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Experimental Capacity Assessment of Cold-formed Boxed Stud Wall Systems Used in Australian Residential Construction

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Experimental Capacity Assessment of Cold-Formed Boxed Stud Wall Systems used in Australian Residential Construction

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ABSTRACT

The performance of residential Boxed stud cold-formed steel structures under axial compression, bending and combined axial and bending is currently being investigated at the University of South Australia. This paper summaries the experimental procedures and capacity assessment of single-plasterboard-sheathed panels (sheathed panels) in comparison with un-lined steel frames (steel frames) tested under axial compressive load. The paper also presents the structural behaviours of sheathed panels (panels with plasterboard sheathing) under the influence of bending only and combined axial and bending loads. The analysis of the test results lead to numerous interesting conclusions about the behaviour of single-plasterboard-sheathed panels within brick veneer wall systems.

INTRODUCTION

Residential construction using cold-formed steel stud wall systems is steadily gaining popularity over recent years in the Australian market. The standard structural system for residential construction in Australia is brick veneer where the stud wall (whether timber or cold-formed steel) is the load-bearing element and an external skin of brickwork is used for weatherproofing, insulation and aesthetic reasons. Hence the stud frame is sheathed on only one side with plasterboard material. This differs from the standard practice used in North

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plasterboard material. This differs from the standard practice used in North America where both sides of the stud frame are usually sheathed, one with internal plasterboard material and the other with insulated external cladding material and a brick skin is not used.

Limited assessments have been made of the additional structural capacity that may be provided by the plasterboard lining on one side of a cold-formed steel stud wall and its contribution is currently ignored in both the US and Australian design codes for cold-formed steel design. In Australia, wind load takes an important part in the design of buildings. Therefore, it is important to examine the structural behaviour of the lined panels under both bending and combined axial and bending.

In this investigation, 14 Boxed stud frames and sheathed panels are tested to define their structural capacity under axial compressive load, wind pressure (bending) and combined axial and bending. Later development of a complementary finite element analysis will aid in the development of current cold-formed steel designs and construction practices.

LYSAGHT SUPRAFRAME® Boxed stud (Boxed stud) is a relatively new section created by Australian BlueScope Steel. The cross sectional area of Boxed stud is similar to the C-stud's, while Boxed stud's effectiveness in term of flexural design is claimed to be significantly better. It is however, reasonably costly compared with a normal open stud C-section. Nevertheless, in term of material sustainability, Boxed stud could be the solution to better structural effectiveness while using less material.

METHODOLOGY

Each of the panels and steel frames consisted of three (3) studs as shown in Figure 1. Each stud was placed at 600mm centres. This arrangement was chosen as it represents a typical stud wall system with two external studs and one middle stud. Previous research by Miller and Pekoz (1994) had proven that equal failure load was found on each stud within the three-stud wall system. The height of the frame was set at 2400mm as used in current practice of Australian residential building design.

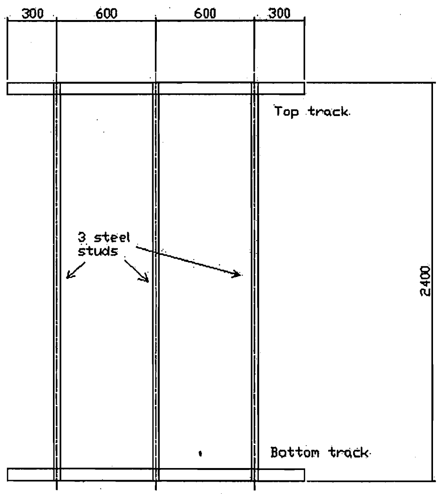


Figure 1: Test layout and dimension of frame

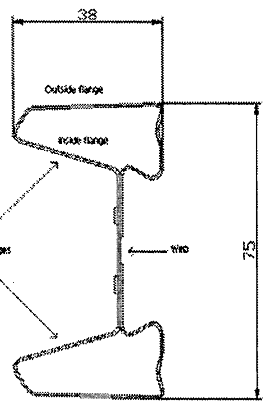


Figure 2: Boxed stud cross-section variables

LYSAGHT SUPRAFRAME® Boxed stud 75×38×0.6 (Figure 2) was chosen for the steel studs. The cost of this section is slightly more expensive compared to the normal C-section. The research was partly to determine the Boxed stud is better in flexural design and is value for money. The Figure 2 above and Table 1 below present the cross-section variables of the Boxed stud 75×38×0.6. The value shown in Table 1 was obtained from section analysis using THINWALL program.

Table 1: Values for Boxed Stud cross-section variables (THINWALL analysis)

Area of section	Ix	Iy	Torsion J	Warping Iw	Zx	Zy
(mm^2)	(mm^4) $\times 10^4$	(mm^4) $\times 10^4$	(mm^4)	(mm^6)$\times$ 10^6	(mm^3) $\times 10^3$	(mm^3)$\times$ 10^3
162.5	11.41	1.998	19.50	61.91	3.067	0.8801

Xc	Yc	Xs	Ys	Xo	Yo	βx	βy
(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
-3.558	0	-12.35	0	-8.79	0	0	0.1608

The track section used is Lysaght 75×75×0.9. This is a non-structural plate designed to fit with either C-section or Boxed section with web height equivalent to 75mm.

The plasterboard selected for the lining of the panels tested in this research is Boral Plasterboard with 2400mm tall, 1200mm wide and 10mm thick sheets. Telue (2001) conducted experimental tests on plasterboard material properties to find the shear modulus of plasterboard (Gp), the shear strain at failure (gp), the failure stress in compression (Cp) and the modulus of elasticity (Ep).

Wafer head screw 8-18 gauge×12 mm long were used to attach the studs to top and bottom tracks. Type S 6-18 gauge 30 mm long plasterboard screws were used to fix the plasterboard to the studs. The screws were placed at 130mm centres along the length of the studs. This spacing was chosen because it is the most viable spacing found by Telue and Mahendran (2001).

Axial test

For the axial compression loading tests, the axial roof loads were applied directly along the longitudinal direction. The intention is to monitor closely the behaviour of each stud within a panel. Therefore, three axial jacks were used to apply the same incremental axial compression load directly onto the three studs to create a uniform incremental compressive load applying on the whole panel. For axial tests, the maximum deflection is predicted to occur at the middle of the studs. Therefore, both dial gauges and strain gauges are placed at the mid length of each stud.

Bending test

Modelling of wind load bending moment was achieved by using two (2) hydraulic jacks symmetrically placed on the stud as shown in Figure 3. This produced a bending moment very similar to that produced by uniform wind pressure method.

The contact area between the jack and the panels was very small, thus a timber beam was used for spreading the applied load on larger surface area. There were two beams used in spreading the load, each was placed at the point of applied load.

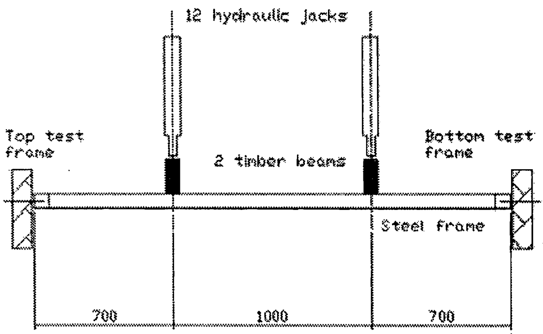


Figure 3: Positions of the jacks, side view of testing frame.

Two different positions of panel placement in the testing rig were tested to simulate the design of external pressure or internal pressure produced by wind load. For external pressure, the wind is directly pressuring the steel frame side of the panel, thus creating compression in the Boxed studs but tension in plasterboard. However, in the internal pressure condition, the pressure is applied on the plasterboard side of the panel producing compression of the plaster-board and tension in steel.

The steel section's surface areas are very small, thus the effect of wind pressure applied on them is negligible and hence there were no test performed to investigate the steel frames under wind load pressure.

Combined axial and bending

For combined axial and bending tests, the loading condition was slightly different because the axial jacks were to apply constant roof load while the bending jack applied increasing step loads.

There were two types of axial compressive load, namely upper and lower bounds roof load. The lower bound roof load was designed for conventional roof, where the load on each stud is 0.42 kN. For truss roof design, the upper bound of the roof load was 2.85 kN.

RESULT

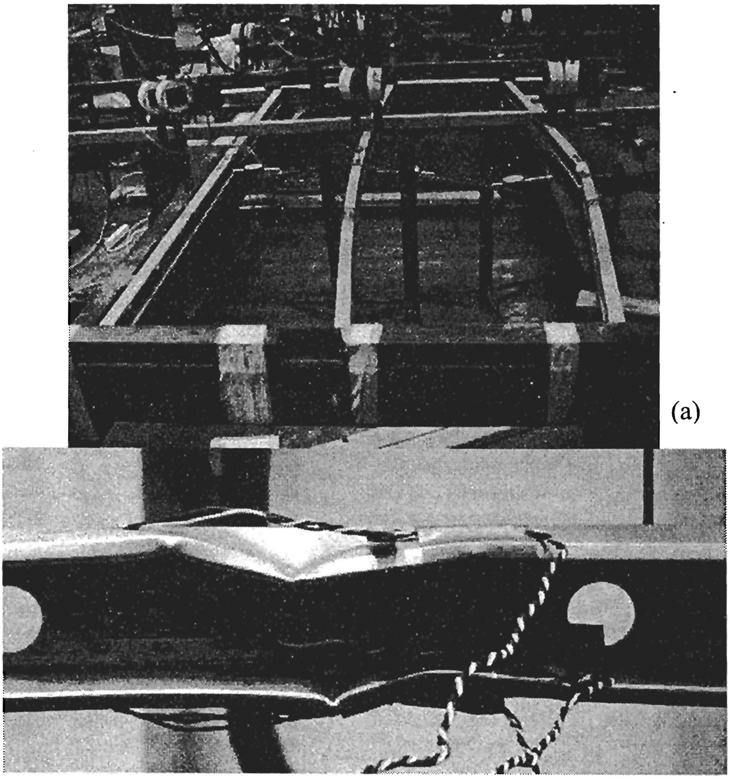
The results from axial compression tests are shown in table 2 and the failure modes are illustrated in Figure 5 and Figure 6.

Table 2: Result for axial compressive tests

Panel	Panel position	Failure load	Failure modes
F1	Steel frame	8.81 kN	Local and flexural buckling, stud buckling laterally
F2	Steel frame	8.82 kN	Same
A1	Sheathed frame	19.9kN	Local buckling, minimal lateral movement, crushing of stud's end
A2	Sheathed frame	20.4 kN	Same
A3	Sheathed frame	20.9 kN	Same

For axial compressive tests, sheathed panels and steel frames were tested by 3 identical experimental tests to clarify the performance of the testing rig. Average value on each test was used to present the result of the experiment.

During the test, it was observed that the failure of the studs was flexural buckling in plane of the steel frames. Some studs were observed to fail by a combination of flexural and local buckling. It was observed that at lower load, the frame started to move laterally. However, near failure load, the frame was buckled in both in plane and out of plane directions. Such behaviour is described in Figure 4.



(a)

(b)

Figure 4: (a) Flexural buckling of Boxed stud steel frame, (b) Local buckling of a Boxed stud.

For sheathed panels, the failure mode was similar to those that occurred in steel frames. During the test, there was insignificant amount of movement in both in-plane and out of plane directions but at failure load, the local buckling occurred suddenly and hence created a very large amount of movement which then led to the permanent deformation of the panel. Such behaviour is described in Figure 5, which plots the deflection against load of steel frames in comparison with sheathed panels. It was observed that at failure load, the amount of deflection is not as substantial as occurred in the steel frame tests, while the local buckling was very significant. This is because the plasterboard provides assistance to stiffen the studs' flanges hence prevents the panel to move laterally. As a result, the permanent deformation occurred in the out of plane direction. Figure 6(a) and (b) shows the local buckling in a stud.

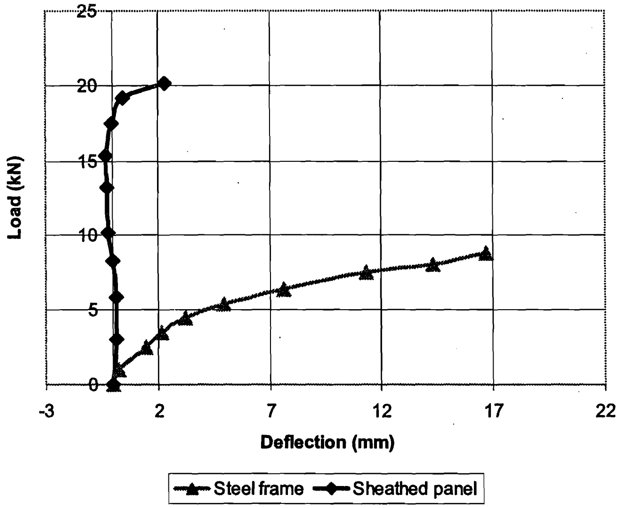


Figure 5: Load versus in-plane deflection of steel frame and sheathed panel.

Since the thickness of Boxed-section is very thin, the applied axial compression led to crushing at the ends of the Boxed studs.

In order to define the assistance of plasterboard to overall stiffness of the panels, a comparison between the results of steel frame and sheathed panel was made as shown in Figure 7. Since Boxed section consisted of inside and outside flanges, the amount of strain occurring in each flange location was different. Therefore, both strain deformation for outside and inside flanges are plotted in Figure 7.

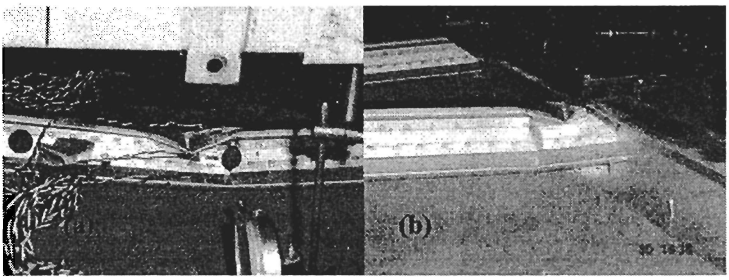


Figure 6: (a) Local buckling of sheathed panel, (b) crushing of Boxed stud.

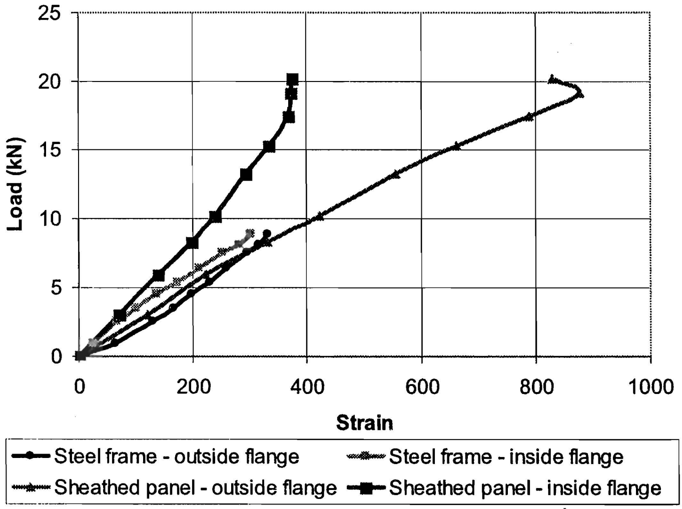


Figure 7: Comparison of load versus strain of steel frames and sheathed panels.

From Figure 5 and Figure 7, it is obvious that the ultimate loads achieved by the lined panels are double the ones achieved by the steel frames. As explained above, this is because of the assistance provided by plasterboard to overall structural capacity of the sheathed panel.

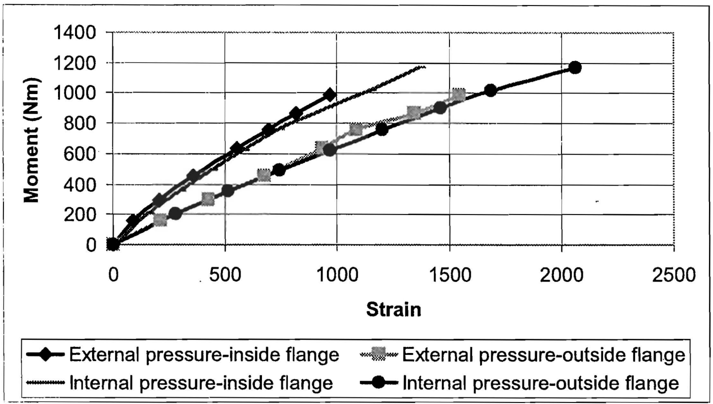
To fully investigate the structural behaviour of Boxed section, which was claimed to have better flexural design in comparison with C-section, it is substantial to examine the behaviour of sheathed panels under the influence of wind load and combined axial and bending. Table 3 shows the results for bending and combined axial and bending tests of sheathed panels.

Table 3: Result for bending and combined axial and bending tests

Panel	Loading	Pressure	Failure moment (kNm)	Failure modes
B1	Bending	Ex	1.006	Local buckling of boxed studs, ripping of plasterboard at failure
B2	Bending	Ex	0.975	Same as above
B3	Bending	In	1.188	Local buckling of boxed studs
B4	Bending	In	1.156	Same as above
AB 1	A&B,LB	Ex	0.995	Local buckling of boxed studs, ripping of plasterboard at failure
AB 2	A&B,LB	In	1.124	Local buckling of boxed studs
AB 3	A&B,UB	Ex	0.923	Local buckling of boxed studs, ripping of plasterboard at failure
AB 4	A&B,UB	In	1.055	Local buckling of boxed studs

A&B = combined axial and bending.
LB = lower bound (constant axial roof load of 0.42 kN conventional roof).
UB = upper bound (constant axial roof load of 2.85kN truss roof)

(a)



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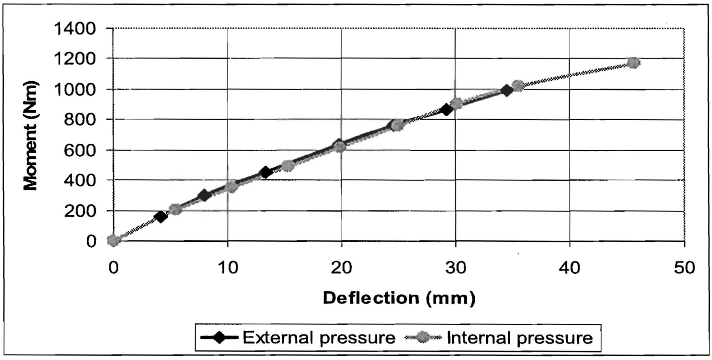

Figure 8: Bending test results (a) Moment versus strain, (b) Moment versus deflection

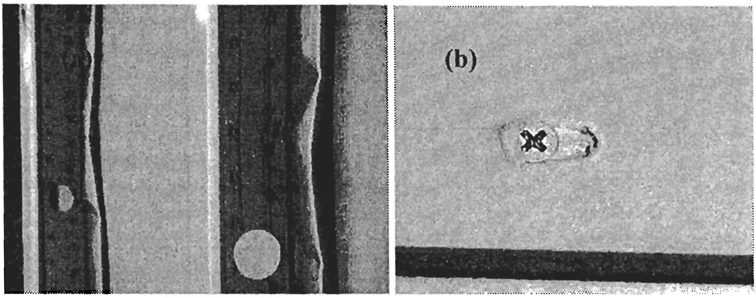

Figure 9: (a) Local buckling of Boxed studs – (b) Ripping of plasterboard when under tension.

(a)
(b)

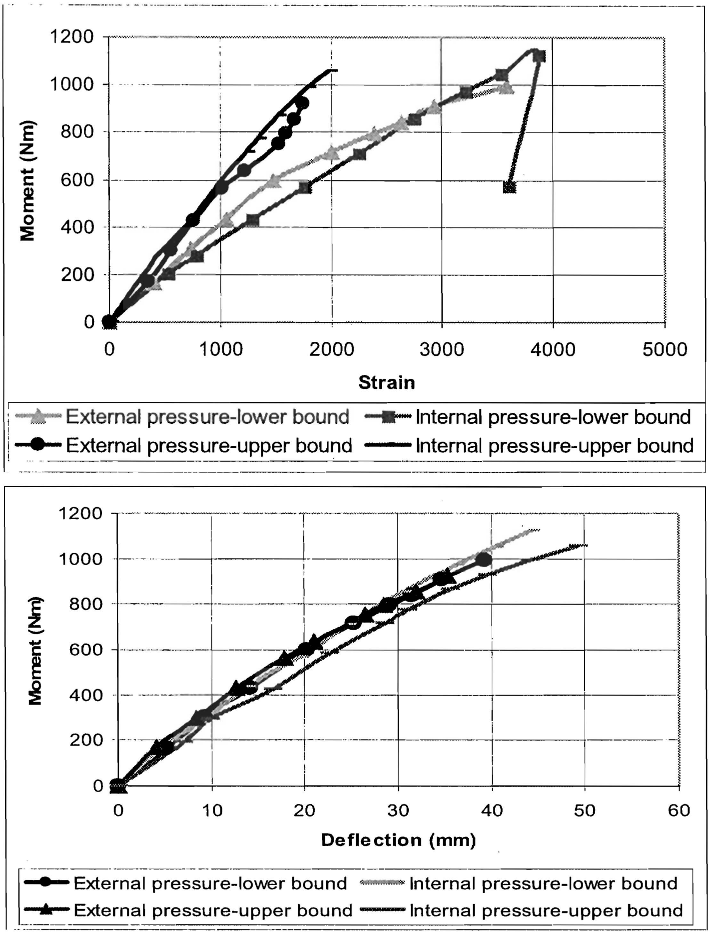

Figure 10: Combined axial and bending test results (a) Moment versus strain, (b) Moment versus deflection.

From Figure 8, it is significant that the sheathed panels show their non-linear characteristics under pure bending load. The only difference is the ultimate load in which the panels failed, panels with plasterboard under tension failed earlier due to plasterboard's brittleness material characteristic. For all bending and combined axial and bending tests, the failure occurred when the Boxed studs buckled locally as shown in Figure 9. This behaviour is common within both bending tests and combined axial and bending tests because the Boxed stud contained inside and outside flanges which provides double shear to the effective section, thus the failure is local buckling of the Boxed studs not ripping of plasterboard at connection between plasterboard and Boxed studs.

For combined axial and bending tests, the panels with roof truss loads (upper bound) underwent less strain deformation while panels under conventional roof load experience more strain deformation. This is because when higher axial compressive load applied on the panels, this load then creates higher compact stiffness on the plasterboard and hence restrained the amount of strain deformation occurring within the steel stud's flanges.

CONCLUSION

From this research, the following remarks can be made based on the experimental tests results:

- The axial failure load of sheathed panel is approximately 56 % higher than those of steel frame. Plasterboard assists significantly to the overall structural capacity of sheathed panels.
- Plasterboard is a brittle material, which is strong when subject to compression but easily failed when under influence of tension.
- Ripping of plasterboard screws is the dominant failure modes when plasterboard is subjected to tension. Modification on connection between plasterboard and steel studs may prevent ripping of plasterboard under external wind pressure that creates tension in plasterboard.
- The Boxed studs has very slender thickness, thus the domineering failure mode is local buckling that happened before the connection between plasterboard and Boxed studs fail.
- Future implemented finite element analysis is proposed to verify the results obtained from experimental results and modify the connection between plasterboard and steel studs in order to prevent ripping of plasterboard when subject to tension.

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NOTATION

The following symbols are used in this paper:
Ix, Iy = Second moment of area about principal axes
Zx, Zy = Section modulus about principal axes
Xc, Yc = Coordinates of centroid
Xs, Ys = Coordinate of shear centre
Xo, Yo = Coordinates of shear centre in principal axes
βx, βy = Monosymmetry parameters