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FINITE ELEMENT ANALYSIS OF HYBRID COLD-FORMED STEEL SHEAR WALL PANELS

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Improving the lateral performance of cold formed steel systems by employing different sheathing materials and bracing systems has been of particular interest to researchers in these days. However, due to their relatively low seismic capacity, the need for higher shear resistance of these structural systems is still felt. Therefore, this study aims to propose three hybrid shear wall panels in order to provide better performance and higher resistance in seismic zones. The numerical method is verified based on the experimental results in the literature and then is used for evaluating the hybrid systems. The proposed walls are analyzed under lateral and vertical loads and then their performances are compared to each other. The results showed better performance and higher shear capacity for hybrid wall system compared to the ordinary cold formed steel shear wall. In addition, the strength to weight ratio approved the economic application of hybrid panels for high seismic regions.

Keywords: Hybrid system, Numerical method, Lateral performance, Hot rolled steel.

1 INTRODUCTION

In recent years, researchers have proposed various systems in order to increase the lateral performance of the cold-formed steel (CFS) frames (Sharafi *et al.* 2018). Application of sheathing boards such as plywood (Serrette and Nolan 2009), oriented strand board (OSB) (Nava and Serrette 2015), steel sheets (Javaheri-Tafti *et al.* 2014) and gypsum wall board (GWB) (Moghimi and Ronagh 2009b) can be mentioned as different methods of increasing lateral capacity. Different configurations of bracing systems through lateral load bearing spans including K brace (Zeynalian *et al.* 2012), Knee brace (Zeynalian and Ronagh 2011, 2012), and strap brace systems (Moghimi and Ronagh 2009a), are the other methods which can be used for increasing the lateral resistance of walls. Hybrid systems (Mortazavi *et al.* 2018, Usefi and Ronagh 2018) including CFS and hot-rolled steel to accommodate the advantages of both structural systems, are also new, interesting fields for enhancing the lateral capacity of CFS structures. In this study, three different hybrid wall panels (HWP) system are proposed and their lateral performances are compared with an ordinary CFS wall. A finite element (FE) method with ABAQUS package (Hibbitt *et al.* 2001) is utilized here for simulation of both hybrid and ordinary shear walls. First, the shear walls are analyzed under lateral load only, and then the effect of vertical load on these systems is also investigated.

2 VERIFICATION OF FINITE ELEMENT METHOD

Specimens C1 and C3 from an experimental work by Balh (2010) were used for verifying the FE method. More details about material properties and specimen dimensions can be found in the literature (Balh 2010). A fix restraint was used to simulate the fixity conditions such as the location of hold downs. The top track was assumed to have no displacement and rotation out of the wall plane. Fasteners with Cartesian criteria were utilized for modeling of screw connections. Based on the mesh convergence study for identifying an appropriate mesh density, the 15 mm with S4R shell element was utilized for modeling the members. Further details of modeling techniques for verifying FE method can be found in Usefi *et al.* (2018). The shear walls were simulated, and the results of shear resistance-lateral displacement of the walls were compared with the experimental data. As it is shown in Figure 1, the results of FE method have relatively good agreement with the experimental data, and therefore can be used for simulation of different wall panels. The differences between experimental and numerical results could be due to simplifications in FE method and experimental errors (Mohajeri Nav *et al.* 2018, Usefi *et al.* 2016).

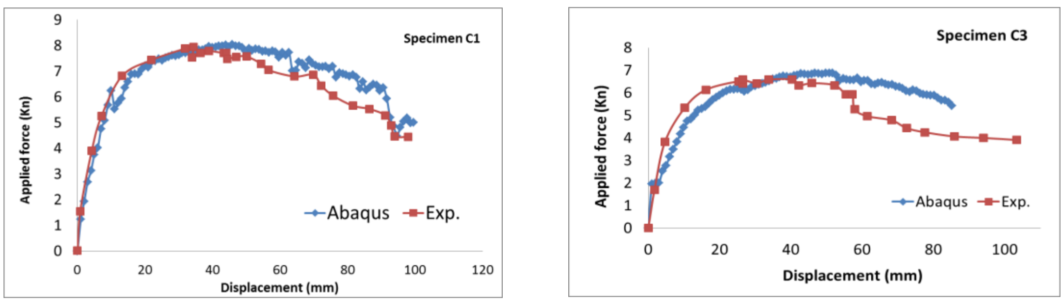


Figure 1. Comparison of experimental and FE results for specimens C1 and C3.

3 LATERAL CAPACITY OF HYBRID SHEAR WALLS

Based on the verified FE approach, a numerical simulation in ABAQUS platform was performed in order to compare the lateral capacity of different hybrid shear walls against an ordinary CFS shear wall. Three different hybrid systems and one ordinary strap braced CFS shear wall were employed for this comparison. The details of the walls and the materials used for simulation of members are given in Table 1 and Table 2, respectively.

Table 1. Details of the wall specimens.

Type of wall	Span (mm)	Stud dimension (mm)	Track dimension (mm)	Hot Rolled (mm)	Strap brace (mm)
CFS wall	2400×2400	89-36-0.75 Couples C section for chord Stud	92-36-1.15	----	90×1
Hybrid System 1		89-36-0.75		Square hollow section 89×89×3.5	150×2
Hybrid System 2					----
Hybrid System 3					

Table 2. Material properties of walls.

CFS members		Hot rolled Members		CFS strap	
Yield stress (MPa)	Ultimate stress (MPa)	Yield stress (MPa)	Plastic strain (MPa)	Yield stress (MPa)	Plastic strain (MPa)
364	400	400	480	360	420

For the ordinary CFS shear wall, coupled c sections were used as the chord studs. The configuration of walls is shown in Figure 2; the white color represents the hot rolled elements (square hollow section), the green color shows the CFS elements, and the red color indicates the strap brace in hybrid wall. A monotonic load, with displacement control method (target of 60 mm lateral displacement), was applied to the top of the walls in order to compare the load-displacement of the three different walls. First, the lateral performance of the walls was studied based on only applying lateral load. Then, in addition to lateral load, a vertical load of 32 kN was also applied to the top track of each wall, and the behavior of walls under both vertical and lateral load was assessed.

Ordinary CFS wall | Hybrid System 1 | Hybrid System 2 | Hybrid System 3

Figure 2. Configuration of walls.

3.1 Comparison of Walls Under Lateral Load Only

Lateral shear resistance of all four walls is shown in Figure 3. According to this figure, the application of hot rolled steel in hybrid system can significantly increase the lateral capacity of the CFS shear walls. The shear resistance of all three hybrid systems is around four times greater than the ordinary CFS shear wall. Moreover, the elastic stiffness of hybrid systems is roughly twice the stiffness of an ordinary CFS shear wall, which is a benefit for a hybrid system to be used in high seismic regions. All walls experienced a plastic deformation after reaching the 8 mm lateral displacement. The shear resistance for hybrid systems increased slightly after first yielding point, while for the ordinary CFS shear wall the resistance decreased after reaching to yield point. All three hybrid panels have approximately similar resistance and stiffness; however, the overall performance of hybrid system 2 and 3 is better compared to hybrid system 1.

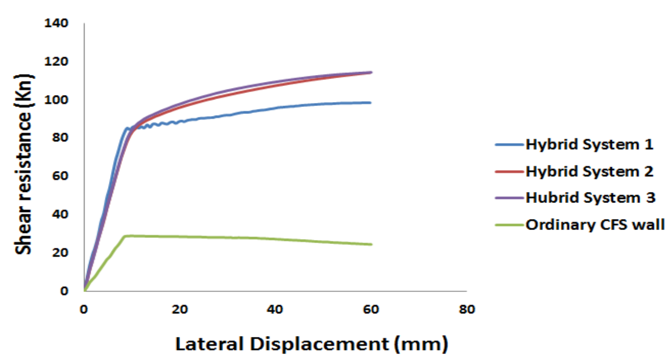


Figure 3. Shear resistance vs lateral displacement of the walls (vertical load ignored).

The results of von-mises stress are also presented in Figure 4. As it is indicated in this figure, the lateral load has been distributed in elements with higher stiffness such as hot rolled, bracing and chord stud elements. In hybrid system 2, only the left hot rolled frame resists the lateral load, while for the hybrid system 1 the overall load is distributed in hot rolled columns and bracing elements. Hybrid system 3 is in better condition compared to other walls since the two sides of the wall is composed of square hollow sections.

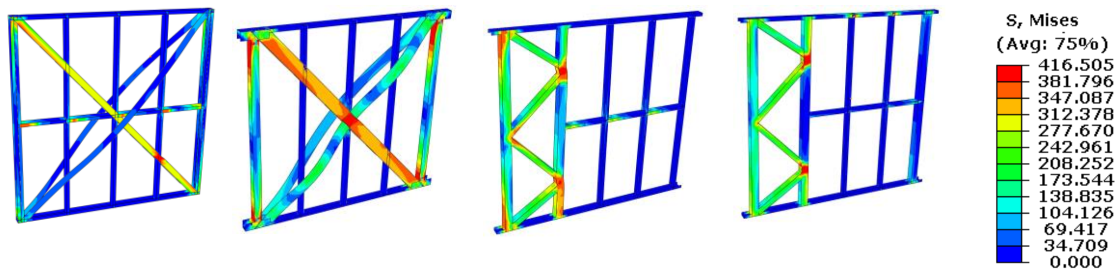


Figure 4. Comparison of von mises stress for shear walls (3D).

3.2 Comparison of Walls Under Lateral and Vertical Loads

A shear wall shall resist all dead, live, gravity and lateral loads in a real condition. Hence, in another attempt, the abovementioned walls were subjected to both vertical and lateral loading. The load displacement curves of the walls under lateral and vertical loading are presented in Figure 5.

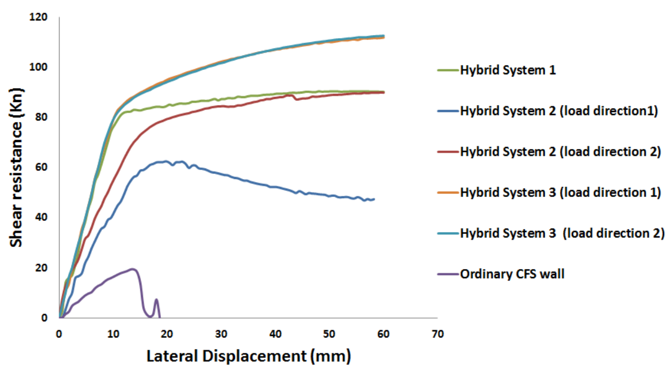
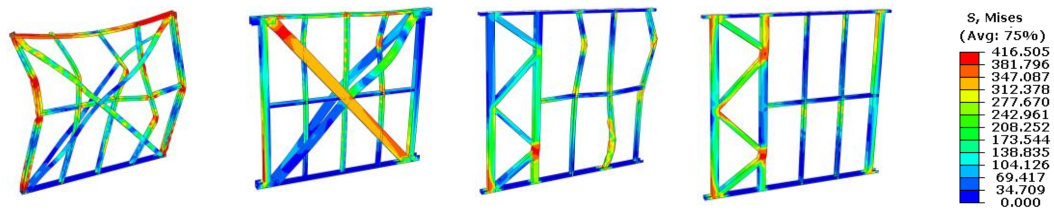


Figure 5. Shear resistance vs lateral displacement of the walls under lateral and vertical loads.

According to this figure, the capacity of all the shear walls has been decreased due to the applying vertical load on the top track. The performance of the ordinary CFS wall under lateral load is completely different from when both lateral and vertical loads are applied. Based on the results, the ordinary CFS wall under vertical and lateral loads failed at lateral displacement of 18 mm and the analysis of the wall was terminated. This indicates that this type of the ordinary CFS shear wall is not suitable for resisting both lateral and vertical loading. For hybrid system 2, the stiffness and shear strength decreased considerably when two loads were applied, while for the hybrid system 1 there is a slightly reduction for these values. As hybrid systems 2 and 3 are not symmetric, lateral load was applied in two directions and the results were compared. In hybrid system 2, when the loading is in direction of CFS frame, the capacity of wall is less than when the direction of load is along the hot rolled part. In hybrid system 3, there is no significant difference between two types of loading, which shows the high capability of this wall to be stable under lateral and vertical load.

Figure 6 shows the deformation and von-mises stress for all walls at the end of analysis under lateral and vertical loading. Hybrid systems 2 and 3 experienced a local failure in middle stud due to the presence of vertical load; however, hybrid system 3 was stable to the end of analysis with no major buckling. The ordinary CFS wall collapsed at the beginning of the analysis and could not undergo both vertical and lateral loads at the same time.



Ordinary CFS wall Hybrid System 1 Hybrid System 2 Hybrid System 3

Figure 6. Comparison of von mises stress for shear walls under lateral and vertical load.

3.3 Strength to Weight Ratio of the Walls (Strength/Weight)

Since the weights of the hybrid systems and ordinary CFS shear walls are different, a criterion is required in order to reasonably compare the performance of the walls. Therefore, in this section, the strength to weight ratio of the walls was calculated and the results were compared with each other. The maximum elastic capacity of the walls was considered for the strength value. Table 3 shows the details of weight, maximum strength, and strength to weight ratio of the walls for both types of loadings. According to the strength/weight ratio of the walls, all hybrid systems have higher strength to weight ratio when both lateral and vertical loads are applied. On the other hands, the ordinary CFS wall has a very low strength to weight ratio, which is not reasonable nor suitable to be used in high seismic regions.

Table 3. Details of weight, maximum strength, and strength to weight ratio of the walls.

Type of wall	Weight (kg)	Maximum strength (lateral load) (kN)	Maximum strength (vertical & lateral load) (kN)	Strength to weight ratio (lateral load) (kN/kg)	Strength to weight ratio (lateral & vertical load) (kN/kg)
Hybrid System 1	91	83.3	82	0.91	0.9
Hybrid System 2	86	84	75	0.97	0.87
Hybrid System 3	102	85	90	0.83	0.88
Ordinary CFS wall	33	28	19	0.83	0.56

4 CONCLUSIONS

Lateral performance of three different hybrid cold-formed/ hot rolled steel shear walls was numerically investigated in this research. It was indicated that the application of square hollow section in the ordinary CFS walls can increase the maximum lateral capacity of the system as well as the stiffness. The results also showed that hybrid system 3 was in better condition compared to other walls when both lateral and vertical loads are applied to the wall. Experimental research on this field is still required to approve the advantageous of hybrid CFS shear walls.

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