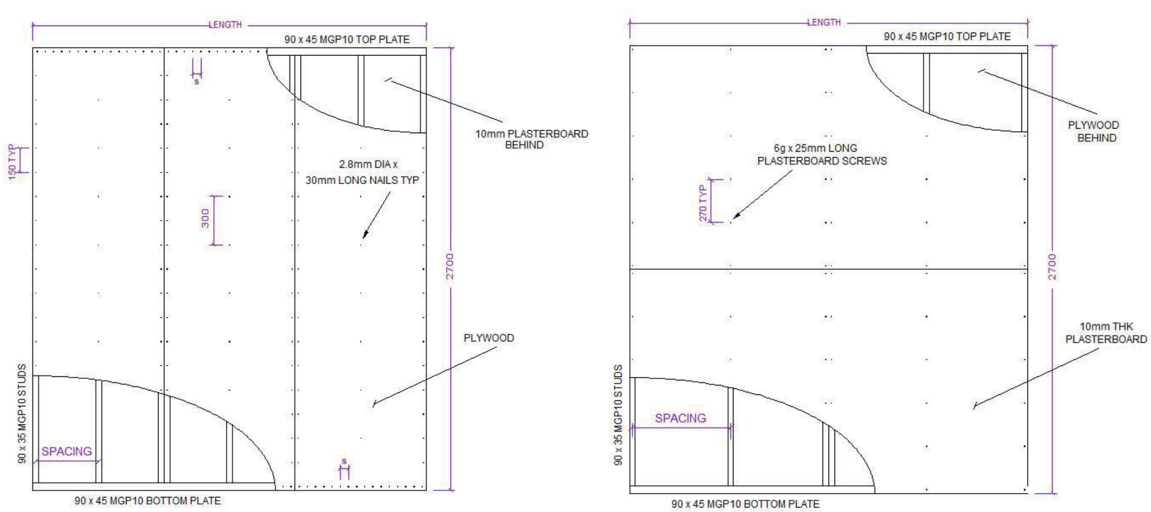

Figure 6. Typical Test Panel: a) Plywood Side, b) Plasterboard Side.

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Table 1. Test Matrix.

Group	Plot Colour	Method *	Bracing Material	Timber Species	Stud Spacing (mm)	Nailing Pattern †	Tie-down	Wall Length (m)
P1	**Red**	Method A (5.6 kN/m)	7 mm F8 3ply radiata pine plywood with a D grade face and back, glued together with a phenolic A bond resin. 1200 mm wide sheets.	*Pinus radiata*	600	150 / 150 / 300	M12	2.4
P9								0.45
P4	**Blue**	Method B (5.2 kN/m)				50 / 150 / 300	n/a	2.4
P7								0.9
P8						50 / 150 / 300, $4M10 \times 70mm$ Coach Screws		0.45
P13	**Black**		4 mm F22 3ply tropical hardwood plywood with a D grade face and back, glued together with a phenolic A bond resin. 900 mm wide sheets.	*Pinus elliottii* var. *elliottii* × *Pinus caribaea* var. *hondurensis*	450			0.45
P14						50 / 150 / 300		0.9
P15								1.8
P16								2.7

* There are two methods described in Detail (h), Table 8.18, AS 1684.2 [1] with different nailing patterns. Method A includes an M12 tiedown rod.
† XX / YY / ZZ where XX denotes nail spacing on the top and bottom chords, YY denotes nail spacing on the vertical edge of the plywood sheet, and ZZ denotes nail spacing along the intermediate stud.

4 – TEST METHOD

The first test panel in each group was tested with a simple displacement-controlled monotonically ramping load at 10 mm/min similar to the method outlined in EN 594 [13]. Results from testing of the first test panel were then used to select a suitable design load for the remaining panels according to the load-controlled method described in [11] for test group M1, which is consistent with the prototype test method in Appendix D of AS1720.1 [14].

Figure 7. Test Panel P15-M.

A 500 kN MOOG hydraulic actuator was used to apply the load at the top plate. Three linear variable displacement transducers were used to capture sliding at the toe of the wall (Δ_4) and overturning (Δ_2 and Δ_3). A stringpot was mounted on an independent steel frame and used to capture the horizontal displacement at the top of the wall (Δ_1). The test setup is shown in Fig. 7.

Global displacement, as measured by the stringpot (Δ_1), is used in this study.

5 – RESULTS

Load – global displacement (Δ_1) plots for the 27 test panels are presented in Fig. 8 to Fig. 10. Black lines denote data for groups P13 to P16, blue lines denote data for groups P4, P7, and P8 [12], and red lines denote data for groups P1 and P9 [12].

Results for unit strength ($\boldsymbol{P_{ULT}}$) and unit initial stiffness ($\boldsymbol{k_i}$) are presented in Table 2.

Table 2. Results.

Test Panel	P_{ULT} (kN/m)	μ (σ)	k_i $(kN/m/mm)$	μ (σ)
P1.1	9.248	9.184 (0.145)	0.505	0.375 (0.120)
P1.2	9.286		0.270	
P1.3	9.018		0.349	
P9.1	4.321	4.555 (0.202)	0.048	0.056 (0.024)
P9.2	4.676		0.083	
P9.3	4.667		0.038	
P4.1	6.451	6.262 (0.179)	0.408	0.376 (0.040)
P4.2	6.241		0.389	
P4.3	6.094		0.332	
P7.1	2.694	2.868 (0.400)	0.116	0.114 (0.033)
P7.2	2.584		0.145	
P7.3	3.325		0.080	
P8.1	1.935	1.885 (0.346)	0.058	0.077 (0.019)
P8.2	2.204		0.096	
P8.3	1.517		0.078	
P13-L	1.871	1.560 (0.340)	0.121	0.114 (0.008)
P13-M	1.612		0.105	
P13-H	1.198		0.116	
P14-L	2.710	3.019 (0.291)	0.177	0.183 (0.051)
P14-M	3.287		0.236	
P14-H	3.061		0.135	
P15-L	4.222	4.903 (0.613)	0.256	0.308 (0.067)
P15-M	5.411		0.384	
P15-H	5.077		0.284	
P16-L	7.647	7.111 (0.552)	0.438	0.481 (0.048)
P16-M	7.141		0.533	
P16-H	6.544		0.471	

As shown in Fig. 11 and Fig. 12, there is a clear linear relationship between the length of a plywood shear wall and its unit strength and unit stiffness. 450 mm long walls, built with M12 tie-downs (Method A), have about half the strength of 2.4 m long walls. 900 mm long walls, built without tie-downs (Method B), have less than half the strength of 2.4 m and 2.7 m long walls and the shorter 450 mm long walls have between 20% to 30% of the strength of 2.4 m and 2.7 m long walls.

It is worth noting that test panels with studs at 450 mm spacings (see dashed black line in Fig. 11) had higher stiffness than test panels with studs at 600 mm spacings despite being fabricated thinner plywood (i.e., 4 mm instead of 7 mm). The additional 3 mm of embedment of each nail into the timber framing may also have influenced this result.

Since timber density is included in design calculations for the capacity of nailed timber connections (see, for example, section 8.3.1 of Eurocode 5 Part 1-1 [15]), and since all the panels in this study failed as a result of nail withdrawal, it seems reasonable to expect test panels fabricated with higher density timber to achieve higher peak loads than those fabricated with lower density timber. Results in this study, however, do not match with expectations. High density test panels P13-H and P16-H had the lowest strength within their respective groups. Low density test panels P13-L and P16-L had the highest strength within their respective groups. Medium density test panels P14-M and P15-M had the highest strength within their respective groups.

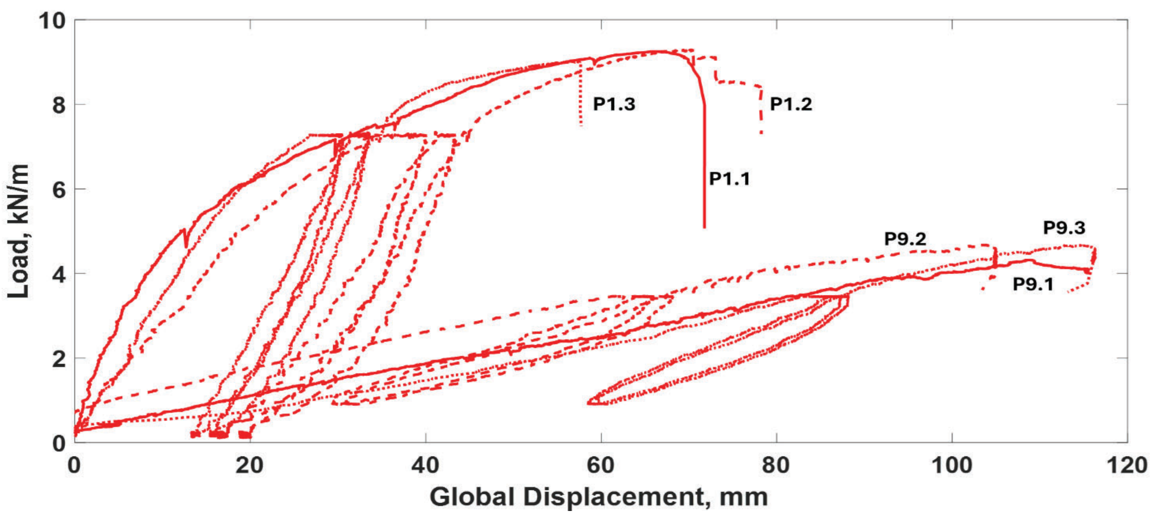

Figure 8. Unit Load (kN/m) vs Global Displacement (mm) for Groups P1 and P9.

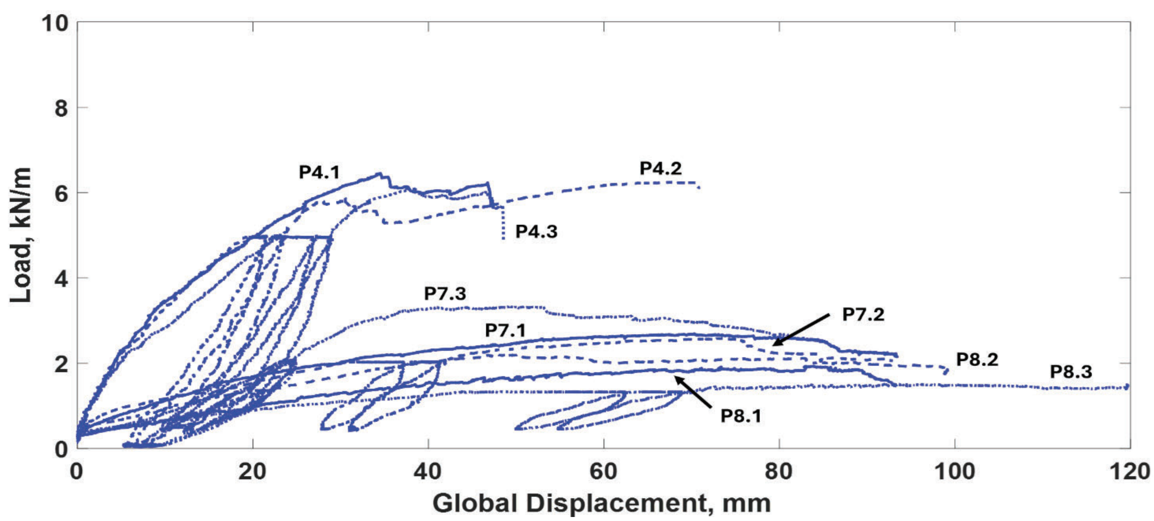

Figure 9. Unit Load (kN/m) vs Global Displacement (mm) for Groups P4, P7, and P8.

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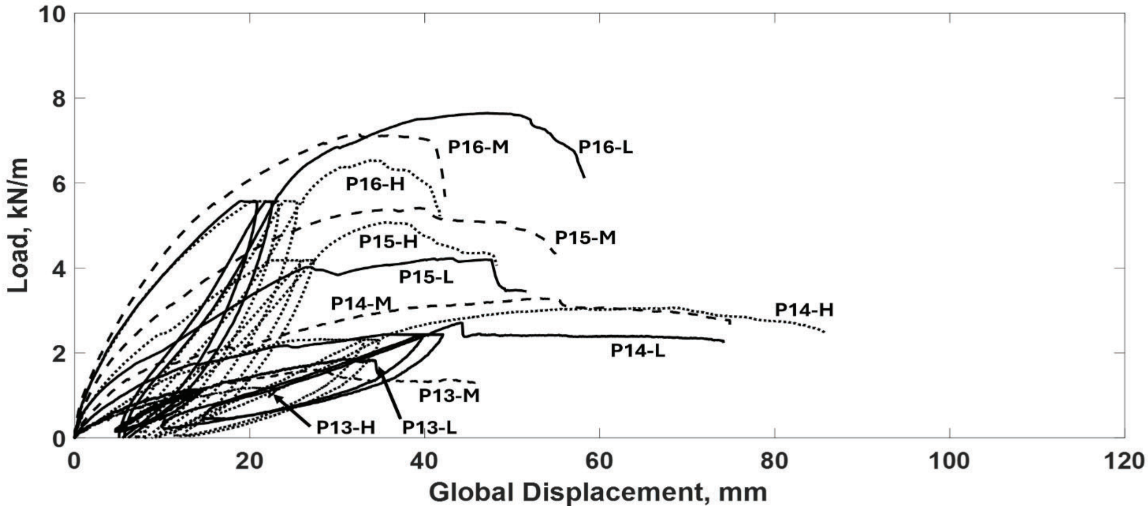

Figure 10. Unit Load (kN/m) vs Global Displacement (mm) for Groups P13 to P16.

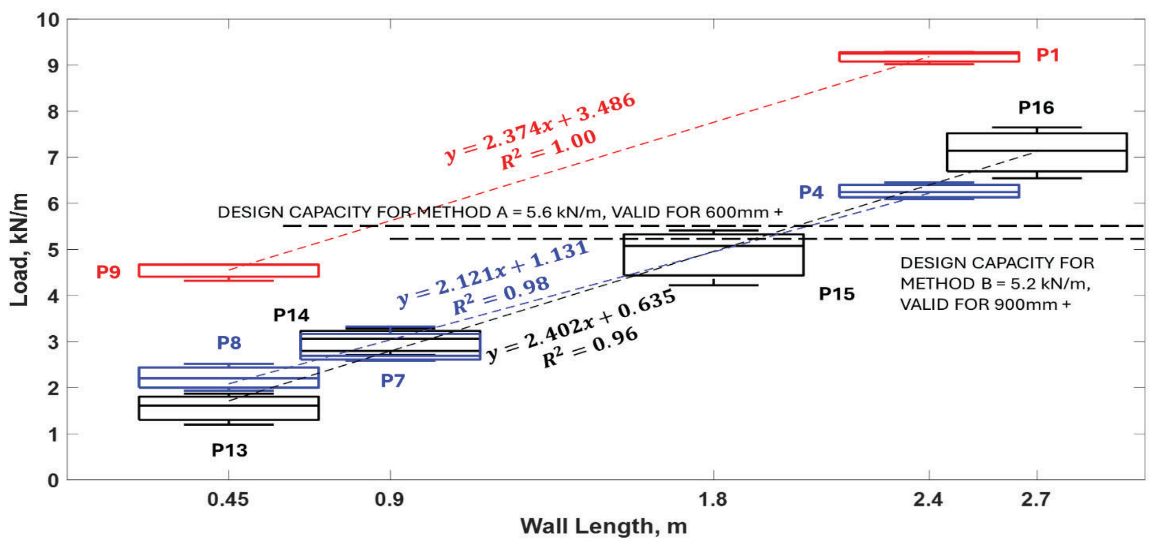

Figure 11. Unit Strength (kN/m) vs Wall Length (m) by Group.

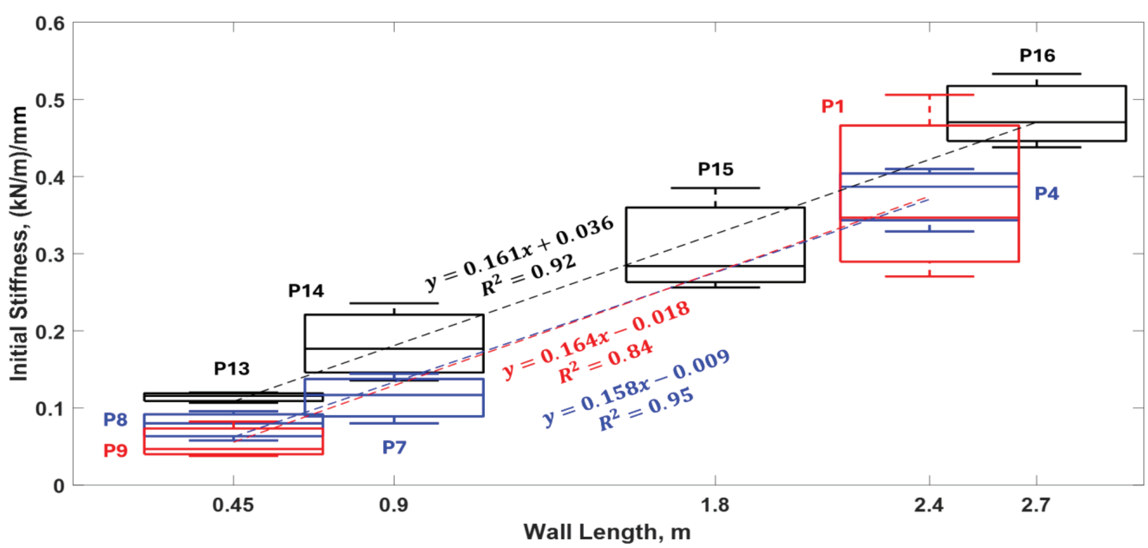

Figure 12. Unit Initial Stiffness (kN/m/mm) vs Wall Length (m) by Group.

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6 – DISCUSSION

The findings here align quite well with the findings of Ni and Karacabeyli [4] (see Fig. 1) and Dhonju et al. [3] (see Fig. 2). There is a length-of-wall effect for both strength and stiffness of timber-framed shear walls with plywood sheathing and no tie-down rods (i.e., the 5.2 kN/m system Method B, Detail (h), Table 8.18, AS 1684.2 [1]).

An appropriate design load for 450 mm long walls (Method B, Detail (h), Table 8.18, AS 1684.2 [1]) is 1.2 kN/m and an appropriate design load for walls equal to or greater than 2700 mm long is 5.5 kN/m with linear interpolation for shear walls between 450 mm long and 2700 mm long. Walls less than 900 mm long should include the 'Kevin' connection at all four corners of the sheet of plywood.

Further study is needed to determine whether the relationship between wall length and unit strength holds true for walls with tie-downs (i.e., the 5.6 kN/m system Method A, Detail (h), Table 8.18, AS 1684.2 [1]). The small amount of data from test groups P1 and P9 isn't sufficient to draw firm conclusions.

7 – CONCLUSION

We have presented here the findings of our study into the length-of-wall effect on the unit strength and stiffness of timber-framed shear walls with plywood sheathing. A total of 27 full-scale test panels in nine different configurations were tested. Variables in the study include wall length (450, 900, 1800, 2400, and 2700 mm), plywood (4 mm F22 vs. 7 mm F8), timber species (radiata vs. a hybrid of slash and Caribbean), nailing pattern, and tie-down (with vs. without).

Results show that there is a linear relationship between the length of wall and both unit strength and unit initial stiffness for all the test groups in this study. This is a robust finding for the bracing system without tie-down rods (i.e., Method B, Detail (h), Table 8.18, AS 1684.2 [1]); however, further study is needed on the bracing system with tie-down rods (i.e., Method A, Detail (h), Table 8.18, AS 1684.2 [1]).

We also recommend further study on the length-of-wall effect on other plywood bracing systems in AS 1684.2 [1] such as Detail (g) which is rated at 3.0 kN/m and Detail (i) which is rated at between 6.6 kN/m and 7.6 kN/m.

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