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Numerical Evaluation of Shear Strength for Cold-Formed Steel Shear Wall Panel

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Abstract**—**The stability of structures made of light-gauge steel depends highly on the contribution of Shear Wall Panel (SWP) systems under horizontal forces due to wind or earthquake loads. Steel plate sheathing is often used with these panels made of cold formed steel (CFS) to improve its shear strength. In order to predict the shear strength resistance, two methods are presented in this paper. In the first method, the steel plate sheathing is modeled with plats strip taking into account only the tension and compression force due to the horizontal load, where both track and stud are modeled according to the geometrical and mechanical characteristics of the specimen used in the experiments. The theoretical background and empirical formulations of this method are presented in this paper. However, the second method is based on a micro modeling of the cold formed steel Shear Wall Panel "CFS-SWP" using Abaqus software. A nonlinear analysis was carried out with an in-plan monotonic load. Finally, the comparison between these two methods shows that the micro modeling with Abaqus gives better prediction of shear resistance of SWP than strips method. However, the latter is easier and less time consuming than the micro modeling method.

Keywords—Cold Formed Steel Shear Wall Panel, CFS-SWP, micro modeling, nonlinear analysis, strip method.

I. Introduction

COLD-FORMED steel SWP is a practical lateral force resisting system in buildings. In general, a typical shear wall panel "SWP-CFS" is made of CFS studs (lipped channel section), top and bottom tracks (plain channel section) and sheathing boards connected to frames by fasteners.

This SWP-CFS has been extensively used in lightweight steel construction. Although effective design recommendations for lightweight steel members and structures have been available, due to the specific characteristics of thin-walled sections and their complex assembly features, the stability of the thin-walled members, the failure modes of connections are still attracting designers and researchers' attention [12], [13].

Different methods are available to estimate the lateral response of CFS-SWP: experimental, analytical and numerical methodologies. The experimental method is based on full scale tests carried out on typical walls and requires a large number of tests, which is reliable but more expensive. An attractive complementary alternative is to use finite element models to evaluate the shear resistance response of CFS-SWP.

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Two modeling techniques are presented in this paper using finite elements method. A simpler one, called "Strips approach" replaces the infill steel sheathing by diagonal strips, which capture only tension or compression force under horizontal load. The second one referred to "micro modeling" relies on detailed modeling of all components of the shear wall using a FE software. Both approaches have been compared with available experimental results given in [2].

Although the micro modeling is known as a complex approach and requires too much theories, the challenge in this work is in the first one, because all fundamentals theories of strip approach is based on hot rolled steel frame (column and beam). In this attempt, the adaptation of the strip approach with CFS framing needs to change the following hypotheses [9], [6]:

- The welded assembly is replaced by screw connections;
- The failure mode governing the shear wall "local or global buckling" is shifted to the screw failure.

Several experimental studies showed that the failure mechanism of a typical SWP is mainly attributed to the two modes of failures: a) buckling of the chord studs and b) failure of connections [4], noting that the failure in the screw connections between the sheathing and the frame dominates the overall failure of the shear wall [4], [13], [14]. Therefore, in this paper, the second mode of failure for both approaches that will be considered.

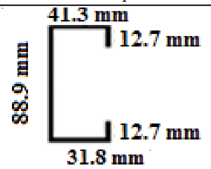
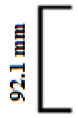
II. Material and Geometrical Properties

In order to compare the numerical results of both approaches with the experimental results of the same specimen, all material and geometric characteristics of "CFS - SWP" are those of the experimental panel presented in the AISI 07, 2007 report [2]. Furthermore, Elastic modulus E_s =2.1*105MPa, Poisson's ratio μ_s =0.3, mass density ρ_s =7800kg/m^3. The yield stress of the steel fy =235 MPa and the tensile stress fu =310 MPa. The geometrical characteristics of all components of this shear wall are summarized in Table I and shown in Fig. 1. The steel plate (without opening) was assembled on one side of the wall with 4.83 mm screw diameter.

III. Strip Approach

The physical interpretation of this approach, results in a tension field which develops in the infill steel plate during the loading resulting in inclined strips forms (Fig. 2). The inclination angle is given by (1) [6], [12].

TABLE I
GEOMETRICAL CHARACTERISTIC

	Dimension profiles	thickness (mm)
Stud		1.09 mm
Track		1.09 mm
thickness of Steel plate sheathing	(h x w) 2438.4 x 1219.2 mm	0.76 mm
Fastener	Spacing (304.8mm /101.1m)	Diameter (4.83mm)

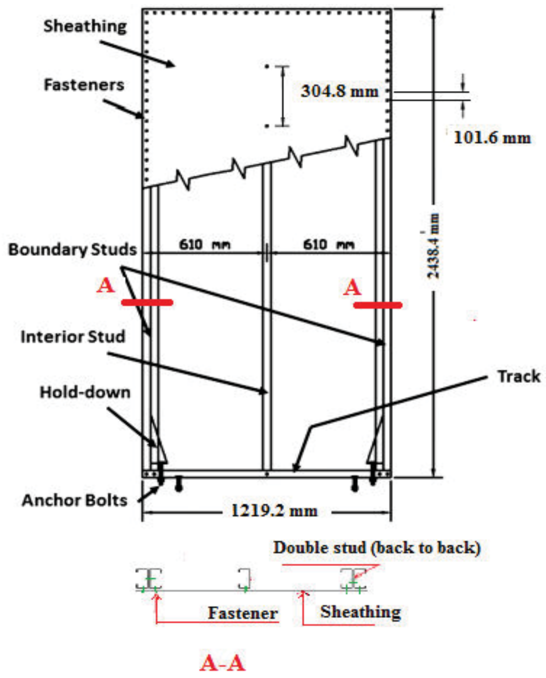


Fig. 1 SWP

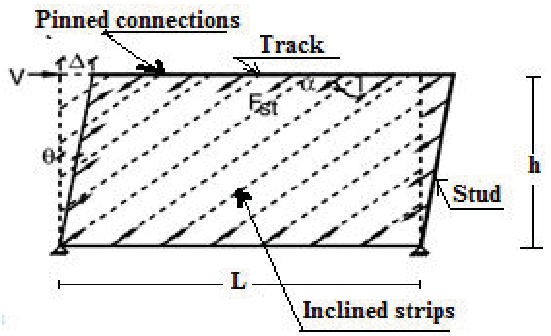


Fig. 2 Strip model

$$\tan\alpha = \sqrt[4]{\frac{1+\frac{tL}{2A_c}}{1+th\left(\frac{1}{A_b}+\frac{h^3}{360 I_c L}\right)}} \tag{1}$$

where α: angle of inclination; t: thickness of the infill plate; A_c: column cross-sectional area; I_c moment of inertia of column section; h: height story; A_b: beam cross-sectional area; I_b: moment of inertia of beam section; L: center-to-center distance of columns.

The width of each strip can be determined from (2) [6]:

$$A = \frac{tL\sin^2 2\alpha}{\sin 2\varphi . 2\sin\varphi} \tag{2}$$

where, A: cross-sectional area of equivalent brace, *φ:* the angle of the brace with respect to the column and all other parameters are as defined above.

IV. Finite Element Modelling

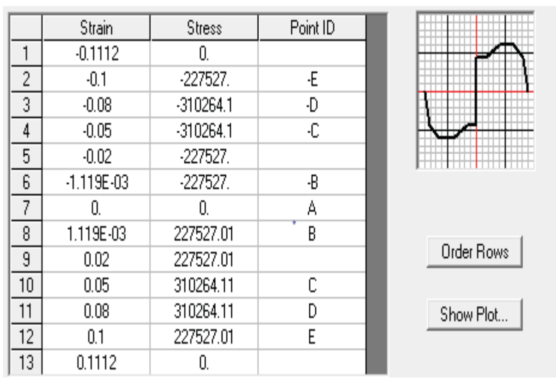
A. Strip Approach

Nonlinear static analyses (Pushover) were carried out [5] to estimate the shear resistance of the wall (model with inclined strips) employing SAP2000 Structural Analysis package [3]. The shear strength of the CFS-SWP is mainly dependent on the number of sheathing-to-framing connections and the connections strength which are used to determine the strip characteristics (Fig. 4) [7]. Moreover, axial hinges (tension /compression) are placed at the midpoint of each pinned strip to capture the shear strength of two fasteners as calculated below (Table II) [5].

The width of a strip is equal to the distance between two fasteners (l = 110 mm) and the thickness is 0.76 mm.

The target displacement conforming to ASCE7-10 was considered equivalent to a drift value of 2.5% h.

To simulate the post-elastic behaviour, the stress–strain curve of the steel members in accordance with ASTM A370 test is input into the software as shown in Fig. 3.



	Strain	Stress	Point ID
1	-0.1112	0.	
2	-0.1	-227527.	-E
3	-0.08	-310264.1	-D
4	-0.05	-310264.1	-C
5	-0.02	-227527.	
6	-1.119E-03	-227527.	-B
7	0.	0.	A
8	1.119E-03	227527.01	B
9	0.02	227527.01	
10	0.05	310264.11	C
11	0.08	310264.11	D
12	0.1	227527.01	E
13	0.1112	0.	

Fig. 3 Strain-Stress curve

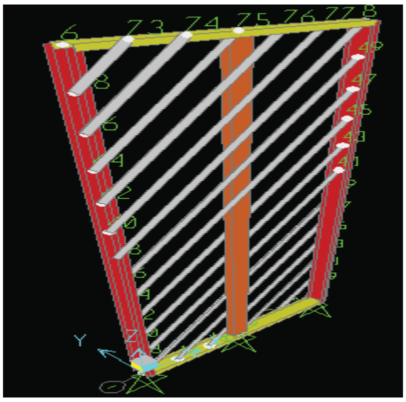


Fig. 4 FE Strip model

B. Micro Modelling

The FE micro models are developed using ABAQUS software [1]

In order to analyze and study the performance of the CFS-SWP, the first step is to consider the geometric and material nonlinearity.

The frame members are modeled using the 4-node S4R shell element with reduced integration. This element has three translational and three rotational degrees of freedom at each node. The overall model is show on (Fig. 5).

The screw connections were modeled by mesh independent fasteners using attachment point technique available in ABAQUS software and a Cartesian connector having the same diameter as screw specimen was introduced [10], [14]. The input of the material stress-strain curve is required in terms of true stress versus true plastic strain. The true stress (σ_{tru}) and true strain (ε_{tru}) were converted from the engineering stresses (σ) and engineering strains (ε) using the following equations [1]:

$$\sigma_{tru} = \sigma_{nom}(1+\varepsilon_{nom}) \quad (3)$$

$$\varepsilon_{tru} = \ln(1+\varepsilon_{nom}) \quad (4)$$

$$\varepsilon_{pl} = \varepsilon_{tru} - \frac{\sigma_{tru}}{E} \quad (5)$$

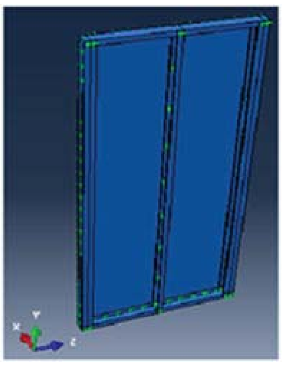


Fig. 5 Finite element model (Micro modeling)

The mesh sensitivity study indicated that the size of the shell element should be less than 80x80 mm for both studs and tracks. Element size smaller than 30x30 mm did not improve the accuracy of the numerical results but needed much more time to complete the analysis. Therefore, element dimension 50x50 mm: Quadratic Shell Reduce Integration 'S4R' was adopted.

Concerning the boundaries conditions of the wall panel, 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 in X, Y and rotation along the Y and Z-directions. A lateral displacement was applied on the top track nodes.

V. Mechanical Characteristics of Connections

A. Strip Approach

Connection capacity based on tilting and bearing can be determined based on section E.4.3.1 of AISI S100 (2007a) [8] and for:

- $t_2/t_1 \leq 1.0$

$$S_{ns} = \text{Min}\left(4.2(t_2^3 d)^{1/2} F_{u2}, 2.7 t_{t1} d F_{u1}, 2.7 t_2 d F_{u2}\right) \quad (6)$$

- $t_2/t_1 \geq 2.5$

$$S_{ns} = \text{Min}\left(2.7 t_{t1} d F_{u1}, 2.7 t_2 d F_{u2}\right) \quad (7)$$

- $1.0 < t_2/t_1 < 2.5$

S_{ns}: shall be calculated by linear interpolation between the previous two cases where: t_1 = thickness of member in contact with screw head or washer; t_2 = thickness of member not in contact with screw head or washer; d = nominal screw diameter; F_{u1} = tensile strength of member in contact with screw head or washer; and F_{u2} = tensile strength of member not in contact with screw head or washer. The connection strength limited by shear failure is generally provided by the manufacturer or determined by tests. The provision of E4.3.3 in AISI S100 (2007a) does not provide design equations for shear strength in screw. According to (SSMA, 2001), the yield stress is f_y =235 MPa and the tensile stress is f_u =310 MPa.

TABLE II
TOTAL AXIAL HINGE

	t_1 (mm)	t_2 (mm)	d (mm)	$F_{u1}=F_{u2}$ (KN)	S_{nsT} (KN)
Calculation	0.76	1.09	4.83	310	4.9

B. Micro Modelling

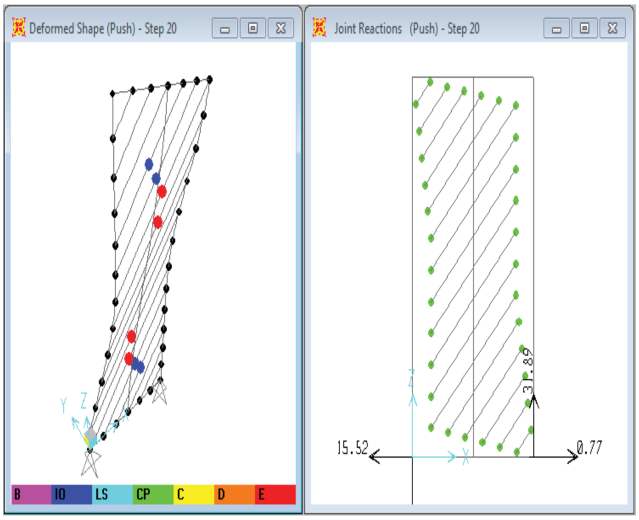
The shear strength behavior of screw was taken from tests conducted by S. G. Buonopane [11] and others and introduced into the FE model as an envelope force-displacement curve. The test was carried out with 4.83mm screw diameter until failure.

VI. Results and Discussion

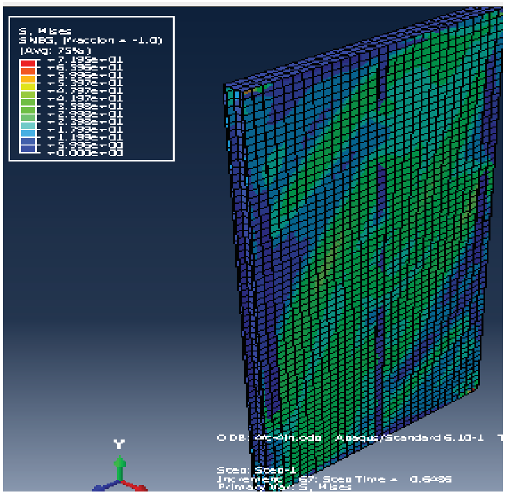
The final stage of the SWP is illustrated in Figs. 6 and 7, where the screws and strips failure are located. However, the ultimate shear strength with the corresponding displacement failure are summarized in Table III.

TABLE III
Response of CFS-SWP

	Experimental (Ex)	FE Strip Model	FE Micro modelling
Peak load (kN)	16.68	14.70	16.09
Δ peak (mm)	62.98	60.95	62.58



(a) (b)



(c)

Fig. 6 Finite element model under in-plane loading: (b) FE strip model, **(**a) Formation of the plastic hinges in the strips, (c) micro model

For this particular case study, the FE strip approach underestimates the shear strength by 10% compared to the experimental results. This is mainly due to the fact that the shear strength of connections was calculated using E.4.3.1 of AISI code which allows for design purposes a security margin. Moreover, the strip approach is a linear method with hinges defined as ultimate axial force.

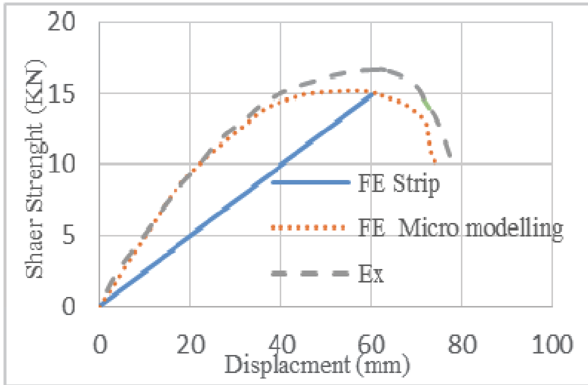


Fig. 7 Shear-displacement curve of SWP-CFS under control displacement

The micro modeling has a better prediction for the ultimate shear strength with the corresponding failure displacement.; This can be attributed to the realistic nonlinear force-displacement curve of the connectors

VII. Conclusion

The most important issue in finite elements modeling of CFS-SWP, is to know the mode of failure in the experimental test. In this case study, the shear connection dominated the shear wall overall behavior.

The micro modeling technique using FE software resulted in a good prediction of the shear strength and the overall behavior.

The simpler strip approach, however, gives a reasonable but less precise prediction of the shear strength of the CFS-SWP. A better result could be obtained by introducing a nonlinear force-deformation curve for fasteners in each strip.

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