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A Comprehensive Review on the Structural Performance of Cold-Formed Steel (CFS) Shear Wall

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Abstract

Cold-Formed Steel (CFS) Structure has attracted the attention of civil engineers around the world for about two decades. Lightness, high execution speed, high flexibility of the structure, low weight of materials and lighter foundation compared to conventional concrete and steel structures, etc., are among its advantages. The reduction of the seismic force on the structure due to the weight reduction of the system compared to concrete and steel structures is one of the reasons that make this type of structure suitable for seismic areas such as Iran. In this research, one of the most widely used lateral load bearing systems has been studied and comprehensively evaluated with the help of the results of important studies conducted in the world, on the CFS shear wall. The present research is a review of the results and achievements of six important articles in the field of CFS shear wall, which have very good citation indices (H-Index and Immediacy Index) in structural engineering journals. Five of the reviewed articles are in Latin and one is in Persian. The results showed that the CFS shear wall is affected by factors such as the presence of covering (especially double-sided) of any kind (such as steel, wooden board and fiber), increasing the thickness of the covering, the presence of the OSB system (even in walls with openings) and reducing the dimensions of the opening. They experience improvement in seismic performance as a result of increasing elastic stiffness and shear capacity.

Keywords: CFS Shear Wall, LSF Structure, OSB System, Shear Wall Cladding, Review Article.

1- Introduction

Cold-Formed Steel Structure (CFS) or Light structure is one of the modern construction systems used to implement buildings with limited floors, usually up to 5 floors, which was first invented in 1950 in Canada and widely used in the industrialized countries of the world since 1990. English, Canada, Japan and Germany are used. The main element in light Structures are thin-walled steel sections (LGS), which are formed using thin steel plates and the Roll Forming method [1, 2]. Among the common lateral load bearing systems in light structures is the CFS shear wall, which, in addition to facilitating the ductility process, creates a suitable seismic behavior in the structure. In general, the use of cold-formed steel members has attracted the attention of construction engineers in the world due to special advantages such as high resistance to weight ratio and very high execution speed. The light weight of this type of element reduces the effective seismic forces in the building, which has made it an effective solution in earthquake-prone areas, including Iran [1-3]. The structural structure of the shear wall in the light steel building is different from the normal steel building, and the main members of the structure are the shear wall panels, load-bearing wall panels, and roof and floor panels, which in the normal steel structure include beams, columns and shear walls [2, 4]. The CFS shear wall is created with cold-formed steel columns with C-shaped sections that are placed vertically at certain distances from each other, and the ends of the column are screwed to a horizontal beam from above and below. The cover placed on this member is made of different materials such as thin steel sheet, corrugated steel sheet, gypsum and wooden cover, etc., which can be installed on one or both sides. Connecting the outer cover to the cold-formed steel element is usually screws, nails, bolts, rivets, etc. [4]. To prevent the uplift forces in the bottom of the cold-formed steel shear wall, a hold-down is used, which is connected to the boundary column and is connected to the foundation and the lower floors of the building by means of special bolts [1, 4]. In this research, an attempt has been made to review the achievements of the important research conducted on the cold-formed steel shear wall (CFS) and to create a complete summary of their results so that the discussed structure can be criticized and fully analyzed.

2-Research Questions

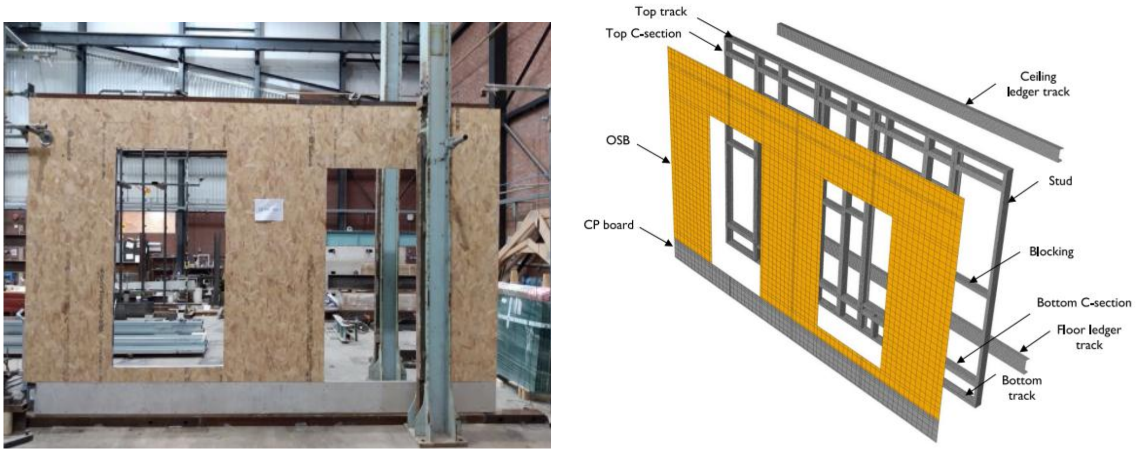
The evaluation of the structural performance of CFS shear wall as a functional member for absorbing and absorbing lateral forces (earthquake and wind) in light steel structures has some ambiguous questions from the perspective of structural engineers. In the following, some of the most important questions that are related to the goals of the current research will be presented.

1) Will the use of any type of coating (thin steel sheet, wood, plaster panel, etc.) on the CFS shear wall increase energy absorption and consumption and, as a result, improve the seismic performance of the structure?
2) Will the use of OSB system increase its performance if there is an opening in the CFS shear wall?
3) Will changing the thickness of the coating in the CFS shear wall change the seismic performance of the LSF structure?

3- Methodology

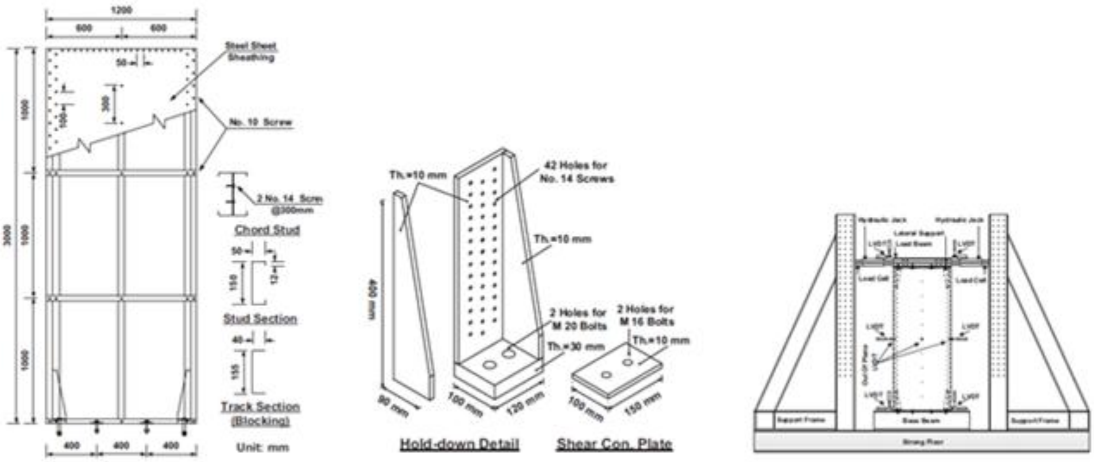
In this section, important indicators of the methodology of the discussed researches (specifications of laboratory samples, members modeled with the software, how to load and other details) will be presented in order to show how to carry out the studies, accurately and appropriate resolution should be considered.

Kechidi and Luorio (2022) [5] evaluated the performance of OSB-clad on CFS shear wall with opening under lateral load. In Figure (1), the modeling schematic and the laboratory sample will be presented in this research. Fathi Belal et al. (2020) [6] modeled the seismic behavior of CFS shear walls in one floor with covers made of steel plate, cement board, etc. The research was carried out in two parts: finite element (with Abaqus software) and laboratory. Mohebi et al. (2015) [7] investigated the CFS shear wall with steel cladding (one and two sides) under cyclic loading. The research was done by SAP2000 software and laboratory test. In figure (2), the details of the laboratory sample and members used in the research of Mohebi et al will be presented.



(a) (b)

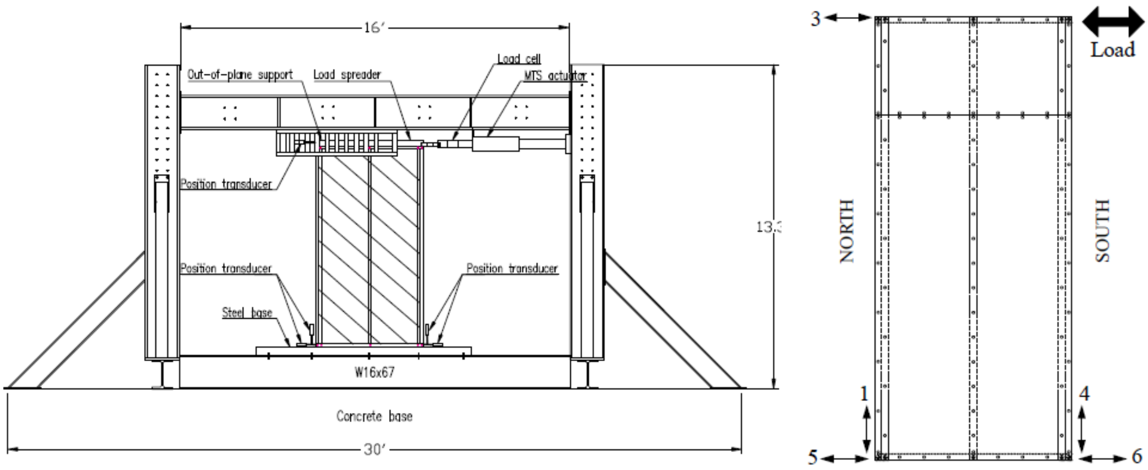
Figure 1- Schematic of LSF shear wall and (b) laboratory sample in Kechidi and Luorio's research [5]



(a) (b) (c)

Figure 2- (a) CFS shear wall modeling schematic, (b) support details and (c) test schematic, in Mohebi et al.'s research [7]

Liu et al. (2012) [8] investigated the performance of CFS shear wall with OSB coating under increasing cyclic loading. This research was conducted on the shear walls of a 2-story building located at the University of Buffalo with the help of a shaking table test (full scale). In figure (3), the schematic of how to perform the test in this study.



(a) (b)

Figure 3- (a) Schematic of the sample and laboratory loading method (CUREE loading protocol with a cyclic frequency of 0.2 Hz applied to the sample) and (b) design details of the shear wall reinforced with OSB, in Liu et al.'s research [8]

Langea and Naujoks (2006) [9] investigated the clad CFS shear wall under combined horizontal and vertical loads. During this study, the specifications of the shear wall covering materials and the spacing of the bolts along the edge of the shear panel were changed. C sections with dimensions $h \times b \times c \times t_n = 97 \times 50 \times 8 \times 1.5$ mm and yield strength fy=320 N/mm^2 were used in studs. The test was carried out in such a way that during 120 seconds, the shear walls were subjected to a load of 40% of the full failure load (Hu). This tension was maintained for 30 seconds and then the shear wall was discharged again. After a pause of 120 seconds, the load was increased at the initial speed of Hu. Chipboard according to DIN 68763 V100-13 mm with polyurethane adhesive panel and Fermacell 0.G.05 gypsum fiber board with thickness of 12.5 mm were used as CFS shear wall covering. Figure (4) shows how to load on the sample in the research of Langea and Naujoks.

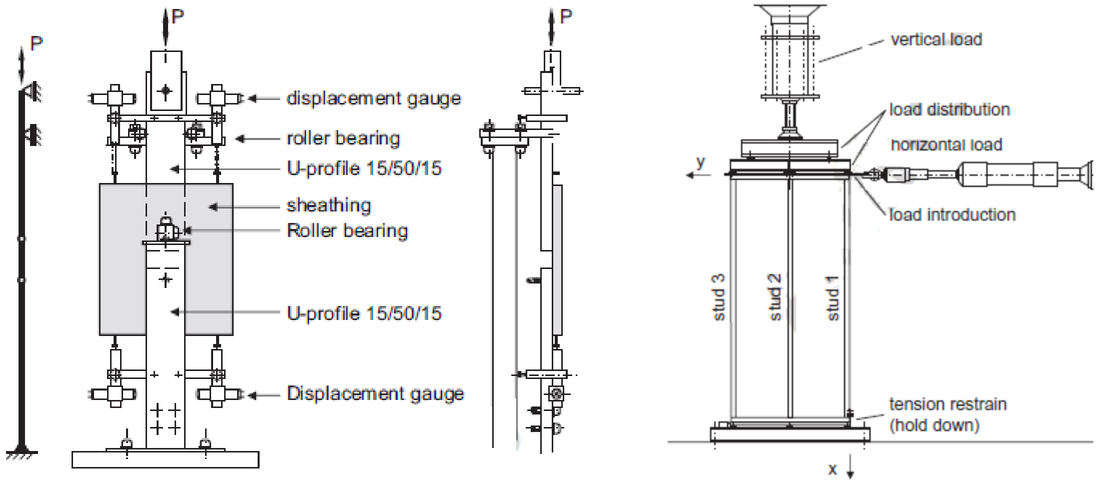


Figure 4- Schematic of laboratory equipment for loading on CFS shear wall under horizontal and vertical load in the research of Langea and Naujoks [9]

Esmaeali Niari et al. (2016) [4] investigated the effect of steel sheet in CFS shear wall under cyclic load. They built and loaded three samples of CFS shear wall with one-story steel cladding in Sahand University Structural Laboratory. The samples were placed horizontally on the laboratory floor and installed vertically in the laboratory frame, and a 100 ton hydraulic jack was used to apply the lateral load. To prevent off-screen displacement, a lateral restraint system was used. In Figure (5), the laboratory sample and how to install the CFS shear wall loading equipment and measure the results in this research will be presented.

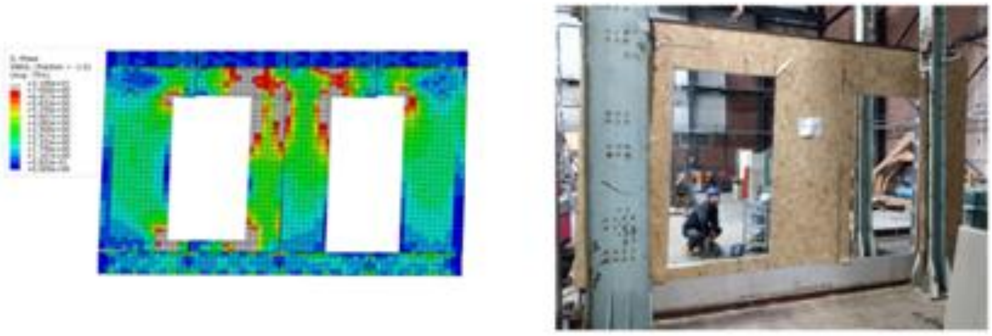
(a) **(b)**

Figure 5- (a) Laboratory sample and tools for measuring the results and (b) the way of loading in the CFS shear wall during the research of Esmaeali Niari et al. [4]

4- Presentation and Analysis of Results

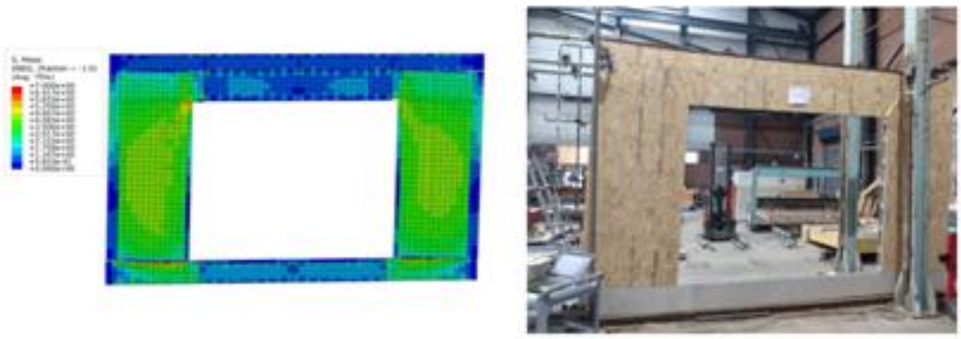
After completing all the stages of software modeling and analysis or the process of making a laboratory sample and applying loading, the desired results are obtained from the set of studies, the most important of which will be presented below.

Kechidi and Iuorio, found that the use of OSB improvement system in the CFS structure has improved seismic performance, reduced stress and reduced displacement in all three ratios of different dimensions of the opening [5]. In figures (6)-(8), finite element models and laboratory samples with different ratios of opening dimensions will be presented in this research.



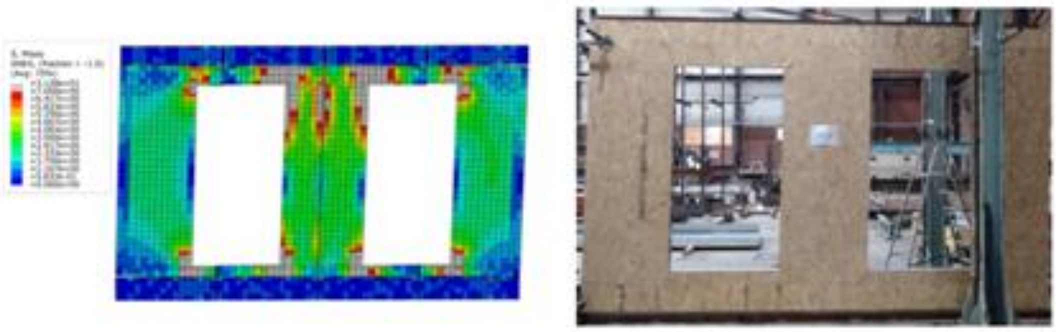
(a) **(b)**

Figure 6- (a) finite element model and (b) proposed laboratory sample number one under the maximum load during the research of Kechidi and Iuorio [5]



(a) **(b)**

Figure 7- (a) finite element model and (b) proposed laboratory sample number two under the maximum load during the research of Kechidi and Iuorio [5]



(a) **(b)**

Figure 8- (a) finite element model and (b) proposed laboratory sample number three under the maximum load during the research of Kechidi and Iuorio [5]

Fathi Belal et al. found that the use of steel cladding increased the load capacity and initial stiffness in CFS shear wall. Compared to the model with steel coating, the model with cement board cover showed less instability in the frame members, compared to their similar models without cover [6]. Overall, the most important research results include the following:

- The use of cladding led to a significant reduction in resistance compared to the reference model. However, performance improved when using the overlay on both sides. In addition, the lateral deflection at failure was much higher (up to 138%) compared to the reference model, increasing the ductility and energy absorption capability of this model [6].
- The failure of the bolt connection in the initial loading stage led to a significant degradation in all the behavior characteristics of the steel-clad model. In addition, it led to instability in the rotation shape of the cover wooden board [6].
- Cover openings significantly reduced the capacity of the wall. However, the initial stiffness in the openings simulating the openings (150 mm × 300 mm rectangle and 300 mm diameter circle) improved the ductility of the model, while a slight decrease in strength in made a comparison with the reference model (an average increase in the maximum ductility of 67% and an average decrease in the final strength of 15%) [6].
- Increasing the size of the opening to place the window and door, especially for the models with opening, caused a significant decrease in the strength of the wall. This issue should be considered when creating openings in steel or wooden reinforcements in other types of structures, including LSF structures [6]. In figure (9) and (10), the stress contour in the finite element model in different conditions of opening placement and graphical comparison of software and laboratory results will be presented, during the research of Fathi Belal et al.

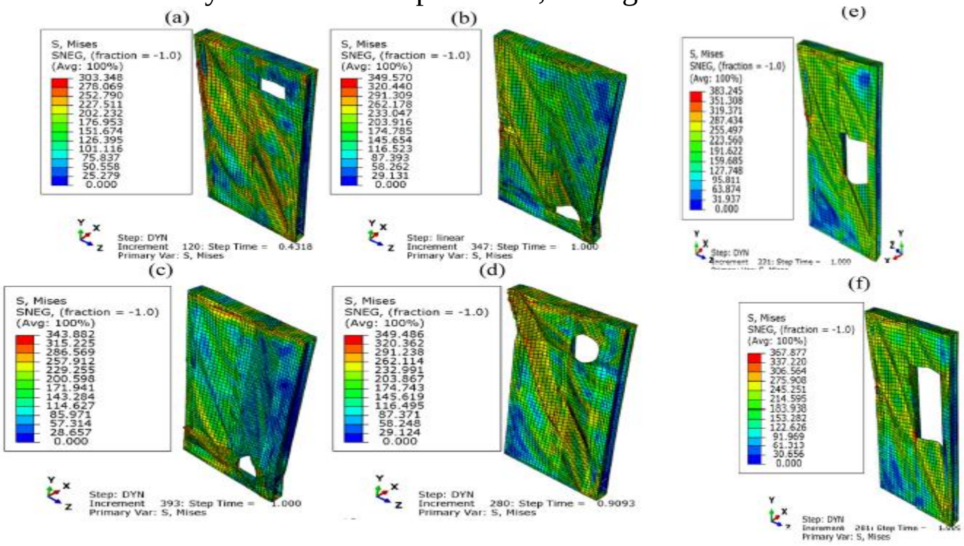


Figure 9- Stress distribution for different models designed in Fathi Belal et al.'s research [6]

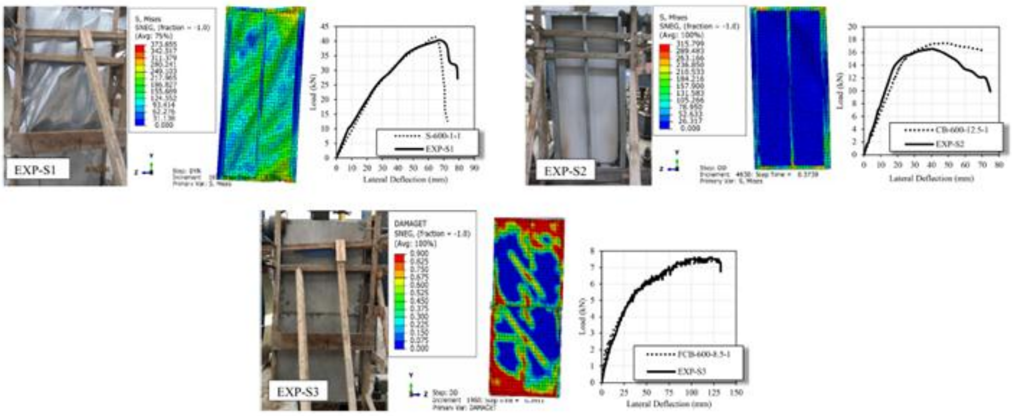


Figure 10- The results of the numerical model and the fracture patterns in comparison with similar samples in the laboratory study by Fathi Belal et al. S3=300 mm) [6]

Mohebi et al. found that the use of double-sided coating of steel, wooden board and fiber for energy dissipation increases the elastic stiffness by 70%, 63% and 115%, respectively, compared to walls with one-sided coating. [7]. in figure (11), laboratory results and hysteresis curve of CFS shear walls in six research samples will be presented. Figure (12) shows the plastic joints formed in the CFS shear wall.

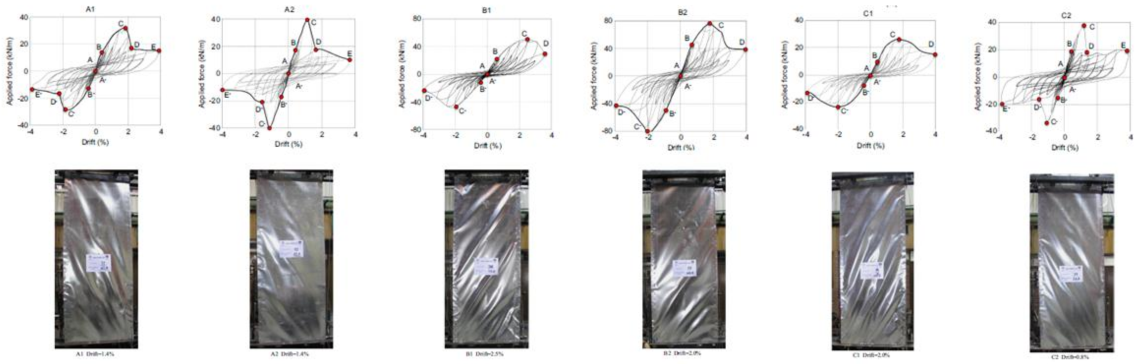


Figure 11- Hysteresis curve and hexagonal and buckled laboratory samples under the effect of loading in Mohebi et al.'s research [7]

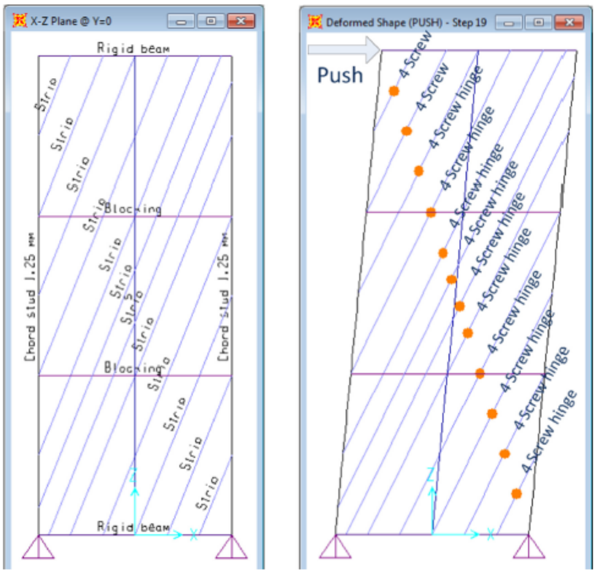
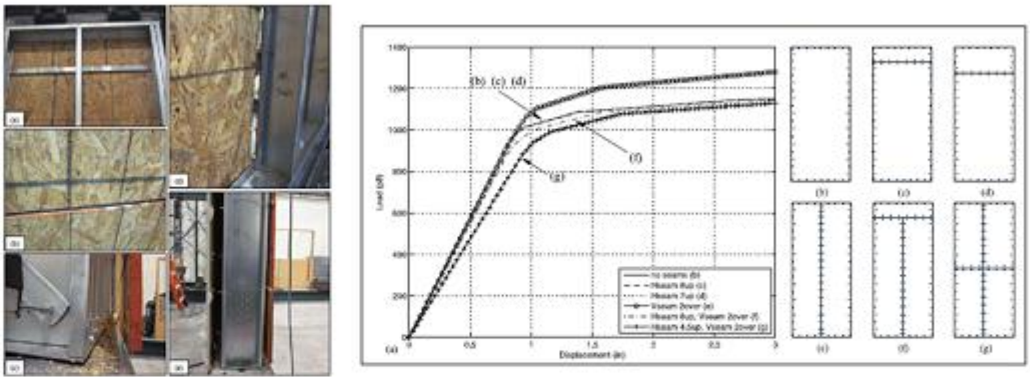


Figure 12- The formation of plastic joints in the CFS shear wall during software modeling in Mohebi et al.'s research [7]

The most important results of Mohebi et al.'s research are as follows:

- The use of double-sided coating with different materials can increase energy loss up to 70% compared to one-sided coating, for the dimensions of CFS shear walls. To achieve this goal, the failure of studs in the wall should be prevented [7].
- The first type samples were broken by connecting the sheath to the frame and caused more energy loss than the failed samples due to the buckling of the tendon. The second type of samples showed a sudden decrease in strength after buckling of tendon studs, and their drift at 80% loading after the maximum value was less than the drift limit of 2.5% determined in the ASCE7-10 standard [7].
- The use of double-sided coating was able to increase the elastic stiffness of the shear walls by 82.33% on average in three types of coating. This result will be more when the failure of the sheath connection is dominant and the buckling of the tendon stud is prevented [7].

Liu et al. investigated four distinct differences, especially in a series of tests on CFS shear walls under loading with cyclic protocols (CUREE) to determine their hysteresis performance, which experimental results showed that the potential energy dissipation mechanism in the fastener connection to sheathing has occurred and has led to tilting of the connection and fastening, stretching and in some cases tearing of the edges of the shear wall [8].



(a) (b)

Figure 13- CFS shear wall performance; (a) in the laboratory sample and (b) the cover diagram resulting from the bilinear spring approximation in Iorio et al.'s research [8]

The results showed that the existence of the Ledger path (direct path in the frame under loading) increases the strength of the shear wall by about 10%, but reduces the energy loss. Gypsum board in CFS shear wall increases the initial stiffness and can increase its strength, but it may have the same behavior as samples without gypsum board. The use of thick inner studs with less thickness than diagonal studs in CFS shear wall has affected the strength of shear wall. The presence of panel seams in the inner space of shear walls has reduced the resistance and increased the flexibility of shear walls, especially for the seams of vertical panels [8].

Langea and Naujox considered three failure modes in the design and loading of CFS shear wall specimens:

1) Fracture of the edges of the sheath in the held area and the release of the screws through the movement of the sheath at the bottom of the compression stud.

2) Local buckling of the cold-formed steel section at the bottom of the compression stud.

3) Local buckling of trapezoidal sheet using shear stress [8]. In figure (14), the results of the laboratory samples under loading in the research of Langea and Naujox will be presented.

(a) (b) (c)

Figure 14-The results of loading laboratory samples in the CFS shear wall during the research of Langea and Naujox [8]

The results showed that the coated cold-formed sections with plate thickness up to 2.5 mm were stabilized with the desired coatings. Sections should only be stabilized with respect to transverse buckling relative to the plane direction of the CFS shear wall. With thick wall sections (42.5 mm) or flexible cladding materials (e.g. plasterboard) it is necessary to determine whether the fasteners are able to resist deflection or not.

Esmaeali Niari et al. found that the failure modes of light shear wall panels with steel cover include shear buckling of the steel cover, stretching of the screws connecting the cover to the surrounding frame, and separation of the steel cover sheet from the surrounding frame. Therefore, the most important factor in the failure of shear panels with steel cover is the rupture of the connections of the cover to the surrounding frame, which has caused the separation of the steel sheet from the surrounding frame and has caused a decrease in the shear strength of the panel. In the investigation of how the thickness of the steel coating affects the behavior of the shear wall, it was concluded that by increasing the thickness of the steel coating from 1 to 1.5 mm, the shear capacity of the panel increased by 35% and the elastic stiffness increased by 7%. Also, by using double-sided coating in the samples, the shear capacity is increased by almost 100% and the elastic hardness is increased by about 23% [4]. In figure (15) and (16), local buckling of column and beam and shear buckling of steel cover in light shear wall will be presented, respectively.

(a) (b)

Figure 15- Local buckling of columns and beams in a light shear wall during the research of Esmaeali Niari et al. [4]

Figure 16- Shear buckling of the steel cover in the light shear wall laboratory sample during the research of Esmaeali-Niari et al. [4]

5-Conclusion

The evaluation of research sources showed that CFS shear wall under the influence of some factors such as cover thickness, cover material, the presence or absence of opening, The presence of cover on one or both sides, the presence of a special structural system such as Ledger frame, etc., have different performance. It shows in the following, the results will be collected and presented in full:

- The use of two-sided steel coating in the CFS shear wall increases its lateral deviation. This issue leads to an increase in ductility and energy absorption in the shear wall.
- Creating an opening and increasing its dimensions in a CFS shear wall with a steel or wooden coating causes its strength to decrease even more, and there is a direct relationship between the dimensions of the opening and reducing the strength of the CFS shear wall.
- The use of double-sided coating in the CFS shear wall with any gender, including steel, wooden board, fiber, etc., increases the elastic stiffness and ultimately increases the energy loss.
- Using the OSB system in the CFS shear wall with an opening will increase its seismic performance. This result is in accordance with the state of no opening, which indicates the

constant positive effect of OSB system on increasing the performance of CFS shear wall in the presence or absence of opening.

- There is a direct relationship between the thickness of the CFS shear wall coating and its shear capacity and elastic stiffness.
- Changing the CFS shear wall coating from one-sided to two-sided, significantly increases its shear capacity and elastic stiffness.

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