ASEC CONFERENCE 2016 –WALL TESTING PROTOCOL

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ABSTRACT: *The design capacity of a cold formed steel wall framing stud can be calculated in accordance with AS/NZS 4600 and/or determined through prototype testing. A number of assumptions are made theoretically to calculate the member capacity in compression and bending. Tested capacities are found to be far more realistic than the capacities obtained through theoretical calculations. The different components of the wall stud tests are: (i) Axial Compression, (ii) Bending, (iii) combination of axial Compression and bending tests. Axial compression tests are conducted on both clad and unclad situations. A way to overcome the uncertainties on wall stud capacity determined through testing in the industry is to have a common testing protocol for the wall studs.*

KEYWORDS: Stud, Axial compression, Bending, AS/NZS 4600, Cladding, Testing

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1 INTRODUCTION

While light framed structures have been used in residential construction for several decades, system developers and designers continually optimise and refine the design of components to achieve a high degree of economy as well as satisfy various architectural trends. In cold formed steel construction, wall structures are mainly formed using wall studs of various types. Different forms of claddings can be fixed to the stud wall type constructions.

Cold formed light gauge steel offers a number of superior features making it an attractive material for wall systems. Specifically, the strength, stiffness, quality and light weight features of cold formed steel wall components make them ideal for construction. With availability of various section sizes, shapes and thicknesses made from different grades of steel, wall frames can be designed for single or multiple storey construction for residential and/or commercial applications.

A benefit of cold formed light gauge steel is that stud sections can be formed in multiple ways that may strengthen or weaken the section. In the forming process it is possible to modify the section by adding lips, ribs, embossments, notches, crimps or elaborate forming techniques. These additional processes may have a positive or negative impact on the strength, stiffness and quality of the section. Testing of stud sections is an accurate method to determine the actual strength of the section based on how it has been formed.

Wall studs can be designed theoretically or by conducting tests [1]. It has been observed through research and testing, that the capacity of un-crimped and un-notched studs achieved by testing is higher than their theoretical values. The effect of any additional forming, notching, embossing or crimping as well the restraints provided by cladding on one flange or both flanges of the stud can only be determined through tests which gives a more realistic capacity of the stud.

This paper highlights the main steps and components involved in typical wall frame assembly testing . The listed steps and assumptions aim to assist structural engineers in testing wall frames and also to provide capacity of the studs in axial compression and bending.

2 WALL FRAMING SYSTEM

2.1 GENERAL

A typical wall framing system consists of wall studs, noggings, top plate, bottom plate, header, sills, external cladding and internal claddings.

Load bearing walls should be designed to carry permanent loads from roof and/or floor above. Non load bearing walls are not designed to carry vertical loads from roof or floor but may act as bracing walls.

For the purpose of this paper, openings are not considered as they are deemed to be supported by headers, and the focus is on studs running between the top and bottom plates.

The contribution of plasterboard towards load carrying capacity needs to be given careful consideration. Experimental evidence indicates that plasterboard can carry considerable compressive load. However it is a common practise to consider plasterboard as restraints to the studs and ignore the contribution towards compression or bending capacity.
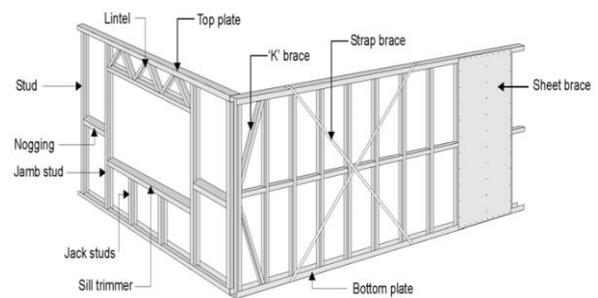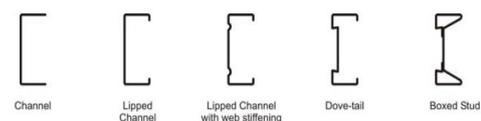

Figure 1: Typical wall framing system

Figure 2: Common profiles of wall studs

2.2 BENEFITS AND NEED FOR TESTING

Extensive research and testing have indicated that the capacity of studs determined through testing may differ to values achieved by theoretical calculations. Testing simulates realistic conditions and eliminates a number of assumptions made when designed by calculations.

2.3 NEED FOR TESTING PROTOCOL

There has been no Australian testing standard or protocol for wall frame testing.
Hence there is a need to develop a testing protocol so that a common approach for wall frame testing can be followed throughout the industry.
Currently, there is no evidence of stud wall frame testing standards in America, Asia and Europe.

2.4 DESIGN ASSUMPTIONS

- Studs can be designed as unclad, clad one side or clad both sides
- Effective lengths for studs: The most critical assessment to be considered is the appropriate effective length for different axes of the stud in bending and compression. The effective length can be determined by rational analysis or by testing. In the absence of such information, it can be taken as suggested in Table 1.
- The effective length values may be reduced to 80% of the values suggested in Table 1 if both flanges of the stud are restrained at the top and bottom plates and at other restraining points.
- In calculating section and member capacities, an allowance should be made for the effects of service holes placed during manufacture or likely to be required during construction for permanent building services. .
- In general, the combined action effect of bending and axial compression is the critical case for strength design.
- Shear strength and web crippling strength of a wall stud is dependent on the stud section only regardless of the cladding condition.

- For cladded walls, wall stud strength may be limited by the cladding to stud connection.

Notes:

a) L_{ex} is the effective length of the stud perpendicular to the wall, L_{ey} is the effective length in the plane of the wall and L_{ez} is the torsional effective length.

b) For cladding on only one side, the effective length may be conservatively assumed to be as for the unclad case.

c) Typical claddings include plasterboard, fibre cement sheet, profiled steel sheeting or plywood directly attached to studs over at least 85% of wall height in accordance with manufacturers' specifications and/or relevant Australian Standards.

d) Where noggings do not provide effective torsional restraint, they should be ignored for L_{ez}.

2.5 LOAD AND LOAD COMBINATIONS [2], [3], [4]

The load combinations used for the determination of the design effects for strength of wall studs are:

$1.2 \, G + 1.5 \, Q_1$
$1.2 \, G + 1.5 \, Q_2$
$1.2 \, G + (W_{uw} + W_{ur \, (down)})$
$0.9 \, G + (W_{uw} + W_{ur \, (up)})$

G = Dead load of roof structure, includes roof structure, roof cladding, roof battens, ceiling battens, ceiling, services and roof insulation if appropriate
Q_1 = roof live load of 0.25 kpa
Q_2 = 1.1 kN
W_{uw} = Wind load normal to wall
W_{ur} = Wind load on roof

For double storey construction, floor load has to be considered when designing lower storey stud.

Table 1: Suggested Effective length values for stud in Bending and Compression [2]

Cladding Condition	Effective Length		
	L_{ex}	L_{ey}	L_{ez}
Unclad / clad one side	Distance between top and bottom plate	Distance from top or bottom plate to nogging or between noggings	Distance from top or bottom plate to nogging or between noggings
Clad both sides	Distance between top and bottom plate	Twice the distance between cladding mechanical connectors	Twice the distance between cladding mechanical connectors

Table 2: *Preliminary Design considerations for wall studs [2]*

Member	Actions			Strength Design		Serviceability Design		
	G	Q	Wu	Restraints	Criteria	G	Q	Ws
(i) Wall studs in load bearing walls	Weights of roof, ceiling and wall	Reaction from roof load 0.25 kPa or 1.1 kN	Wind pressure normal to wall & Wind load transferred from roof (down)	Varies depending on cladding conditions	Combined compression and bending		H/200 (<12mm) under soft body impact on wall	H/150 (<20mm)
(ii) Wall studs in load bearing wall	As in (i) plus weight of upper floor and walls and lower storey ceiling	Reaction from floor load 1.5 kPa	Wind pressure normal to wall & Wind load transferred from roof (down)	Varies depending on cladding conditions	Combined compression and bending		H/200 (<12mm) under soft body impact on wall	H/150 (<20mm)
(iii) Wall studs in non-load bearing wall	Own self weight		Wind pressure normal to wall Differential wind pressure between wall faces		Mainly bending under lateral wind pressure or shear if used as shear wall		H/200 (<12mm) under soft body impact on wall	H/150 (<20mm)

2.6 TEST METHOD

The method covers compressive and bending tests of steel stud frame assemblies. Three types of tests are required to determine the structural capacity of the wall studs:

a) Axial compression only : for determining axial compressive strength without any bending load.

b) Bending only: for determining bending strength without any axial load.

c) Combined compression and bending: for determining bending capacity in combination with axial compressive load. This test is optional, bending only and compression only test will provide a conservative answer.

2.7 APPARATUS

2.7.1 The wall testing rig needs to have provisions for fixing the wall panel vertically with the bottom plate bearing fully on the support. Support needs to be provided at the bottom plate in horizontal and vertical directions while the top plate needs to be supported only in the horizontal direction. The supports need to be such that it does not provide any rotational restraint at plate level.

2.7.2 The rig needs to have provision to apply and measure controlled axial compressive load via hydraulic jacks (or similar) directly above the studs. A loading plate (Min 6mm thick) with cross sectional dimension same as the studs needs to be provided on the top plate directly over the studs.

2.7.3 The rig needs to have provision to apply and measure controlled uniform pressure over one face of the wall panel via air bag (or similar). Deflection gauges need to be provided at mid-height of the internal studs to measure lateral deflection.

2.8 TEST SPECIMEN

Three different test specimens are:

a) Unclad wall frame: test frame needs to be constructed for the specified wall height with minimum 5-studs at 600mm centres. Fix the studs to top plate, bottom plate and noggings with the frame screws (or as specified by the framing system). The number of rows of nogging and its spacing needs to be specific for that particular wall height.

b) Clad on one face only with plasterboard: test frame needs to be constructed as specified in (a) above. Install 10mm thick plasterboard on one face of the wall frame and screw fix to plates and studs as per industry standards. Provide appropriate gap (approx. 10mm) at top and bottom so that plasterboard does not take any direct axial load. Apply minimum 2 coats of plasterboard jointing compound and allow at least 12 hours curing time between coats. After applying the final coat, the
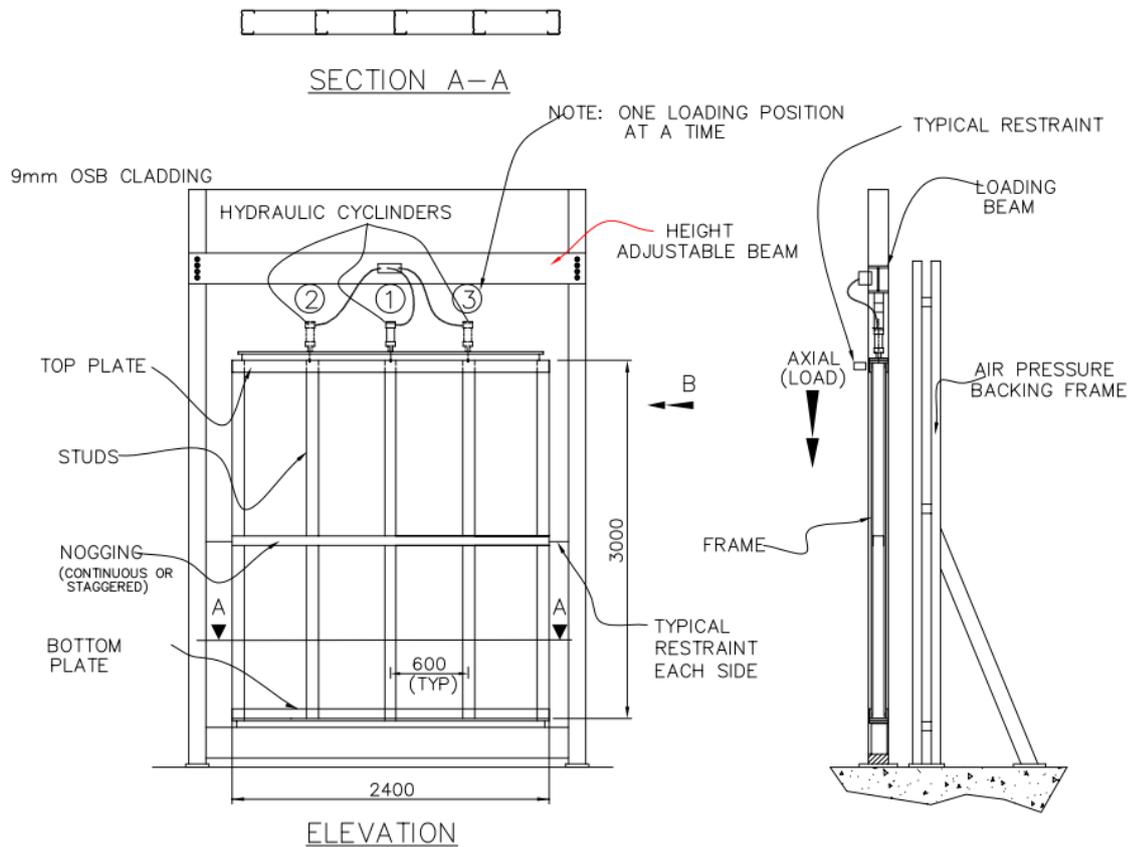
Figure 3: Typical wall test rig

sample needs to be allowed to cure for min 12 hours before testing.

c) Clad on both faces with plasterboard and external cladding : test frame needs to be constructed as specified in (b) above. Install external cladding (profiled steel cladding, fibre cement cladding etc.) directly to the wall studs and plates. The cladding needs to be fixed to the wall frame as per manufacturer's recommendations.

2.9   TEST PROCEDURE

2.9.1   Unclad wall frame:

2.9.1.1   Axial load – load needs to be applied to the three internal studs only. Do not apply axial load to the end studs.

2.9.2   Wall clad on one face only with plasterboard:

2.9.2.1   Axial load – axial load needs to be applied to internal wall studs as specified in section 2.9.1.1.

2.9.2.2   Bending load – uniform pressure needs to be applied to the wall frame such that the unrestrained flange of the stud is in compression. Note that the test frame used for compression test should not be used for bending test. A minimum of 2 frames needs to be tested for bending load. A false cladding (fibre cement or similar) needs to be used on the unclad face to act as a medium to apply air pressure. Fibre cement plank is clip fixed to the

studs so that it does not provide any restraints to the flange of the stud on which it is fixed and is therefore acting as an unclad face.

2.9.2.3   Combined bending and axial load – the maximum axial load to be applied in this test will be approximately half of that achieved in axial compression test in section 2.9.2.1. This load needs to be applied to all internal studs concurrently. Maintain this load and start applying bending load as specified in section 2.9.2.2. A minimum of 2 frames needs to be tested for combined bending and axial load.

2.9.3   Wall Clad on both faces with plasterboard and external cladding:

2.9.3.1   Axial load – axial load needs to be applied to internal wall studs as specified in section 2.9.3.1.

2.9.3.2   Bending load – for this test, air pressure is applied to one face of the wall and then repeated on the other face to determine the minimum failure pressure.

2.9.3.3   Combined bending and axial load – the maximum axial load to be applied in this test will be approximately half of that achieved in axial compression test in section 2.9.3.1. Maintain this load and start applying bending load to the face that provided minimum failure pressure in 2.9.3.2. A minimum of 2 frames needs to be tested for combined bending and axial load.

2.10 TEST OBSERVATIONS AND RESULTS

During the course of the test note the maximum load reached before the load starts to drop. Note the failure mode and location. For wall frames cladded on both faces, remove the cladding on at least one face to observe the failure mode.

The design values are to be calculated by applying appropriate sampling factor specified in Section 7 of NASH Standard Part 1 [2] and as outlined in NASH Technical Note 4 [5]. The coefficient of variation to be used is calculated from the test results but shall not be less than 10 %. A lower coefficient of variation may be adopted if appropriate documentation is available to show significantly lower material variability in the type of steel used for the frames. Material obtained from multiple sources will lead to greater variability.

2.11 REPORTS

The report needs to include the following:

2.11.1 Steel grade and properties - The section sizes and thickness used for the wall framing members, wall height, number of rows & maximum spacing of noggings, external cladding and internal cladding used.

2.11.2 Failure load for each test; axial compressive load in kN and bending load in kN/m (failure pressure x stud spacing). Bending capacity can be calculated using bending load and stud height.

2.11.3 Coefficient of variation and sampling factor used in determining the design values.

2.11.4 Stud interaction curve with axial compression on y-axis and bending on x-axis. Both failure curve and design curve shall be included. A sample stud interaction curve is shown in Figure 4.
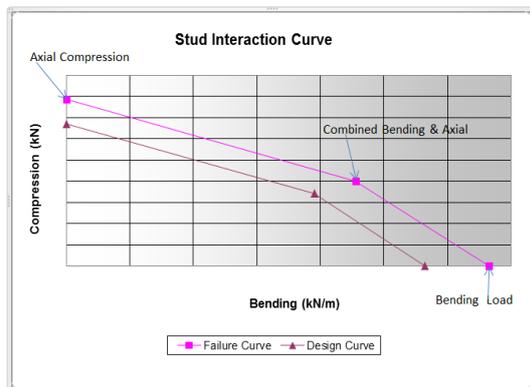

Figure 4: Typical stud interaction curve

3 CASE STUDY

WALL FRAMING DESIGN EXAMPLE (As per AS/NZS4600:2005 and NASH Standard) [1], [2]

WALL STUD DESIGN
DESIGN ASSUMPTIONS
Stud type = 90x0.55 Ribbed Lipped Channel, G550
Stud height = 2700 mm
Nogging = 1350mm (max)

CROSS-SECTIONAL DIMENSIONS:

Overall depth, D	= 90 mm
Overall flange width, B	= 38mm
Thickness, t	= 0.55 mm
Internal corner radius, R	= 2 mm
Stiffener length, L	= 8.0 mm
Material spec	= G550

SECTION PROPERTIES:

A_g	=	97.9 mm^2
A_e	=	40.96 mm^2
x_o	=	27.57 mm
r_x	=	36.12 mm
r_y	=	13.95 mm
r_{o1}	=	47.56 mm
Z_x	=	2826 mm^3
Z_{ex}	=	1679 mm^3
I_x	=	127700 mm^4
I_w	=	29470000 mm^6
J	=	9.98 mm^4
E	=	200000 MPa
f_{odc}	=	101 MPa
f_{odx}	=	188.7 MPa
F_y	=	410 MPa
F_u	=	410 MPa

(F_y and F_u reduced to 410 MPa as per clause 1.5.1.4 of AS/NZS 4600:2005)

Suggested effective length values for studs for brick veneer walls (plaster board screw fixed to one side)

$k_x = 0.8$ $k_y = 0.8$ $k_z = 0.8$
$l_{ex} = 2160mm$ $l_{ey} = 1080mm$ $l_{ez} = 1080mm,$

MEMBER SUBJECT TO CONCENTRICALLY LOADED COMPRESSION

Clause 3.4.1 of AS/NZS 4600:2005

(Design section capacity)
$$\emptyset_c \ N_s = \emptyset_c \ A_e \ f_y$$
$$= 0.85 \times 60.78 \times 495 = 14.27 \text{ kN}$$

CRITICAL STRESS (f_n) according to Clause 3.4 of AS/NZS 4600:2005
Clause 3.3.3.2.1 to compute f_{ox}, f_{oy} and f_{oz}

$$f_{ox} = \pi^2 \ E / (l_{ex} / r_x)^2 \qquad = \qquad 551.97 \text{ MPa}$$

$$f_{oy} = \pi^2 \ E / (l_{ey} / r_y)^2 \qquad = \qquad 329.33 \text{ MPa}$$

$$f_{oz} = (G \ J \ (1 + (\pi^2 \ E \ I_w / G \ J \ l^2_{ez}))) / A \ r^2_{o1}$$
$$= 228.82 \text{ MPa}$$

Clause 3.4.3 of AS/NZS 4600 (Subject to torsional or flexural-torsional buckling)

$$f_{oc} = f_{oy} = \pi^2 \ E / (l_{ey} / r_y)^2 = 329.33 \text{ MPa}$$

$$f_{oxz} = ((f_{ox} + f_{oz}) - \sqrt{((f_{ox} + f_{oz})^2 - 4 [1 - (x_o/ r^2_{o1})^2]} f_{ox} + f_{oz}) / 2 [1 - (x_o/ r^2_{o1})^2]$$

$$= \qquad 193.64 \text{ MPa}$$

f_{oc} = Lesser of f_{oc} and f_{oxz} = 193.64 MPa

$\lambda_c = \sqrt{(f_y / f_{oc})} = 1.46$
SINCE $\lambda_c \leq 1.5 \rightarrow f_n = (0.658 / \lambda^2_c) \ f_y$

$$= 168.1 \text{ MPa}$$

Clause 3.4.6 of AS/NZS 4600 (Subject to distortional buckling)

Lesser of:

a. $\emptyset_c \ N_c = \emptyset_c \ A_{efn} \ f_n$ (A_e @ f_n = 56.76)
$$= 0.85 \times 56.76 \times 168.69$$
$$= 8.14 \text{ kN}$$

b. For $f_y/13 \leq f_{od} \leq f_y/2$

$\rightarrow \emptyset_c \ N_c = \emptyset_c \ A_g \ f_n$
$= \emptyset_c \ A_g \ f_y [0.055(\sqrt{f_y / f_{od}} - 3.6)^2 + 0.237]$
$= 12.80 \text{ kN}$

The design compression capacity:

(Design section capacity)
$\emptyset_c \ N_s$ =14.27 kN

(Design member capacity) Flexural/ Torsional/ Flexural-torsional buckling
$\emptyset_c \ N_c$ = 8.14 kN (which governs design)

(Design member capacity) Distortional buckling criteria
$\emptyset_c \ N_c$ = 12.80 kN

SUMMARY:

Axial compression capacity $\emptyset_c \ Nc$ = 8.14 kN

MEMBER SUBJECT TO BENDING

Clause 3.3.2.2 of AS/NZS 4600:2005

Design Section moment Capacity,

$$\emptyset_b \ M_s = 0.95 \times Z_e \ f_y = 0.654 \text{ kNm}$$

Clause 3.3.3.2 of AS/NZS 4600
MEMBER SUBJECT TO LATERAL BUCKLING

$$f_{ox} = \pi^2 \ E / (l_{ex} / r_x)^2 \qquad = 551.97 \text{ MPa}$$

$$f_{oy} = \pi^2 \ E / (l_{ey} / r_y)^2 \qquad = 329.33 \text{ MPa}$$

$$f_{oz} = (G \ J \ (1 + (\pi^2 \ E \ I_w / G \ J \ l^2_{ez}))) / A \ r^2_{o1}$$
$$= 228.82 \text{ MPa}$$

Elastic buckling moment, $M_o = C_b \ A \ r_{o1} \ \sqrt{(f_{oy} \ f_{oz})}$
$$= \qquad 1.278 \text{ kNm}$$
$M_y \qquad = \qquad Z_f \ f_y$
$$= \qquad 1.159 \text{ kNm}$$

$\lambda_b \qquad = \qquad \sqrt{(M_y / M_o)} \qquad = \qquad 0.952$
For $\quad 0.60 \quad < \quad \lambda_b \quad < \quad 1.336$
$\rightarrow M_c = 1.11 \ M_y [1- (10 \lambda_b^2 / 36)]$
$$= 0.963 \text{ kNm}$$

Critical stress, $f_c \ = M_c/Z_f$
$$= 340.76 \text{ MPa}$$

NOTE:
- Z_c was calculated at the uniform yield stress, f_y.
- Since $f_c < f_y$, the value of Z_c will be slightly higher at the critical stress, f_c. As a result, it gives slightly higher nominal member moment capacity in bending.

Design member moment capacity,

$\emptyset_b M_b = \emptyset_b Z_c f_c = 0.90 Z_c M_c / Z_f$
$= 0.51$ kNm

Clause 3.3.3.3 of AS/NZS 4600:2005
MEMBER SUBJECT TO DISTORTIONAL BUCKLING

Elastic buckling moment in the distortional mode,

$M_{od} = Z_f f_{od}$
$= 0.533$ kNm

$\lambda_d = \sqrt{(M_y / M_{od})} = 1.47$
For $\lambda_d > 0.674$
$\rightarrow M_c = M_y / \lambda_d (1 - (0.22 / \lambda_d))$
$= 0.67$ kNm
$f_c = M_c / Z_f$

Design member moment capacity,
$\emptyset_b M_b = \emptyset_b Z_e f_c = 0.90 Z_c M_c / Z_f$
$= 0.358$ kNm

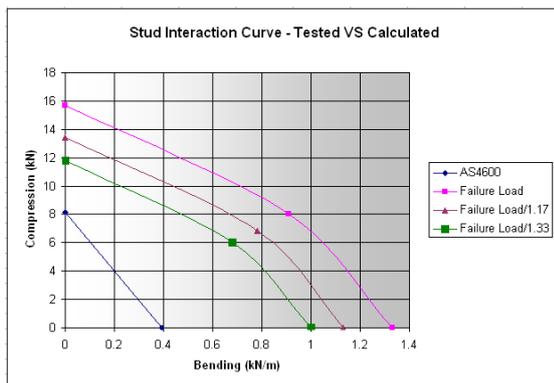**SUMMARY:**

Design Section Capacity, $\emptyset_b M_s = 0.65$ kNm

Design Member Capacity, $\emptyset_b M_b = 0.51$ kNm
(Lateral buckling)

Design Member Capacity, $\emptyset_b M_b = 0.36$ kNm
(Distortional buckling – which governs design)

$Wl2/8 = 0.36$ kN-m
$L = 2700$mm
Bending Load $W = 0.39$ kN/m

Failure load curve was based on following tests
  a) Axial compression tests
  b) Bending tests
  c) Axial compression + bending tests
The above tests were conducted with plasterboard screwed on one side and fibre cement planks clipped on one side. Fibre cement planks clipped on one side is only to provide a medium to apply

air pressure and not act as a restraint for the flange on which it is fixed.
Failure load is further reduced using sampling factors based on the number of tests and coefficient of variation. Design curve is based on AS/NZS 4600:2005 calculations.
The above stud interaction curves clearly indicate the capacity determined from tests is much higher than that derived from theoretical calculations. This is primarily due to the assumptions made in effective length calculations based on restraints and partial fixity at the ends.

4 CONCLUSIONS

This paper outlined the basic features of wall frame assemblies made of light gauge cold formed steel.
The need for Wall framing testing protocol was discussed.
The loads expected on typical residential walls were discussed. Detailed lists of the expected actions along with relevant design criteria for serviceability and strength limits states were presented. The relevant load combinations were also summarised.
The paper detailed the assumptions for designing wall studs and outlined typical effective length considerations of stud members.
The paper also emphasised the importance of testing and discussed the various components/steps involved in wall frame testing
With extended research it has been found that stud capacity derived by testing method is more realistic as compared with that of theoretical calculations.

ACKNOWLEDGEMENT

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