NUMERICAL STUDY ON THE SHEAR RESISTANCE OF COLD-FORMED STEEL SHEAR WALL WITH STEEL SHEATHING

S. Esmaeili Niari[*], B. Rafezy and K. Abedi
Department of Civil Engineering, Sahand University of Technology, P. O. Box 51335/1996, Tabriz,Iran

ABSTRACT

Shear wall panel as one of the primary lateral load resisting components, has been extensively used in lightweight framing of low and mid-rise residential constructions. In this paper, the shear resistance of cold formed steel stud walls with single sided steel sheathing has been investigated under monotonic loading by finite element analysis. The numerical modelling of shear wall taking into account geometric large deformation and material nonlinearity has been conducted using finite element method .The results obtained from FEM have been verified against the available experimental results. Using finite element analysis, parametric study is carried out considering height-width ratio of wall, stud and sheathing thickness and screw spacing in order to obtain the shear carrying capacity of the wall. The numerical results have shown the good seismic performance of cold formed steel stud walls with steel sheathing.

Keywords: Shear resistance; cold formed steel; shear wall; steel sheathing; finite element analysis

1. INTRODUCTION

Cold-formed steel (CFS) framed shear wall is a practical lateral force resisting system in buildings [1]. In general, CFS wall panels consist of CFS studs (lipped channel section), top and bottom tracks (plain channel section) and blockings covered by boards on interior and exterior faces. Gypsum, plywood, profiled metal sheets, steel sheets, sandwich panels and oriental strand boards are used as face sheathings. The concept of using cold-formed steel sheathing, however, is relatively new [2]. The bottom tracks of the wall panels are attached to the ground supported slab by anchor bolts. Figure 1 shows a typical cold-formed steel

---

[*] E-mail address of the corresponding author: Esmaeili.shirin@gmail.com (S. Esmaeili Niari)
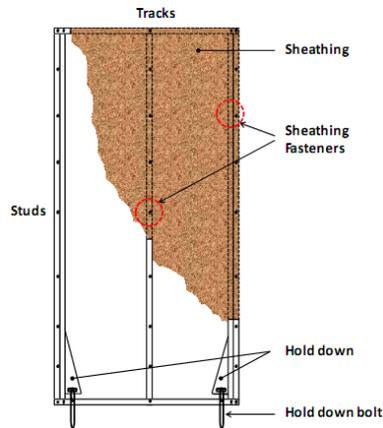
shear wall.

Figure 1. CFS shear wall

Studies on CFS wall panels sheathed with gypsum or wood based boards have been carried out by many researchers such as Fulop and Dubina [3,4], Branston et al. [5], Serrette et al. [6], Fiorino et al.[7,8], Xuhong et al. [9].

Regarding the steel sheathed shear walls, tests have only been carried out in the US by Serrette [6], Yu et al. [1,10] and Ellis [11]. The tests performed by Serrette [6], at the Santa Clara University, were limited to 2:1, 1220x2440mm, and 4:1, 610x2440mm, shear walls using 0.84mm CFS framing with nominal sheathing thicknesses of 0.46mm and 0.68mm . Yu et al. [1], at the University of North Texas, expanded the test program for steel sheathed shear walls by including specimens constructed with 0.76mm and 0.84mm nominally thick sheathing. Balh [2] Carried out tests on single-storey cold-formed steel frame/steel sheathed shear walls constructed from various framing and sheathing thicknesses to develop a Canadian design method for steel sheathed shear walls.

The aims of this paper are as follows:

To study the shear resistance of steel sheathed CFS shear walls and;

To investigate into the effects of some parameters on the shear resistance of CFS shear walls.

2. FINITE ELEMENT MODELLING

Different approaches are available to estimate the lateral response of sheathed CFS shear walls: experimental, analytical and numerical methodologies. The experimental approach is based on full scale tests carried out on typical walls and it is frequently used. In fact, nominal shear strength design values provided by building codes [12] in tabulated form are based on the experimental test results. Due to the required large number of tests, it is clear that this approach is the most expensive one and, in addition, it can be used only when the wall characteristics (geometry and material) are within the range of experimental results. In order to overcome the limitations of the experimental approach, finite element procedures

can be used to evaluate the shear response of sheathed CFS shear walls. Numerical models are usually calibrated using available experimental results and they can be used to simulate the structural response of walls having characteristics different from tested walls [8].

In order to employ proper FE models to analyze and study the performance of the CFS shear walls, the first step is to model CFS shear wall considering geometric and material nonlinearities. The commercially available software package ABAQUS/Standard [13], version 6.9-2, was used to develop the FE models.

The 4-node S4R shell element with reduced integration was selected for the modeling of shear walls. This element has three translational and three rotational degrees of freedom at each node. The element accounts for finite membrane strains and arbitrarily large rotations. Therefore, it is suitable for large- strain analyses and geometrically nonlinear problems. The screw connections were modelled by mesh independent fasteners. Using of mesh-independent fastener is a convenient method to define a point-to-point connection between two or more surfaces. These connections may be in the form of spot welds, rivets, screws, bolts, or other types of fastening mechanisms. The fastener can be located anywhere between the parts that are to be connected regardless of the mesh. In other words, the location of the fastener can be independent of the location of the nodes on the surfaces to be connected. Each layer connects two fastening points using connector element [13]. In Figure 2 fastener configuration has been shown.
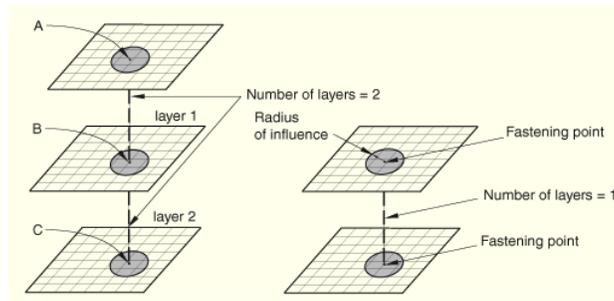

Figure 2.Typical one-layer and two-layer fastener configuration

In the nonlinear analysis carried out in the present study, the input of the material stress-strain response is required in the form of true stress versus true plastic strain. The true stress (σ_{true}) and true strain (ε_{true}) were converted from the engineering stresses (σ) and engineering strains (ε) using the following equation [14]:

$$\sigma_{true} = \sigma\,(1+\varepsilon)$$

$$\varepsilon_{true} = \ln\,(1+\varepsilon) - \frac{\sigma_{true}}{E} \tag{1}$$

The displacements along the X, Y and Z-directions and rotations along Y and Z-directions of bottom track were restrained and the top track was assumed to have no

displacement and rotation along the Y and Z-directions. The displacement controlled loading process was used and the lateral displacement was applied on the top track nodes.

2.1 Verification of the Finite Element Modeling

Experimental results on the steel sheathed CFS shear walls tested by Nisreen Balh [2] were used to evaluate the validity and accuracy of the numerical model. The characteristics of the models tested by Nisreen Balh are given in the following.

Nominal dimensions of the steel studs were 92.1mm for web, 41.3mm for flange and 12.7mm for lip. Nominal dimensions of the steel tracks were 92.1mm for web and 31.8mm for flange. Except for 610mm long walls, a field stud was placed at a spacing of 610mm on-centre in the 1220mm long walls. The sheathing was then placed on the frame, marked, and installed with No.8 gauge 19.1mm pan head screws according to the fastener schedule in Table 1. The sheathing was fastened around the perimeter of the wall specimen along the tracks and the chord studs at an edge distance of 9.5mm and along the field stud, if available. The section structural material properties are shown in Table 2. Figure 3 shows wall specimen before test and Figure 4 shows the finite element models of CFS shear walls [2].

Table 1: Test matrix [2]

Configuration	Sheathing thickness (mm)	Wall length (mm)	Wall height (mm)	Fastener spacing (mm)	Framing thickness (mm)
Model 5	0.76	1220	2440	100/300	1.09
Model 6	0.76	1220	2440	50/300	1.09
Model 8	0.76	610	2440	100	1.09
Model 9	0.76	610	2440	50	1.09

Figure 3. Wall specimen before test [2]

Table 2: Material properties [2]

Specimen thickness (mm)	Member	Base metal thickness (mm)	Yield stress, F_y (Mpa)	Tensile stress, F_u (Mpa)
0.76	sheathing	0.76	284	373
1.09	stud/track	1.14	346	496

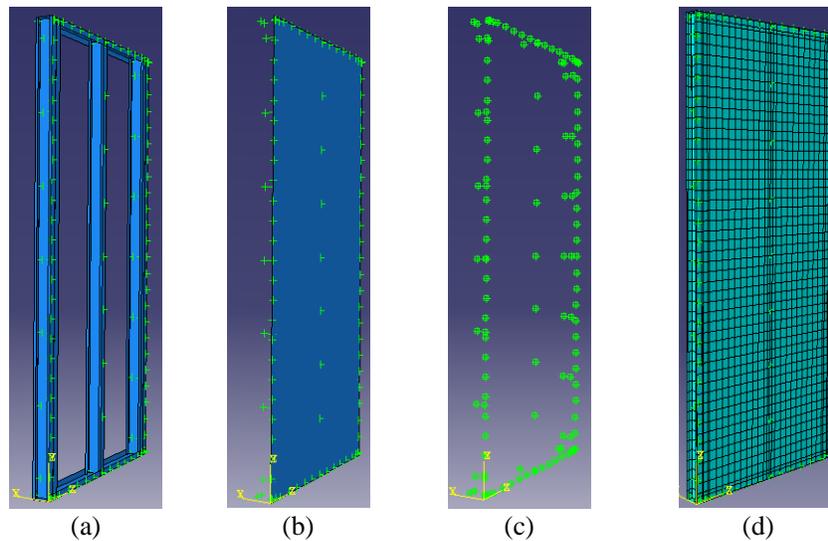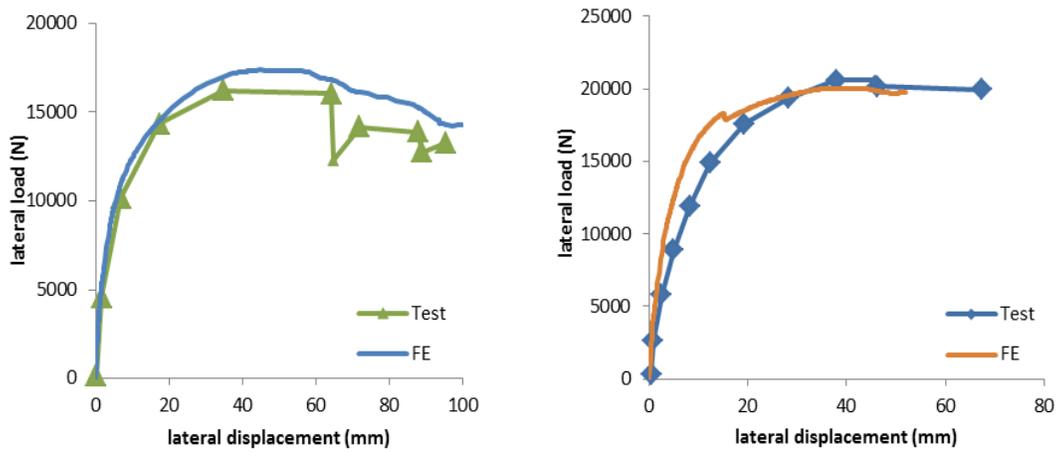

| (a) | (b) | (c) | (d) |

Figure 4. Finite element model. (a) Frame; (b) Sheathing; (c) Screws; (d) Meshing

Load-displacement curves of cold-formed steel stud walls have been shown in Figure 5. Comparison of the numerical results with the test results indicated that the numerical results were close to those of tests (as shown in Figure 5).
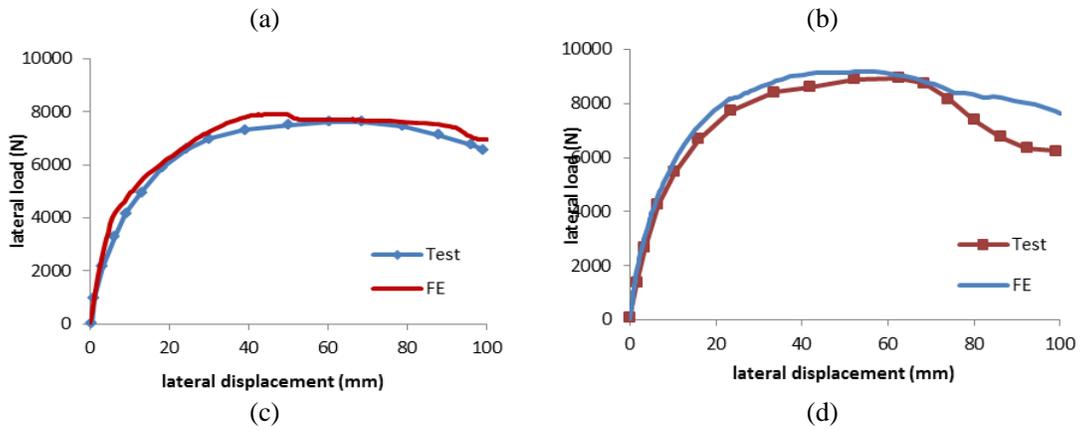
Figure 5. Comparisons of numerical and experimental results for: (a) Model 5, (b) Model 6, (c) Model 8, (d) Model 9

Therefore, it has been found that the finite element modeling is reliable enough to be used to undertake a parametric study for investigating into the effects of some parameters on the behaviour of CFS steel sheathed shear walls.

3. PARAMETRIC STUDY

3.1 Material Properties
Coupon tests were conducted to obtain the actual properties of the materials used in the shear wall modelling. The testing procedure is conformed to the ASTM A370 [15] "Standard Test Methods and Definitions for Mechanical Testing of Steel Products". Test sample has been shown in Figure 6. The stress-strain curve obtained from the coupon test is provided in Figureure 7. The yield stress $f_y=347$ *MPa* was obtained by using the 0.2% nominal proof stress and the tensile stress is $f_u=400$ *MPa* .
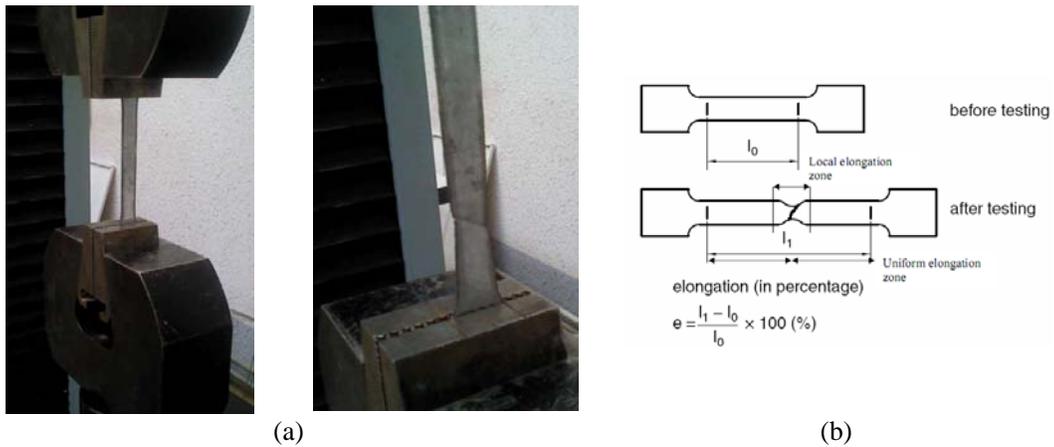

Figure 6. Material tension testing. (a) Test sample. (b) Necking and failure of test sample
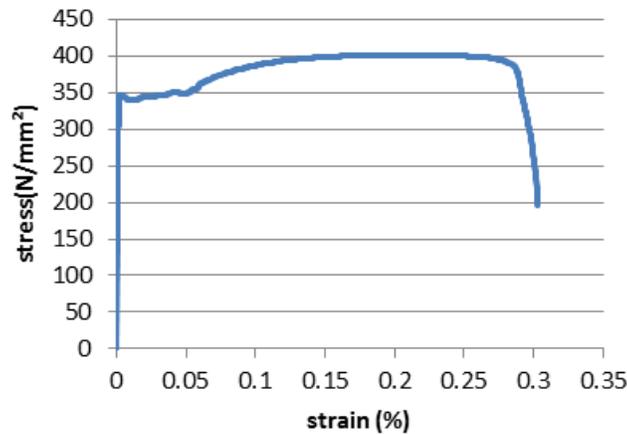
Figure 7. Stress-strain curve

The shear resistance of cold-formed steel stud walls is affected by many factors, such as materials of studs and sheathing, screw spacing, height-width ratio of wall, stud & screw spacing and so on. In the present study, a series of parametric analysis were undertaken to study the effects of stud thickness, sheathing thickness, screw spacing, and wall height-width ratio on the shear resistance of walls. In the following the results of parametric study are given.

3.2 The Effects of Stud and Sheathing Thickness on the Shear Resistance of Walls
CFS shear walls with height-width ratios of 4 (height 2440mm and width 610 mm) and 2 (height 2440mm and width 1220 mm) and with stud thicknesses of 0.7mm, 1mm, 1.2mm and 1.5mm and sheathing thicknesses varied between 0.5mm to 2mm were selected for investigating into the effects of stud and sheathing thicknesses on the nominal shear capacity of steel sheathed CFS shear walls. The characteristics of numerical models are provided in Table 3.
Monotonic load with displacement control was applied to the top of shear walls and shear behaviour of walls were investigated. Figure 8 illustrates the definitions of the notations used in the analysis label.
Figure 9 and 10 illustrate the load-lateral displacement response for the CFS panels with height-width ratio of 4 and 2, respectively.
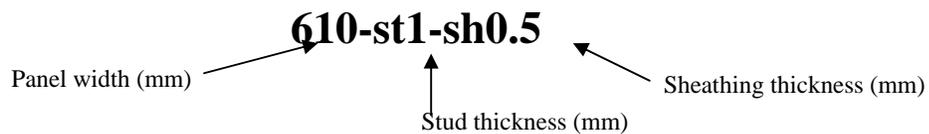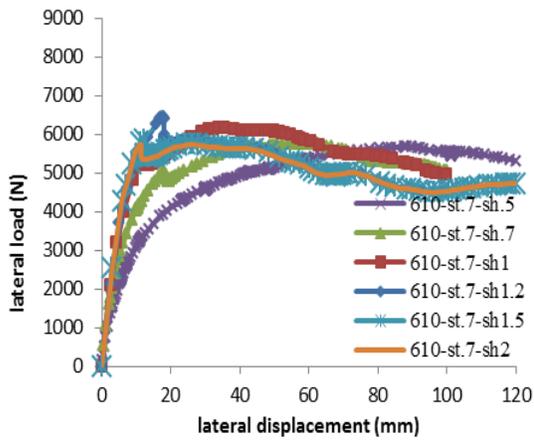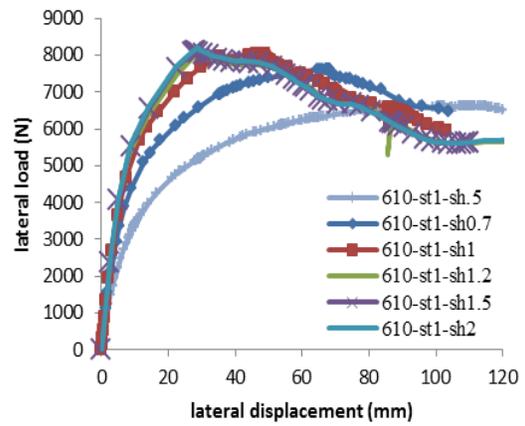

Figure 8. Definitions of analysis label

Table 3: Characteristics of specimens

Panel width*height (mm)	stud thickness (mm)	sheathing thickness (mm)	Panel width*height (mm)	stud thickness (mm)	sheathing thickness (mm)
610×1220	0.7	0.5	1220×2440	0.7	0.5
		0.7			0.7
		1			1
		1.2			1.2
		1.5			1.5
		2			2
	1	0.5		1	0.5
		0.7			0.7
		1			1
		1.2			1.2
		1.5			1.5
		2			2
	1.2	0.5		1.2	0.5
		0.7			0.7
		1			1
		1.2			1.2
		1.5			1.5
		2			2
	1.5	0.5		1.5	0.5
		0.7			0.7
		1			1
		1.2			1.2
		1.5			1.5
		2			2

(a)

(b)

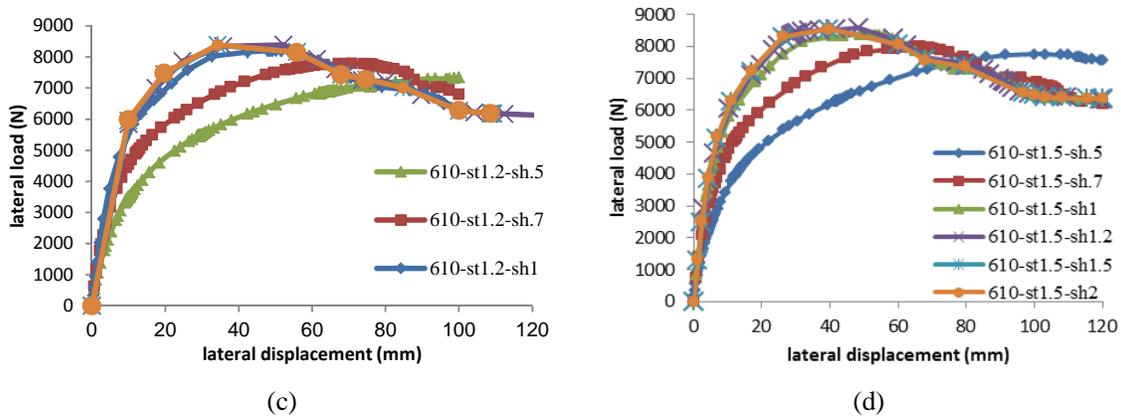(c)   (d)

Figure 9. Load- Lateral displacement response for the 610×1220 panels. (a) st=0.7; (b) st=1; (c) st=1.2; (d) st=1.5

(a)   (b)
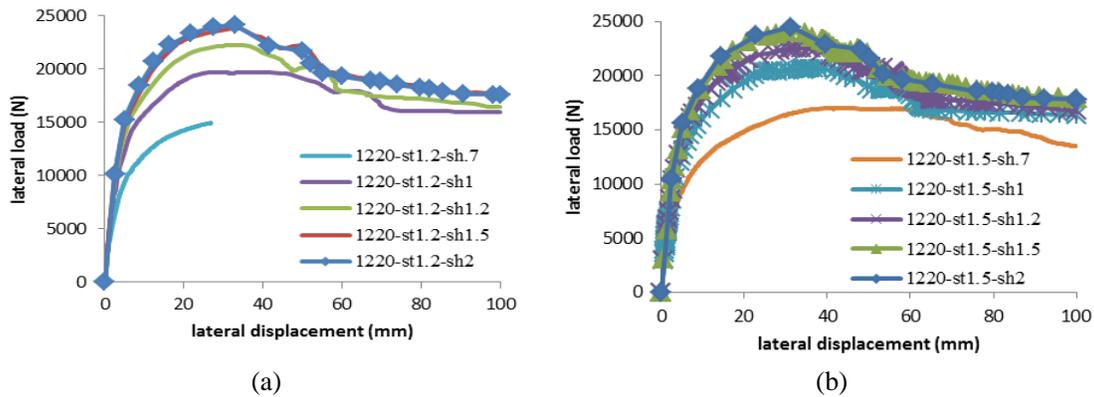
Figure 10. Load-Lateral displacement response for the 1220×2440 panels. (a) st=1.2; (b) st=1.5

The nominal shear strengths are calculated as the peak load of load-displacement curve and are given in Table 4. Figure 11 also illustrates the nominal shear strength per unit width of walls. It can be seen that increasing the sheathing thickness, increases the nominal shear capacity of walls. In the case of wall height-width ratio of 4, up to the 1.2mm sheathing thickness, the nominal shear strength increases linearly, but for sheathing thickness greater than 1.2mm, the nominal shear capacity remains almost constant. There is no significant difference between nominal shear strength of the walls when the stud thickness increases from 1.2mm to 1.5mm.

In the case of wall height-width ratio of 2, up to the 1.5mm sheathing thickness, the nominal shear strength increases linearly with high slope, however, for sheathing thickness greater than 1.5mm, the increasing rate of nominal shear capacity is less. Although increasing the stud thickness from 1mm to 1.2 mm provides a significant increase in the nominal shear strength of the wall, but there is no remarkable difference between nominal shear strength of the wall with 1.2mm and 1.5mm stud thickness.

These results indicate that the thicker steel sheets did not significantly increase the shear resistance of CFS shear walls. This result has also been obtained in the experimental study, carried out by Yu [10].
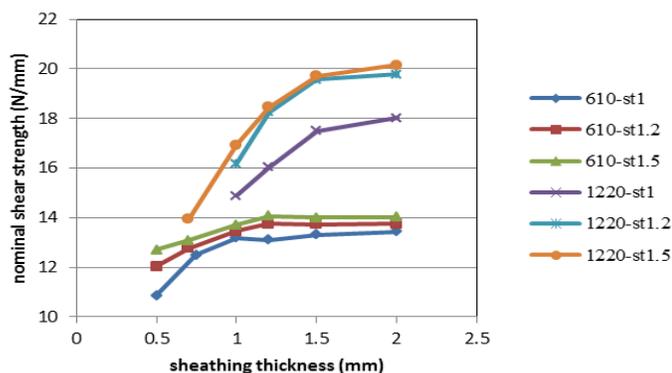

Figure 11. Comparison of nominal shear strength for walls with different height-width ratios
and different thicknesses of stud and sheathing

Table 4: Results of analyses

Analysis label	Nominal shear strength (N/mm)	Drift ratio (%)
610-st1-sh1	13.18	1.98
610-st1-sh1.2	13.1	1.15
610-st1-sh1.5	13.31	1.16
610-st1-sh2	13.43	1.19
610-st1.2-sh1	13.45	1.96
610-st1.2-sh1.2	13.75	2.14
610-st1.2-sh1.5	13.74	1.41
610-st1.2-sh2	13.75	1.4
610-st1.5-sh1	13.71	2
610-st1.5-sh1.2	14.06	1.99
610-st1.5-sh1.5	14	1.63
610-st1.5-sh2	14.01	1.63
1220-st1-sh1	14.87	0.76
1220-st1-sh1.2	16.02	0.88
1220-st1-sh1.5	17.5	1.28
1220-st1-sh2	18	1.24
1220-st1.2-sh1	16.17	1.14
1220-st1.2-sh1.2	18.25	1.44
1220-st1.2-sh1.5	19.56	1.31
1220-st1.2-sh2	19.77	1.36
1220-st1.5-sh1	16.93	1.84
1220-st1.5-sh1.2	18.46	1.45
1220-st1.5-sh1.5	19.7	1.25
1220-st1.5-sh2	20.15	1.24

In all the analysis, the in-plane shear force caused the buckling of the steel sheathing and large out-of-plane deformation of the sheathing. Figure 12 shows the failure mode of a 610mm*1220mm CFS wall with 1mm stud thickness and 0.5 mm sheathing thickness. It can be seen that diagonal buckling has occurred in the sheathing of wall. The buckling of the steel sheathing and large out-of-plane deformation of the sheathing were the primary failure modes for steel sheathed CFS shear walls. Distortional buckling of studs is also observed in this case.

Figure 13 shows the observed failure modes for a 1220mm*2440mm wall with 1mm stud and sheathing thickness. Steel sheet buckling and distortional buckling of boundary studs was the failure mode of this wall.
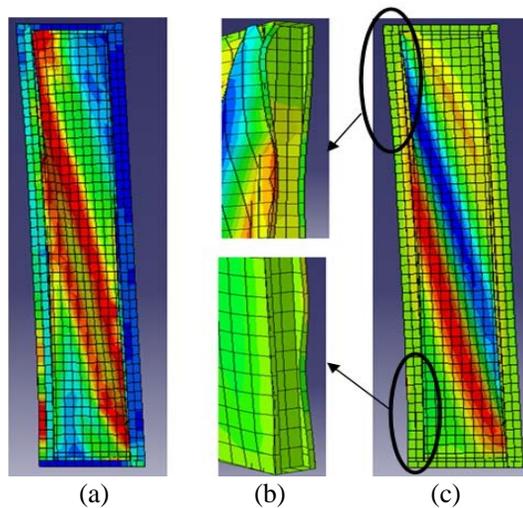

(a)   (b)   (c)

Figure 12. Result of analysis for 610-st1-sh0.5 wall. (a) Von-Mises stress. (b) Distortional buckling of stud. (c) Out of plane displacement

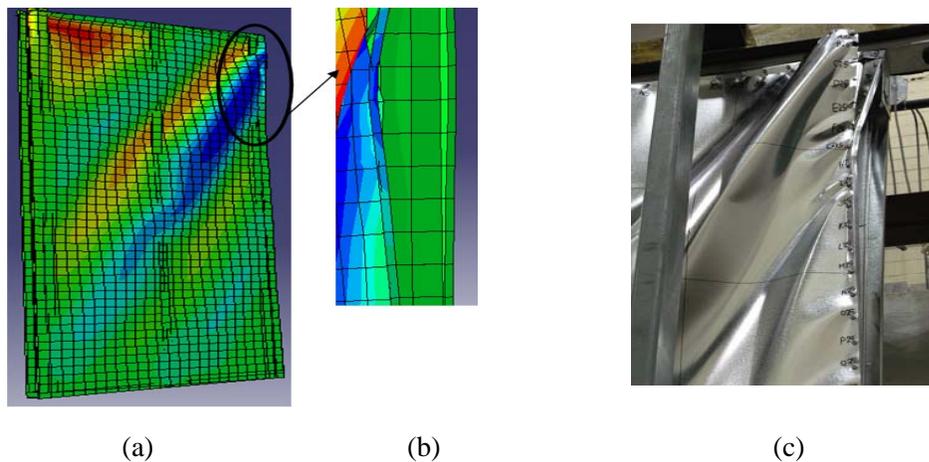(a)   (b)   (c)

Figure 13. Result of analysis for 1220-st1-sh1 wall. (a) Out of plane displacement; (b) Flange buckling of stud; (c) Flange buckling of stud in experiment

3.3 The Effects of Screw Spacing on the Shear Resistance of Steel Sheathed CFS Shear Wall
The strength and stiffness of the screw connections between CFS framing members and sheathings play the key role in CFS wall panel behaviour. Most of the nonlinearity in the load–deformation behaviour of the CFS wall panels under in-plane shear is due to the nonlinear response of the screw connection between the CFS members and the boards [16].

In this section, the effects of screw spacing at the perimeter of the wall on the nominal shear strength of CFS walls have been investigated. It should be noted that the screw spacing at the field stud of the 1220mm width panel is 300mm. The characteristics of wall panel analyzed for investigating into the effects of screw spacing is given in Table 5. The lateral load-displacement responses of walls with different screw spacing at the perimeter of the wall are shown in Figure 14. The notation "sc" in the analysis label indicates the screw space. This figure illustrates that by reducing the screw spacing, the shear resistance of walls was increased. Figure 15 present the plots of the nominal shear strength vs. the screw spacing at panel edges.

Table 5: Characteristics of Specimens

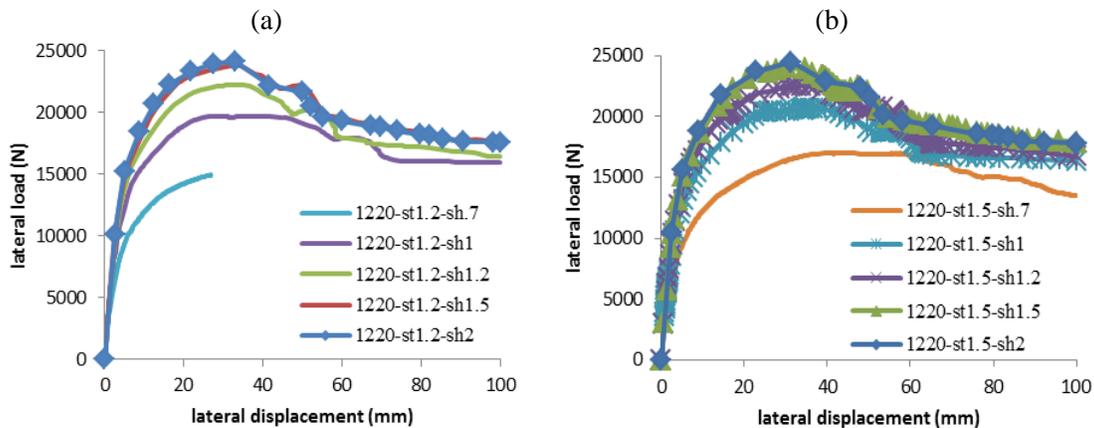| Panel	Screw space(mm)	Panel	Screw space (mm)
610-st1.2-sh1.2	50	1220-st1.2-sh1.2	50
	100		100
	150		150
	200		200
	-		300

Figure 14. Lateral load-displacement response of walls with different screw spacing. (a) panel 610×2440; (b) panel 1220×2440
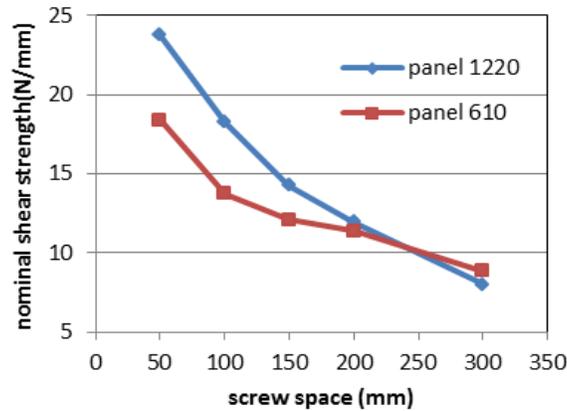
Figure 15. Nominal shear strength vs. the screw spacing at panel edges

Also, 610mm×1220mm CFS shear wall with stud and track thickness of 1.2mm was selected for investigating into the effects of variable screw spacing at the tracks and studs on the shear strength of the wall.

At first, the screw space of stud is considered 100mm and the screw space of track is assumed variable between 50mm and 200mm as shown in Figureure 16. Table 6 also indicates the characteristics of numerical models. The lateral load-displacement responses of the wall are given in Figure 17(a). This figure indicates that changing the distance between the track screws, has considerable effect on the nominal shear strength of the wall. By reducing the screw space from 200mm to 50mm, the nominal shear strength increases more than 3000 N. It is worth noting that "sctr50" in Figureure 17(a) indicates that the screw space of track is 50mm.

Then, the screw spacing at the track is considered 100mm and screw spacing at the studs is assumed variable between 50mm and 200mm as shown in Table 6. Figure 17(b) shows the lateral load-displacement responses of the wall. It is found that, changing the screw space of the stud from 50mm up to 200mm, while the screw space of track is fixed, have no considerable effect on the nominal shear strength of the wall. It should be noted that "scstud50" in Figureure 17(b) indicates that the screw space of stud is 50mm.

Table 6: characteristics of specimens

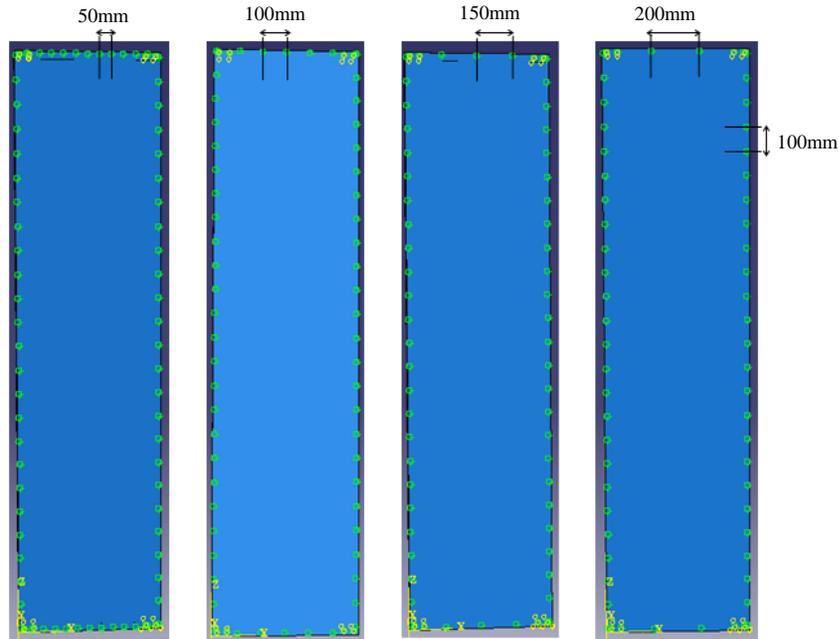| Analysis label	Screw space at track (mm)	Screw space at stud (mm)	Analysis label	Screw space at stud (mm)	Screw space at track (mm)
610-st1.2-sh1.2	100	50	610-st1.2-sh1.2	100	50
		100			100
		150			150
		200			200

Figure 16. variable screw space at tracks

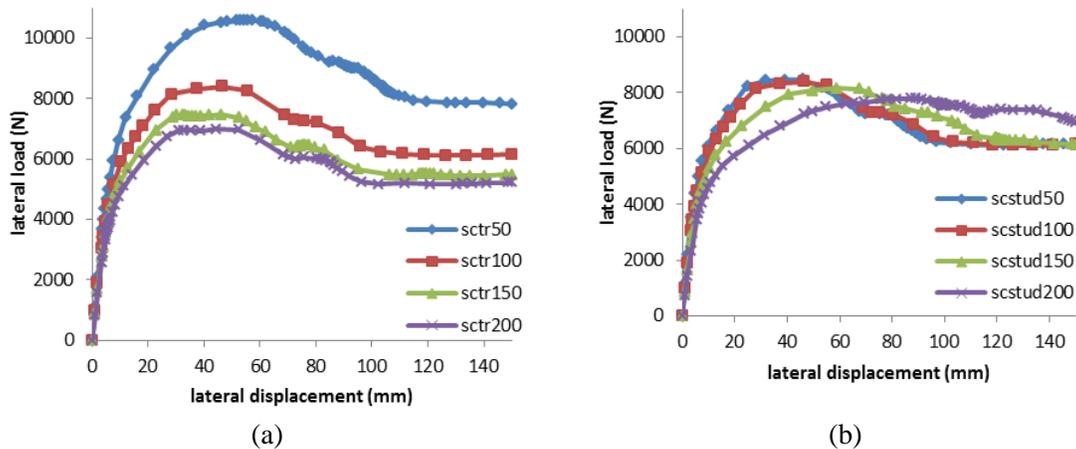(a)   (b)

Figure 17. Lateral load-displacement response of walls with different screw spacing on (a) track; (b) stud

In Figure 18 the nominal shear strength per unit length of the wall for 610-st1.2-sh1.2 shear wall with different screw configurations is plotted. The curve with label "sc stud" indicates the shear wall with track screw spacing of 100mm and variable stud screw spacing between 50mm and 200mm. The curve with label "sc track" indicates the shear wall with stud screw spacing of 100mm and variable track screw spacing between 50mm and 200mm. The curve with label "sc-edge of panel" indicates the shear wall with variable stud and track screw spacing between 50mm and 200mm.

It can be seen that changing the screw space of the stud from 50mm to 200mm, without changing the screw space of the track, has no considerable effect on the nominal shear strength of the wall. But with decreasing the screw space of track, while the screw space of stud is fixed, the nominal shear strength increases effectively. Also, this figure indicates that the screw spacing of the track has determining effect on the behaviour of CFS shear wall.
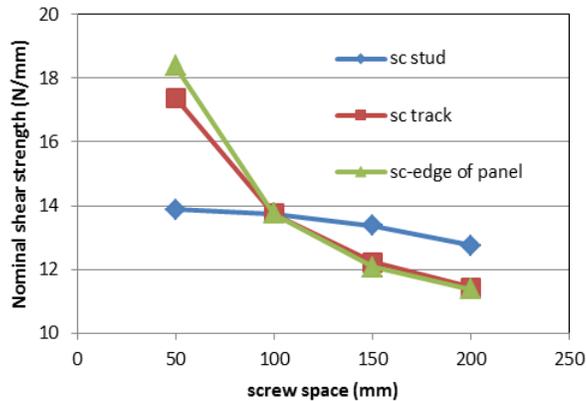

Figure 18. Nominal shear strength vs. the screw spacing at panel edges

5. CONCLUSION

In the present study, nonlinear monotonic analysis on the CFS framed walls with single sided steel sheet sheathing was conducted. Based on the finite element modelling, several parametric studies have been carried out for investigating into the effects of some parameters on the behaviour of CFS steel sheathed shear walls. The nominal shear strength of the walls for monotonic loading was obtained from the numerical results. It was shown that the buckling of the steel sheathing, flange distortion of the boundary studs and pullout of sheathing screws were the main failure modes of steel sheathed CFS shear walls. The numerical results also indicated that the use of thicker steel sheet and thicker stud would not improve effectively the nominal shear strength of the shear walls. It was also observed that decreasing the screw spacing at the perimeter of the walls increases considerably the nominal shear resistance of CFS shear wall and also the screw spacing of the track has determining effect on the behaviour of CFS shear wall.

REFERENCES

1. Cheng Yu. Shear resistance of cold-formed steel framed shear walls with 0.686 mm, 0.762 mm, and 0.838 mm steel sheet sheathing. *Engineering Structures*. **32** (2010) 1522-29.
2. Balh N. Development of seismic design provisions for steel sheathed shear walls.

Department of Civil Engineering and Applied Mechanics. McGill University, Canada. MSc thesis.(2010).

3. Fulop LA and Dubina D. Performance of wall-stud cold-formed shear panels under monotonic and cyclic loading Part II: numerical modelling and performance analysis. *Thin Walled Structures*. **42** (2004) 339–49.

4. Fulop L and Dubina D. Design criteria for seam and sheeting-to-framing connections of cold-formed steel shear panels. *Journal of Structural Engineering*. **132:4**(2006) 582–90.

5. Branston AE, Chen C, Boudreault F and Rogers C. Testing of light-gauge steel frame wood structural panel shear walls. *Canadian Journal of Civil Engineering*. **33** (2006) 561–72.

6. Serrette R. Additional shear wall values for light weight steel framing. Research Report . 97 – 2, Revision 2007. American Iron and Steel Institute (1997).

7. Fiorino L, Iuorio O and Landolfo R. Sheathed cold-formed steel housing: a seismic design procedure. *Engineering Structures*.**34** (2011) 538–47.

8. Fiorino L et al. Performance-based design of sheathed CFS buildings in seismic area. *Thin-Walled Structures*. http://dx.doi.org/http://dx.doi.org/10.1016/j.tws.2012.03.022.

9. Xuhong Zh et al. Study on shear resistance of cold-formed steel stud walls in residential structure. *Advances in Engineering Structures, Mechanics & Construction*. (2006) 423–435.

10. Yu Ch and Chen Y. Detailing recommendations for 1.83 m wide cold-formed steel shear walls with steel sheathing. *Journal of Constructional Steel Research*. **67**(2011) 93-101.

11. Ellis J. Shear resistance of cold-formed steel framed shear wall assemblies using CUREE test protocol. Simpson Strong-Tie Co., Inc (2007).

12. AISI S213-07/S1-09, North American Standard for Cold-formed Steel Framing-Lateral Design 2007 edition with Supplement No. 1, American Iron and Steel Institute (AISI), Washington, 2009.

13. ABAQUS/standard version 6.9-2.

14. Phama C and Hancockb G. Numerical simulation of high strength cold-formed purlins in combined bending and shear. *Journal of Constructional Steel Research*. **66** (2010)1205-17.

15. ASTM A370. A370-06. Standard test methods and definitions for mechanical testing of steel products. American Society for Testing and Materials (2006).

16. Nithyadharan M and Kalyanaraman V. Experimental study of screw connections in CFS-calcium silicate board wall panels. *Thin Walled Structures*. doi:10.1016/j.tws. 2011.01.004.