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INFLUENCE OF PLASTERBOARD ON THE STRUCTURAL PERFORMANCE OF TIMBER-FRAMED SHEAR WALLS

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ABSTRACT: Timber-framed shear walls are commonly used in residential buildings to provide lateral strength and stiffness against wind and earthquake loads. Wood-based panel products, such as plywood and oriented strand board, are typically fixed to timber framing with nails or screws to provide the necessary racking resistance of a shear wall. Plasterboard is a panel product used on walls to achieve a smooth finished surface. Plasterboard provides some strength and stiffness to the wall even though its primary function is architectural; however, most shear wall tests ignore the influence of plasterboard. The aim of this study is to quantify the influence of plasterboard on the structural performance of timber-framed shear walls. To achieve this aim, six (6) timber-framed shear walls (groups P1 and P2) were fabricated with 7mm F8 plywood sheathing on one side and 10mm plasterboard on the other side and tested under a monotonic loading protocol. Results were then compared with previous test results of three (3) similar timber-framed shear walls (group M1) without plasterboard. Results show that plasterboard improved the ultimate racking strength of these shear walls by up to 53%, a statistically significant result. Shear wall stiffness and failure modes were not affected by adding plasterboard.

KEYWORDS: Shear wall; Plasterboard; Monotonic loading

1 INTRODUCTION

Timber-framed shear walls do the important work of resisting racking forces from wind and earthquake that act on buildings. These shear wall systems usually comprise wood-based panel products, such as plywood or oriented strand board (OSB), nailed or screw-fixed to the structural timber framing. Shear wall systems then get tested in a laboratory to find their racking strength and stiffness and the data collected in these tests is used to justify their design rating. It is common practice to use only structural elements in a test panel, such as timber framing, sheathing, connectors, tiedowns and anchors. Plasterboard, also known as gypsum board or drywall, is rarely attached to laboratory test panels even though it is ubiquitous in residential construction and known to provide some strength and stiffness (*e.g.*, [1,2]).

Here, we report on our experimental test plan to quantify the influence of plasterboard on the structural performance of timber-framed shear walls. Following a brief literature review, the test method is described. Results are presented and compared to previous work [3] on timber-framed shear walls without plasterboard. Analysis and discussion highlights the additional capacity of timber-framed shear walls due to plasterboard.

2 LITERATURE REVIEW

The contribution of plasterboard to the racking resistance of residential buildings is formally recognised in the Australian Standard AS1684.2:2021 [4] where cl.8.3.6.2 allows for a design racking capacity of 0.45 kN/m if one side of the wall is sheeted and 0.75 kN/m if both sides of the wall are sheeted up to a maximum of 50% of the total racking resistance requirement for the building.

Wolfe [5] conducted an early comparison of walls with solid timber diagonal braces checked into studs. Wolfe found that gypsum wallboard improved the strength of these walls by as much as 300% and improved stiffness by as much as 400%.

Patton-Mallory *et al.* [1] tested several combinations of walls with plywood and gypsum board. They found that walls with plywood on one side and gypsum board on the other side outperformed walls with plywood only on one side by 30% – 40%. They did not report on stiffness.

Of note, both Wolfe [5] and Patton-Mallory *et al.* [1] found that the overall capacity of the shear walls could be predicted accurately by summing the capacity of the component parts of the system.

Liew *et al.* [2] found that walls with plasterboard fixed on one side of the shear wall using screws, but no adhesive, achieved ultimate capacities of 2.0 – 3.5 kN/m. This result is far better than the nominal design capacities in AS1684 [4].

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Uang and Gatto [6] found that adding plasterboard to an OSB or plywood sheathed shear wall improved ultimate strength by 6% - 18% and improved stiffness by 30% - 90%. They also found that adding plasterboard altered the failure mode of the shear walls from the sheathing-to-timber connections to the framing timber itself.

Satheeskumar *et al.* [7] conducted simulated wind load tests on a full-size house building. The building was tested in two different conditions: 1) with structural elements only, and 2) with architectural claddings such as plasterboard and cornices. They found that plasterboard and cornices contributed about 40% of rigidity to the building.

This literature review shows that plasterboard does, in fact, contribute to the structural performance of timber-framed buildings; however, further work is needed to quantify the influence of plasterboard on typical shear wall systems that are in use in Australia.

3 DESCRIPTION OF TEST PANEL

Our standard test panel is 2700 (h) × 2400mm (l) with plywood sheathing fixed to one side of the panel and plasterboard fixed to the other side of the panel. Timber framing is kiln dried (KD) MGP10 *pinus radiata* with 90 × 35mm studs at 600mm spacings and 90 × 45mm top and bottom plates. Timber is sorted by density into four groups (*i.e.*, high, medium, low, and very low density). Timber framing for the three (3) P2 test panels is taken from sorted very low-density timber and is representative of the JD5 joint group. Timber framing for the three (3) P1 test panels is taken from sorted low, medium, and high-density timber to ensure that a broad range of densities are represented (nominally JD4 joint group). Joint groups for different species are defined in Australian standards for the purpose of joint design.

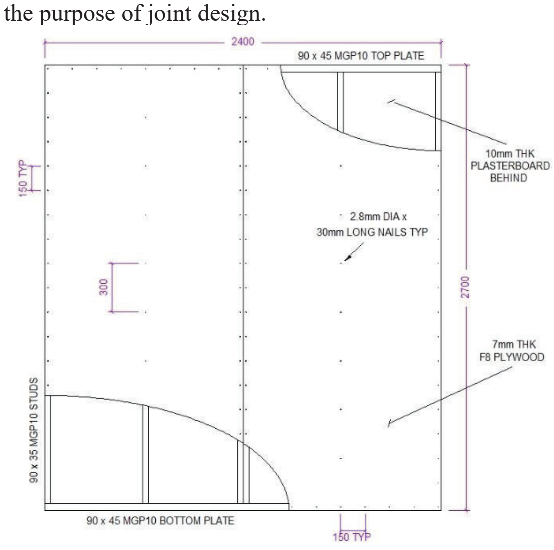

Figure 1: *Typical Test Panel (Plywood side).*

Plywood sheets are 2700 (h) × 1200mm (l) × 7mm thick F8 plywood sheathing consisting of three (3) veneers of radiata pine with a D grade face and back glued together with a phenolic A bond resin. The plywood sheets are connected to the timber framing with 2.8 (ϕ) × 30mm (l) galvanised clouts at 150mm spacings around the edges of the sheets and 300mm spacings at intermediate studs (Figure 1). The nail pattern precisely follows Detail (h) of Table 8.18 in AS1684.2 [4].

Plasterboard sheets are 1350 (h) × 2400mm (l) × 10mm thick randomly selected off the shelf from three (3) different Australian manufacturers. The plasterboard sheets are connected to the timber framing with 6g × 25mm (l) screws (*i.e.*, 3.5mm (ϕ)) at 270mm spacings and no adhesive (Figure 2).

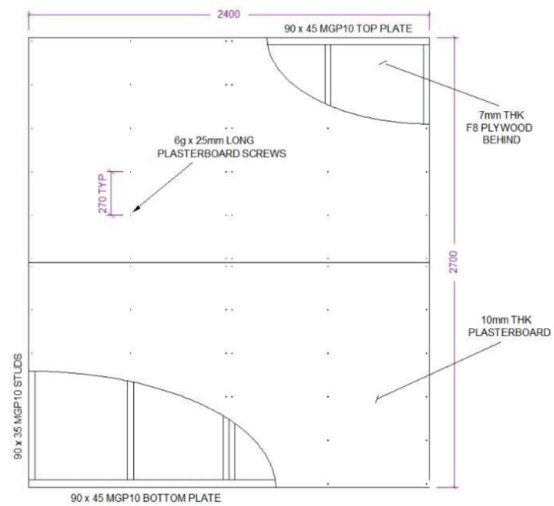

Figure 2: *Typical Test Panel (Plasterboard side).*

To resist sliding, the test panels were anchored to a steel floor beam with 3M12 bolts through the bottom plate at 1200mm spacings. To resist overturning the test panels were secured with an M12 tiedown rod from the top plate nearest the ram end. 50 × 3mm square washers were used with each bolt and tiedown rod.

The test panels in this study are almost identical to the test panels in the loading protocol study by Cowled, Crews, and Gover [3] with two exceptions: 1) plasterboard was not used in the previous study, and 2) the timber framing in the previous study was sourced from the Southern Queensland pine resource, which is either *pinus elliottii* var. *elliottii* (a.k.a. slash pine), *pinus caribaea* var. *hondurensis*, or a hybrid of the two species. Material properties of these species are comparable to those of radiata pine. These timber species have similar strength grades. Slash pine and Caribbean pine have a slightly higher density than radiata pine (*i.e.*, 650 kg/m^3 and 575 kg/m^3 respectively compared to 550 kg/m^3 for radiata pine). Slash pine has a better rated joint group (*i.e.*, nominally JD4 compared to nominally JD5 for radiata pine and Caribbean pine) [8]. All other aspects of the test setup, including tiedowns and anchors are identical to the test setup in [3]. The loading mechanism and loading protocol used in this study is identical to that used on test group M1 in [3].

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4 TEST METHOD

Test panels P1.1 and P2.1 were tested with a simple displacement-controlled monotonically ramping load at 10 mm/min similar to the method outlined in EN 594 [9]. Results from testing of P1.1 and P2.1 were used to select a suitable design load of 7.2 kN/m and 6.9 kN/m respectively which were then used to test the remaining panels according to the load-controlled method described in [3] for test group M1, which is consistent with the prototype test method in Appendix D of AS1720.1 [10].
A 500kN MOOG hydraulic actuator was used to apply the load at the top plate. Three (3) linear variable displacement transducers were used to capture sliding at the toe of the wall (Δ_4) and overturning (Δ_2 and Δ_3). Two (2) laser sensors, mounted on an independent steel frame, were used to capture the horizontal displacement at the top of the wall (Δ_1). The test setup is shown in Figure 3.

Figure 3: *Test Panel P2.1.*

Since the data from the laser sensors is not clean, the displacement used for plotting has been measured at the hydraulic actuator and adjusted to match the laser data using a nonlinear least squares optimisation algorithm. Adjusted displacement then is:

$$\Delta_{adj} = \alpha \cdot \Delta_1 \tag{1}$$

where α is the multiplier obtained from curve-fitting using the nonlinear least squares optimisation described above.
Racking displacement can also be corrected to remove the sliding and overturning components to obtain the shear component of the displacement:

$$\Delta_s = \Delta_1 - \Delta_4 - (\Delta_2 - \Delta_3) \cdot \frac{h}{l} \tag{2}$$

where, h and l are the height and length of the test panel.

5 RESULTS

Load – adjusted displacement (Δ_{adj}) plots for the P1 (blue lines) and P2 (red lines) groups of test panels are presented in Figure 4 along with those of the M1 group of test panels from [3] (black lines).

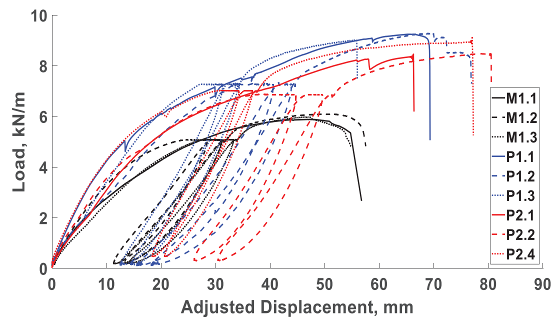

Figure 4: *Load – Adjusted Displacement Plots for Groups M1 (plywood only) [3], P1 (plywood & plasterboard), and P2 (as per P1 except with very low-density timber).*

The clearest observation from this plot is that plasterboard significantly improves the ultimate capacity of plywood braced shear walls. Initial stiffness also appears to be higher in the P1 and P2 groups compared to the M1 group; although, this relationship is not as clear when load is plotted against global displacement or corrected racking displacement.
Structural performance characteristics have been calculated in this paper in accordance with the methods outlined in ASTM E2126 [11]. The maximum load obtained is P_{ULT}. The global secant shear modulus is calculated at $0.4 \times P_{ULT}$:

$$G' = \frac{P}{\Delta_e} \times \frac{h}{l} \tag{3}$$

where P and Δ_e are the load in kN and displacement in mm at $0.4 \times P_{ULT}$ where global displacement is used (*i.e.*, including components of shear, overturning, and sliding). The internal secant shear modulus, calculated at $0.4 \times P_{ULT}$, uses the corrected shear displacement, Δ_s, from (2):

$$G_{int} = \frac{P}{\Delta_s} \times \frac{h}{l} \tag{4}$$

The yield load is found by deriving an equivalent energy elastic-plastic (EEEP) curve from the global load – displacement curve.

$$P_y = \left(\Delta_u - \sqrt{\Delta_u^2 - \frac{2A}{K_e}} \right) K_e \tag{5}$$

where, A is the area under the load – global displacement curve, Δ_u is the ultimate displacement (*i.e.*, corresponding to the last data point on the load – displacement curve where the absolute load is equal to or greater than $0.8 \times P_{ULT}$, K_e is the elastic shear stiffness equal to $(0.4 \times P_{ULT})/\Delta_e$.

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The ductility ratio is:

$$D = \frac{\Delta_u}{\Delta_y} \quad (6)$$

where, Δ_y is the global displacement taken from the EEEP curve at P_y.

Structural performance characteristics for the P1 and M1 group of test panels are presented in Table 1 below.

The P1 group of test panels, which were fabricated with plywood on one side and plasterboard on the other side, achieved a mean ultimate strength of 9.18 kN/m and a tight variance (σ = 0.12 kN/m). The P2 group of test panels, which were identical to the P1 group except for having very low-density timber framing, achieved a mean ultimate strength of 8.72 kN/m (σ = 0.39 kN/m). Both results are significantly higher (53% & 46% respectively) than the mean ultimate strength of 5.99 kN/m for the M1 group of test panels in [3] (σ = 0.10 kN/m), which were fabricated without plasterboard and tested in the same laboratory with identical boundary conditions and the same loading protocol. The higher ultimate and yield strength of the P1 and P2 groups of test panels, as compared to the M1 group, is statistically significant with a *p*-value of 0.05 on a one-sided Wilcoxon ranksum test.

Table 1: *Results*

Test Panel	P_{ULT} (kN/m)	P_y (kN/m)	G' (kN/mm)	G_{int} (kN/mm)	D
M1.1	5.89	5.39	1.05	3.15	6.03
M1.2	6.09	5.47	1.01	1.55	3.90
M1.3	5.98	5.36	0.77	2.10	3.03
μ	**5.99**	**5.41**	**0.95**	**2.27**	**4.32**
σ	0.10	0.06	0.15	0.81	1.54
P1.1	9.25	7.87	1.35	2.62	4.57
P1.2	9.29	8.09	0.73	2.04	2.60
P1.3	9.02	7.90	0.95	2.32	2.56
μ	**9.18**	**7.96**	**1.01**	**2.33**	**3.24**
σ	0.12	0.09	0.26	0.24	0.94
P2.1	8.46	7.31	0.87	0.56	3.04
P2.2	8.53	7.11	1.13	2.87	4.89
P2.4*	9.16	7.76	1.34	2.52	5.12
μ	**8.72**	**7.39**	**1.12**	**1.99**	**4.35**
σ	0.39	0.34	0.24	1.24	1.14

* Data unavailable for test panel P2.3, so panel P2.4 was made.

Curiously, plasterboard did not improve the global and internal stiffness of the test panels in this study. This finding contradicts previous studies which found that plasterboard improved stiffness [5,6,7].

The in-group variance of ductility is high enough to make the higher ductility of the M1 group seem unremarkable.

Failure modes were similar between the test panels in this study and the M1 group of test panels. The primary mode of failure in all groups was nail pullout of the plywood-to-timber connection (see Figure 5). Two nail pull-through failures were observed in test panel M1.1 because this panel failed dramatically under load control. Timber fractures were observed in P1.1 (top of the end stud) and P1.2 (bottom plate near the heel of the wall, see Figure 6). Tearing of the plywood was observed at one nail in P1.2 and two nails in P2.4. The plasterboard in the P1 and P2 groups of test panels experienced localised crushing of the plasterboard at the screw holes, pull-through failures, and some tearing of the plasterboard at the corners (see Figure 7).

Figure 5: *Nail Pullout, Test Panel P1.1.*

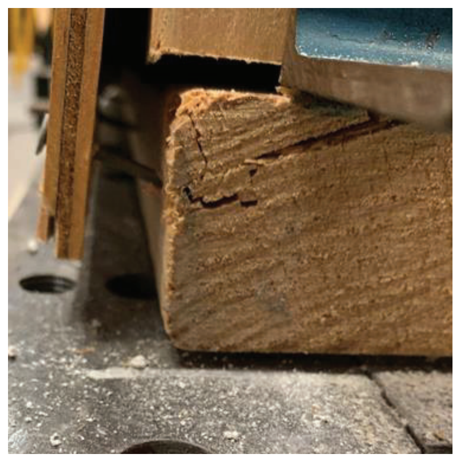

Figure 6: *Timber Fracture, Test Panel P1.2.*

Figure 7: *Plasterboard Damage, Test Panel P2.1.*

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6 DISCUSSION OF LIMIT STATES

The shear wall system in this study is described as Method A of Detail (h), Table 8.1, AS1684.2 [4] and it has a published design capacity of 5.6 kN/m.

A similar shear wall system was originally tested in 1975 by Frodin and Ross [12], following a devastating cyclone in Darwin the previous year. Differences between test panel TP4 in [12] and the M1 group of test panels in [3] include the use of unseasoned hardwood timber framing instead of KD pine, 3.18mm (ϕ) clouts instead of 2.8mm (ϕ) clouts, studs at 450mm spacings instead of 600mm spacings, a panel height of 2.4m instead of 2.7m, a panel length of 2.7m instead of 2.4m, and the use of steel strapping at the corners of test panel. TP4 in [12] achieved an ultimate strength of 9.72 kN/m.

Several decades later, C.G. 'Mick' McDowall [13] tested panel TP2, which differed from the M1 group of test panels from [3] in only one respect; that is, TP2 in [13] was 2.4m high compared to the 2.7m high M1 group of test panels in [3]. TP2 in [13] achieved an ultimate strength of 8.21 kN/m.

It should also be noted that the loading protocols in [12] and [13] differed to the loading protocol used for the M1 group of test panels in [3] with design loads for TP4 in [12] being 2.07 kN/m (held for 5 min) and 2.87 kN/m (held for 5 min) and the design load for TP2 in [13] being 4 kN/m (held only once for 5 min); whereas, test panels M1.2 and M1.3 in [3] held a design load of 5 kN/m twice for 5 min. As argued in [3], the use of different loading protocols may have influenced results.

Adopting Mick McDowall's 2004 methodology [13] for determining limit state design values, also described in [3], the upper limit for the factored design strength of this wall system, based on TP2 from [13], would be:

$$Q^* = 0.8 \times 8.21 = 6.57\ kN/m \tag{7}$$

This result exceeds the design value of 5.6 kN/m in AS1684.2 [4] by 17%; however, the more recent work by Cowled, Crews, and Gover [3] raised concerns because it found that the factored design strength of this system, based on the M1 group of test panels, was 14% lower than the published design value:

$$Q^* = 0.8 \times \frac{5.89 + 6.09 + 5.98}{3} = 4.79\ kN/m \tag{8}$$

The work in the current study reassures us that, when architectural finishes such as plasterboard are considered, the design strength of this system does, in fact exceed the published design values. For this shear wall system an appropriate design load exceeds the published design load of 5.6 kN/m by 28%:

$$Q^* = 0.8 \times \frac{\begin{gathered}9.25 + 9.29 + 9.02 + \ldots\\ \ldots 8.46 + 8.52 + 9.16\end{gathered}}{6} = 7.16\ kN/m \tag{9}$$

7 CONCLUSIONS

We have presented here the findings of our study into the influence of plasterboard on the structural performance of timber-framed shear walls tested in accordance with the monotonic load-controlled test method outlined in AS1720.1 [10]. Test panels were 2700 (h) × 2400mm (l) using MGP10 framing and 7mm thick F8 radiata pine plywood sheathing fixed with 2.8 (ϕ) × 30mm (l) galvanised clouts at 150mm spacings around the edges of each panel and 300mm spacings along the intermediate stud. The P1 ($n = 3$) and P2 ($n = 3$) groups of test panels in this study also had 10mm thick plasterboard fixed to the other side with 6g × 25mm (l) plasterboard screws at 270mm spacings. The P2 group of test panels were fabricated with very low-density timber framing (nominally JD5 joint group) whereas the P1 group of test panels were fabricated with timber from a range of densities (nominally JD4 joint group). Results of this study were compared to the M1 group of test panels in a previous study [3] ($n = 3$) which did not have plasterboard attached. Test conditions, including tiedowns, anchors, and loading protocol, were identical for both the P1 and M1 group of test panels.

We found that plasterboard improves the ultimate and yield strength of timber-framed plywood-braced shear walls by 37% to 53%; however, stiffness and ductility are unaffected by the addition of plasterboard in this study.

Since the published capacities of timber-framed shear walls are primarily based on testing of panels without plasterboard cladding, as is the case for shear wall systems described in Table 8.1 of AS1684.2 [4], our findings provide the construction industry with confidence.

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REFERENCES

[1] Patton-Mallory, M., Gutkowski, R.M., Soltis, L.A.: *Racking Performance of Light-Frame Walls Sheathed on Two Sides* (Research Paper FPL 448). Forest Products Laboratory, Madison, Wisconson, U.S., 1984.

[2] Liew, Y.L., Duffield, C.F., Gad, E.F.: The influence of plasterboard clad walls on the structural behaviour of low rise residential buildings. *Electron. J. Struct. Eng.*, 2:1-16, 2002.

 https://doi.org/10.52202/069179-0445

[3] Cowled, C.J.L., Crews, K., Gover, D. Influence of loading protocol on the structural performance of timber-framed shear walls. *Const. Build. Mater.*, 288:123103, 2021.
[4] AS 1684.2:2021. *Residential timber-framed construction – Part 2: Non-cyclonic areas.* Standards Australia, Sydney, Australia, 2021.
[5] Wolfe, R.W. *Contribution of Gypsum Wallboard to Racking Resistance of Light-Frame Walls* (Research Paper FPL 439). Forest Products Laboratory, Madison, Wisconson, U.S., 1983.
[6] Uang, C.-M., Gatto, K. Effect of Finish Materials and Dynamic Loading on the Cyclic Response of Woodframe Shearwalls. *J. Struct. Eng.*, 129(10):1394-1402, 2003.
[7] Satheeskumar, N., Henderson, D.J., Ginger, J.D., Humphreys, M.T., Wang, C.H. Load sharing and structural response of roof-wall system in a timber-framed house. *Eng. Struct.*, 122:310-322, 2016.
[8] Forest and Wood Products Australia Ltd. *WoodSolutions - Wood Species - Softwood*. https://www.woodsolutions.com.au/wood-species/softwood. 2023.
[9] EN 594:2011. *Timber structures – Test methods – Racking strength and stiffness of timber frame wall panels*. European Committee for Standardization, Brussels, Belgium, 2011.
[10] AS 1720.1:2010. *Timber structures – Part 1: Design methods*. Standards Australia, Sydney, Australia, 2010.
[11] ASTM E2126-11. *Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Vertical Elements of the Lateral Force Resisting Systems for Buildings*. ASTM International, West Conshohocken, PA, 2018.
[12] Frodin, J., Ross, A.H. *CapCiv-2 – A Report on Shear Testing of Plywood Sheathed Wall Panels for the Plywood Association of Australia*. Capricornia Institute of Advanced Education, Rockhampton, Australia, 1975.
[13] McDowall, C.G. *Combined Racking and Uplift Test Results for Panels of DD and Less than DD Grade Plywood & Some Thoughts on Choosing Limit States*. Plywood Association of Australia, Brisbane, Australia, 2004.