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Optimization Of Lateral Loads Resisting Systems In Light Gauge Steel Buildings.

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ABSTRACT

The research aimed to study the behavior of cold-formed steel (CFS) structures with different sheath materials and framed shear walls to improve their resistance to higher forces in mid-rise construction. The study involved constructing and evaluating twelve full-scale specimens with varying building parameters at Port Said University. The primary focus was to investigate the behavior of cold-formed section shear wall panels under monotonic lateral loads. For the experiment, the walls were covered with thermal board and fiber cement board. Different factors like lateral load capacity, failure modes, and the relationship between load and displacement were studied. Tests were conducted on CFS wall panels sheath with different thicknesses of boards with and without strap bracing. The aim was to analyze the behavior of the specimens under lateral loads. The thermal board type is a new type used in Egypt compared to other types of sheeting. The Thermal board and the fiber cement board (FCB) is suitable for climate in Egypt. As a result, the thermal board and fiber cement board (FCB) is suggested to be investigated in this research. The aspect ratio of all the walls was 2:1and 1.333:1. All the shear walls had a steel thickness of 0.95 mm and had hold-downs in order to transfer lateral load and uplift from the frame to the foundation.

Keywords: Cold-formed steel Wall frame, Monotonic test, Fiber Cement board, Thermal board, lateral load.

1. INTRODUCTION

The use of cold-formed steel (CFS) structures has become common in the building industry mainly because of their convenience, exceptional strength, and cost-effectiveness. Numerous researchers have investigated the behaviors of CFS wall frames, which are mostly fastened with Oriented-Strand Board (OSB) and gypsum board sheath. Steel sheets as a sheath material for CFS wall frames have gained popularity in building construction due to their increased shear resistance capabilities. The AISI S213 standard [1] [2] [3] provides information on the use of plywood, OSB, gypsum board, and steel sheet in the lateral design of CFS wall frames. CFS shear walls consist of structural components and panels connected using rivets or self-tapping screws. The arrangement of panel connecting screws has a significant influence on structural performance. This study mainly investigates the structural strength and behavior of a cold-formed steel (CFS) wall frame that includes a fiber cement board (FCB) and thermal board as cladding. Due to the need for more sufficient supporting information on this specific design, emphasis is placed on analyzing the frame's performance under monotonic load. The construction of test specimens included the use of two different thicknesses of sheath, including 10 mm and 20 mm, with connections on both sides. The paper discusses and presents the strength and failure mechanisms of each test specimen.

The Egyptian code for Steel Structures in the new version permits the use of either the working stress design or LRFD method. The Egyptian code for steel structure design and construction is mostly similar to the American Code, with slight differences to adapt the Egyptian practice [15].

The Egyptian Code of Practice for Steel Construction and Bridges (Allowable Stress Design - ASD) Code No. (205) ECP 205 for the design of cold-formed steel structures, first issued in 2001, was updated in 2012 to align with the new Egyptian Building Code. The updated code included new provisions for the design of cold-formed steel structures using the limit state design method. The Egyptian provisions apply primarily to steel sections with a thickness of not more than 8 mm, although the use of thicker material is not precluded. The minimum thickness of plates for cold-formed members used for load-carrying purposes in buildings shall be taken as 1.25 mm, while for sheets, the minimum thickness shall be 0.5 mm. It is worth noting that all percentages in the Egyptian code have been decreased by 5% in the AISI ASD and LRFD standards of design. In addition, ECP-205-ASD provides a lack of CFS wall sheath by boards. Studies are being undertaken to include shear wall details in the next versions in future editions [7].

DaBreo et al. (2014) [9] conducted experimental tests on various types and configurations of sheath steel CFS shear walls to modify Canadian design standards and expand the range of wall panel combinations permitted in the Canadian code. The dimensions of the test specimens were 4:1 (width-to-height ratio). The findings indicate that the wall with an aspect ratio of 1:1 exhibits more rigidity compared to the wall with an aspect ratio of 4:1. Additionally, blocking has a notable impact on minimizing stud buckling and twisting deformation, hence enhancing wall stiffness and shear strength.

Brière (2017) [6] and Santos (2017) [23] conducted 16 experiments on double-sheath shear walls, with the height of these walls being 2.44 meters and the width being 1.22 meters, resulting in an aspect ratio of 2:1. The frame studs used were made of ASTM A653 Grade 340 (50) steel, with thicknesses of either 1.73 mm or 2.46 mm. The sheaths had a thickness of either 0.36 mm or 0.47 mm and were made of ASTM A653 Grade 230 (33) steel. The sheath was fastened to the frame using either #10 or #12 screws, with a spacing of either 50 mm or 100 mm.

Previous research has examined the modeling of three-dimensional archetypal structures using several types of CFS-framed shear walls. Fiorino et al. (2017) [14] examined the use of strap-braced shear walls as lateral load-resisting elements in typical CFS-framed building archetypes. The performance of these walls was evaluated using the methodology described in FEMA P695 (2009). Shakeel et al. (2019) [26] applied a similar methodology in their other experiments, investigating shear walls with gypsum board sheath and wood sheath. Recent research by Landolfo et al. (2022a) [18] evaluated previous studies and results obtained from analyzing computational models of archetype buildings to propose new seismic design rules to be included in Eurocode 8.

Numerous European scholars have conducted numerous studies on CFS-framed wall panels, including Fülöp and Dubina (2004) [14], who performed an experiment on OSB-clad shear walls of 360x244 cm. The study examined the impact of loading type and found that wall specimens had a load capacity approximately 10% greater under monotonic loading compared to reversed cyclic loading. Researchers from Italy, particularly (Iuorio et al., 2014; Landolfo et al., 2006) [17], have extensively studied the structural performance of CFS constructions.

Throughout the past twenty years, numerous studies have focused on CFS-framed wall panels, which have been developed and discussed in various reports to generate databases on the lateral behavior and strength of CFS wall panels. The literature contains research that has examined several parameters that significantly affect the behavior of wall panels. The factors considered in this study consist of the cross-sectional properties and material characteristics of the CFS members, the type and thickness of the sheath panels, the aspect ratio of the wall panels, the presence of openings, the type and spacing of the connection screws, and the loading method used for testing.

Extensive laboratory research has focused on the single-sided shear wall. Serrette et al. (1996) [25] presented the first design parameters for steel-framed shear walls that were covered with plywood, oriented strand board, and gypsum wallboard. Subsequently, Serrette et al. (1997) [24] conducted a study that explored a wider variety of design alternatives, such as flat-strap steel X-braced walls and steel sheath walls. Ellis (2007) [10] and Yu et al. (2007) [32] provided additional data on the shear strength of steel-sheath shear walls with different sheath thicknesses, aspect ratios, and fastener spacings. Yu et al. (2007) [32] observed that applying a staggered fastener arrangement enhanced the overall shear strength of the wall and decreased deformation of the chord studs under load. The research was further conducted by Yu and Chen (2009) [30], Yu (2010) [33], and Yu and Chen (2011) [31]. The design parameters utilized for CFS sheath shear walls in Canada were suggested by Balh et al. (2014) [5] and DaBreo et al. (2014) [9] , depending on research undertaken by Ong-Tone (2009) [21], Balh (2010) [4], El-Saloussy (2010) [11] , and DaBreo (2012) [8]. Shamim et al. (2013) [29] conducted dynamic shaking table testing on single- and double-story CFS-clad shear walls. Shamim and Rogers (2013, 2015) [29] [28] carried out numerical analysis. In Rizk's (2017) [22] study, CFS-coated shear walls were examined out-of-plane deformation and twisting of the chord studs were observed due to the eccentric placement of the single sheath panel, despite the use of frame blocking members.

Liu, X., Zhang, W., Yu, C., Li, Y., Jiang, Z., & Yu, S. (2022) [19]. Experimental study on cold-formed steel shear walls with different corrugated steel sheath three monotonic loading tests were conducted first to provide a reference value of the ultimate displacement Δ_m. To meet the requirement of the failure limit state that the shear capacity of all specimens be reduced to 80% of the peak load under the test procedure, and Δ_m is taken as the maximum value of the ultimate displacement of the three monotonic tests (i.e., Δ was unified as 61.2 mm in all cyclic loading tests).

Moghimi and Ronagh [20] examined wall frame assemblies with diagonal bracing, brackets, gusset plates, and base anchors subjected to lateral cyclic stresses. The use of diagonal strap bracing or brackets at the four corners significantly enhanced the shear resistance of the CFS wall frames.

Yu and Chen (2011) [31] research focused on cold-formed shear wall panels covered with steel sheets, specifically examining panels with dimensions of 1.83 meters in width and 2.44 meters in height. The study involved 19 specimens of various configurations of steel members and boards, subjected to both monotonic and cyclic loading regimes. Factors such as framing member web dimensions, steel sheet thickness, corner connection between studs and tracks, and bracing configurations were considered. The results showed that failure mechanisms beyond buckling of boards and screws were also present. Another source of failure was the buckling of internal studs when wall width is 1.83 meters and subjected to reversed cyclic stresses. Specific configurations were established to prevent stud failure. The study also found that the nominal shear capacity may overestimate the actual strength for CFS panels with an aspect ratio of 3:2. The findings suggest that the nominal shear strength for CFS walls with a width of 1.83 meters is applicable for design methods.

2. MATERIAL CHARACTERISTICS AND METHODOLOGY.

2.1 Material

The material properties of light-gauge steel shear walls with Scottsdale frames. The objective of these frames is to develop a shear wall that will be examined using different types of bracing and sheath boards. The study will focus on the impact of using fiber cement board and thermal board as sheath materials on the shear walls and bracing types. The shear walls will be tested under monotonic loading in order to evaluate their response to lateral loads.

The table (Table 2.1) presents the details of the shear wall used in this study, categorized by the type of bracing (without bracing, K bracing, and X bracing) and the type of board (fiber cement board and thermal board).

The sections for these walls are selected from section steel coil, specifically the 7-series panel roll formers. with a width of 90 (7-090), a BMT thickness of 0.95, and a weight of 1.39 KG/meter. Two types of steel gauges, Gauge 350, and Gauge 550 are considered in the design Figure (1). The study involved conducting light gauge steel shear wall experiments on a total of 12 walls. These walls were divided into two groups: six walls with dimensions of 1.2 m * 2.4 m and six walls with dimensions of 1.8 m * 2.4 m. Each wall had a special blend of thermal board and fiber cement board, as well as different types of bracing. Monotonic loads were applied to all walls. Section: 0.95mmBMT G350: Properties in accordance with AS/NZS 4600:2005 with steel properties Steel Properties

C90_37-0.95BMT-G350

C90_37-0.95BMT-G550

Base Metal Thickness (BMT) = 0.95 BMT + Z275 coating (0.04mm) = approx. 0.99

Zinc: Z60- Z330

And Min yield strength Fy is 340 MPa, Min tensile strength Fu is 450 MPa for Gauge 350 and for gauge 550 the Min yield Fy is 550 MPa and Min tensile strength Fu is 665 MPa.

The construction board specification for thermal board with density is (850-900 kg/m) EN 1015-10 and compressive strength is 8 N/mm EN 1015-11 with fire classification is A EN13501-1, Capillary water absorption 0,0315kg/m2 dk - 05 (W1) EN 1015-18, Thermal Conductivity 0,035 W(m.k) EN 12664, Specific heat capacity 850 j/kg. K EN 12667, with advantages Excellent adhesion, Thermal insulation, Breathable, environmentally friendly, Light weight and Economic, sound insulation, Water resistance, Acoustic, Fire resistance, Hight impact and compressive strength. And Fiber cement boards are cement boards that have been strengthened with fiber mesh and fiber glass. They are available in thicknesses of 10 and 12 mm and come in dimensions of either 120 x 120 cm or 120 x 240 cm. Cement boards are produced from ordinary Portland cement. They are free from asbestos and any hazardous elements (environmentally friendly), Dry bulk density (kg/m3) according to EN 12467 approx. 1150, Bending strength (MPa) according to EN 12467 ≥ 7 , Tensile strength perpendicular to the plane of the board (N/mm2) according to EN 319 is 0.65 , Shearing strength (N) according to EN 520 607 , Thermal conductivity (W/mK) according to EN ISO 10456 is 0.35, Water vapor diffusion coefficient μ (-) according to EN ISO 12572 (66)

2.2 Type of the screws

1- Blind rivet: The size 5/32″ *3/8″ is chosen specifically for use on all Light Gauge Steel (LGS) components, including track, studs, and bracing elements. Shear strength is 0.85 KN and Tensile is 1.02 KN.
2- Self-Drill Screw: is used to secure a board onto the LGS frame. For fixing the fiber cement board with a thickness of 10 mm. It was secured with a #8 Truss head zinc-plated screw measuring 4.2 mm in

diameter and 25 mm in length. Similarly, for fixing the thermal board with a thickness of 20 mm, was selected a #8 Truss head zinc-plated screw measuring 4.2 mm in diameter and 32 mm in length Figure (2).

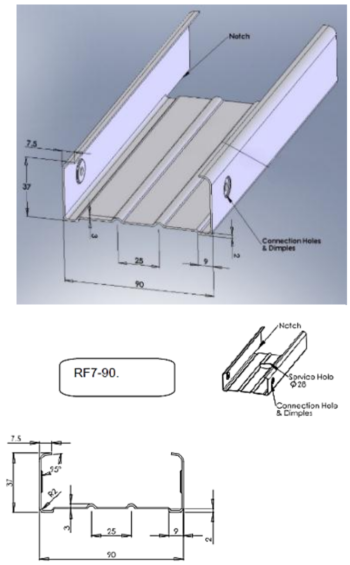


Figure (1): Dimension for Section (RF7-090).

Figure (2): Self-Drill Screw

3- Hold Down Screw: Hex head Tek screw size (5.5 * 19 mm) with tensile resistance is 2 KN and shear resistance is 0.68 KN.

4- Hold-down devices are used in conventional cold-formed steel (CFS) structural systems as a component of the lateral force-resisting system. Their main function is to transmit the CFS wall panel chord stud forces between floors and to the foundation system at the base of the wall. To ensure effective load transmission. The HD-1 hold-down was manufactured in the laboratory using a steel unequal leg angle with dimensions of 50 mm width and 100 mm length and with thickness 2.5 mm Figure (3) & Figure (4). The horizontal leg has a 16-mm-diameter hole for the anchor rod, while the vertical leg contains several holes to accommodate the screws that link the hold-down device to the vertical CFS frame member.

5- Anchor bolt: The device was secured to the base plate using a 16-mm-diameter steel threaded rod, which has a yield strength of 480 MPa and a tensile strength of 600 MPa.

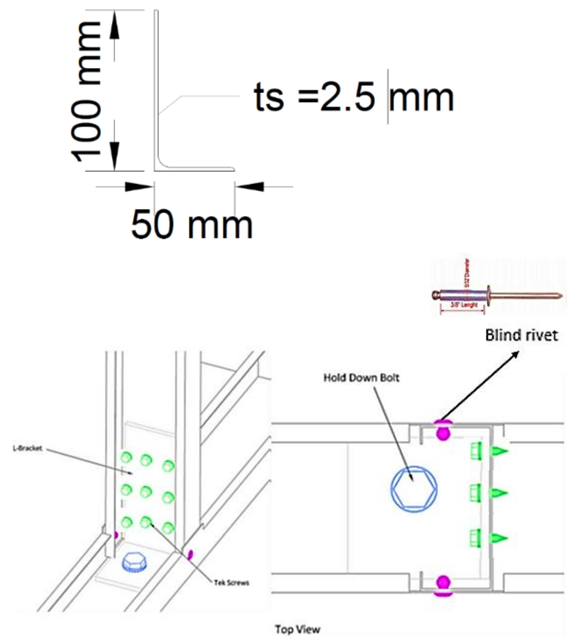
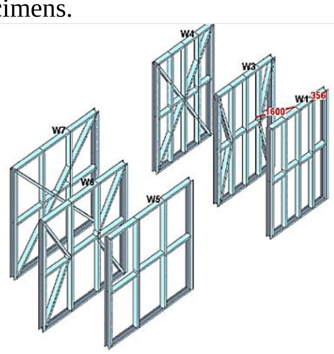


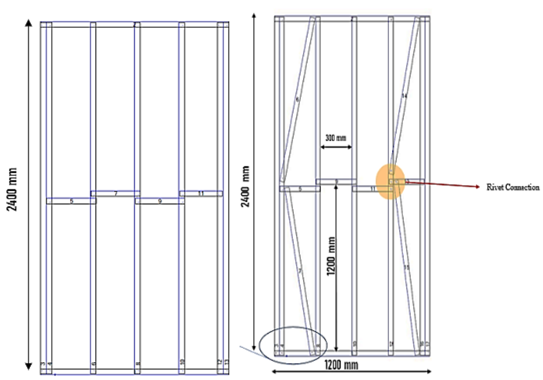
Figure (3): Hold Down Fixation with back-to-back Stud.

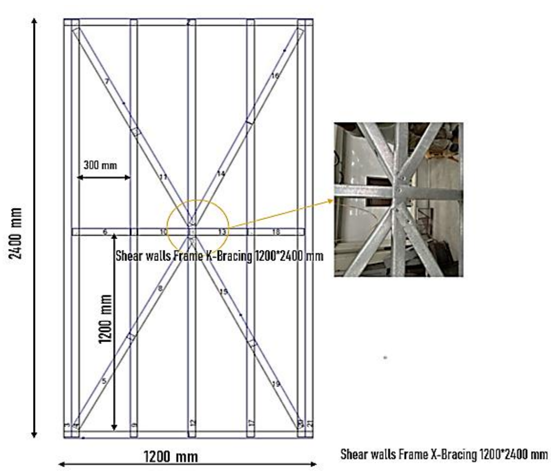
Figure (4): Hold Down Fixation with back-to-back Stud on Laboratory.

2.3 Experimental Testing and Test Configuration

The experimental testing includes twelve specimens. The dimensions of the specimens were 1200x2400 mm and 1800x2400 mm for width and height, respectively. There are three unsheathed frames, SW0, SW03, and SW05, with different types of bracing. Additionally, there are three 10 mm sheath FCB frames, SW02, SW04, and SW06, with a size of 1200 x 2400 mm. There are also three 10 mm sheath frames, SW07, SW09, and SW11, with a size of 1800 x 2400 mm. These frames have K and X-strap braced CFS. Lastly, there are three thermal board 20-mm sheath frames, SW08, SW10, and SW12, with a size of 1800*2400 mm. These frames have K and X-braced CFS. The CFS frame's upper and lower tracks were selected from Scottsdale Sections channels with dimensions of 90x37x0.95mm (web depth x flange size x thickness). The end studs consisted of two back-to-back channels, each sized 90x37x0.95mm (referring to the web depth, flange size, and thickness). The noggin member was chosen from the same C channel placed at the midpoint of the CFS wall frame. K&X-strap bracing. bracing Figure (5) illustrates the specific characteristics of all the specimens.







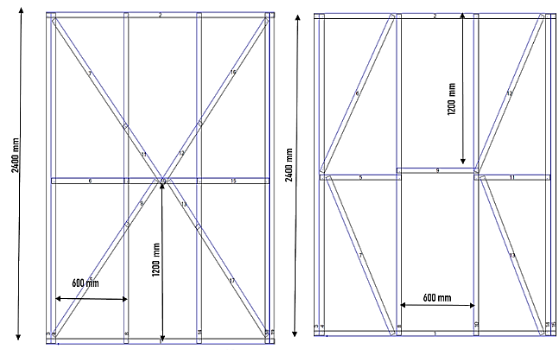


Figure (5): Shear walls Frame1200* 2400 mm and 1800*2400 mm.

2.4 Loading Protocol and test setup

The CFS shear wall panel specimens, sheath by twelve boards and performed the bending test as shown in Figure (6), were subjected to testing at the structural laboratory of Port Said University. The test is performed on the same sample using a monotonic displacement control loading protocol at a rate of 5 mm/sec. The wall panel was fixed to the resilient column using five threaded anchor bolts, each with a diameter of 16mm.

Figure (6): Bending test for thermal board and fiber cement board.

This setup allows the transfer of the horizontal shear force from the wall to the ground (column). The hold-down parts are inserted to provide a solid connection between the web of the end stud and the ground beam. The hold-down is connected to the stud web using nine hex head screws, as previously mentioned. It is also connected to the rigid column through the lower track using a 16-mm bolt diameter. This ensures that the tension force from the end studs is effectively transferred to the ground (column) and prevents any failure due to the uplifting of the wall.

The wall panel specimens were supported by HEB 400-length, 4000 mm-thick steel plates, which were joined to steel support columns. These columns were attached to the laboratory's strong floor. The transfer of lateral load to the wall panel specimens was achieved by using a 5550-mm-long steel I-Beam, which was securely fastened to the wall top track using self-tapping screws. The load distribution beam was connected to a hydraulic actuator with a load capacity of 2000 KN and a stroke of ± 250 mm using a steel plate and bolts. A steel bar of 2700 mm in length was attached to the load distribution beam and linked to the shear walls and column using bolts. This is a simulation of gravity loading. The measurement of the lateral force exerted on the wall panels was conducted using a load cell placed between the hydraulic actuator and the load distribution beam. The LVDTs were used to measure the horizontal displacement at the upper part of the wall panel, horizontal slippage at the base of the wall, and vertical uplift at the hold-down positions Figure (7) and (8).

The wall panel specimens performed monotonic loading tests in displacement-controlled mode with a loading rate of 5 mm/min as shown in Figures (9) and (10).

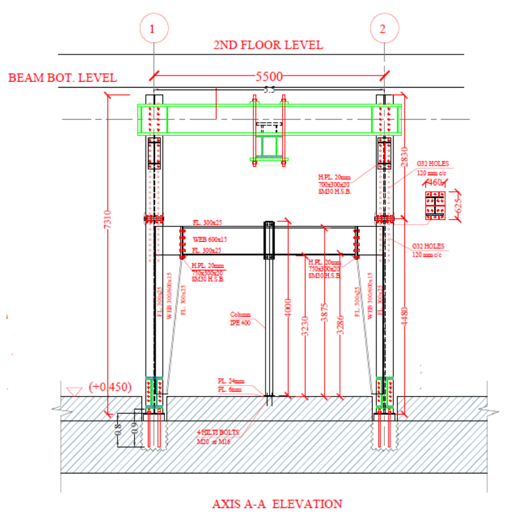


Figure (7): Test setup and configuration.

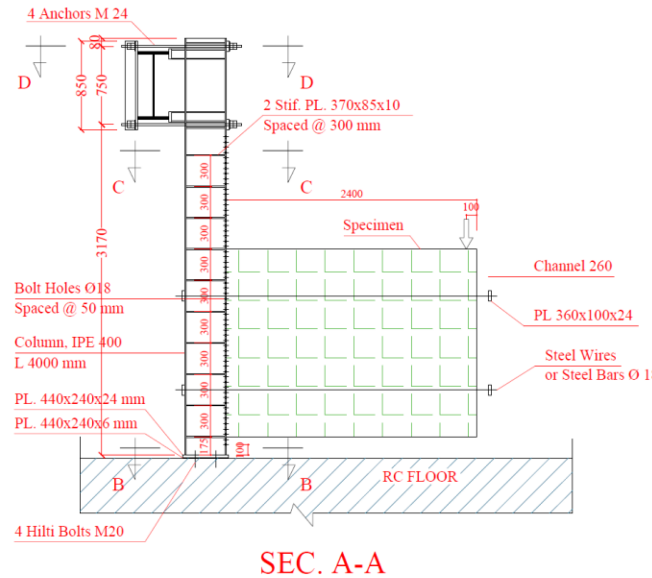


Figure (8): Hydraulic actuator direction.

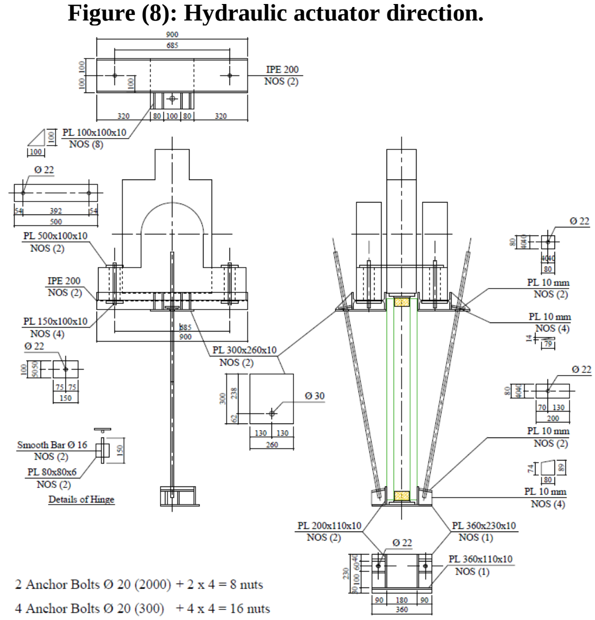


Figure (9): Out of plane direction setup.

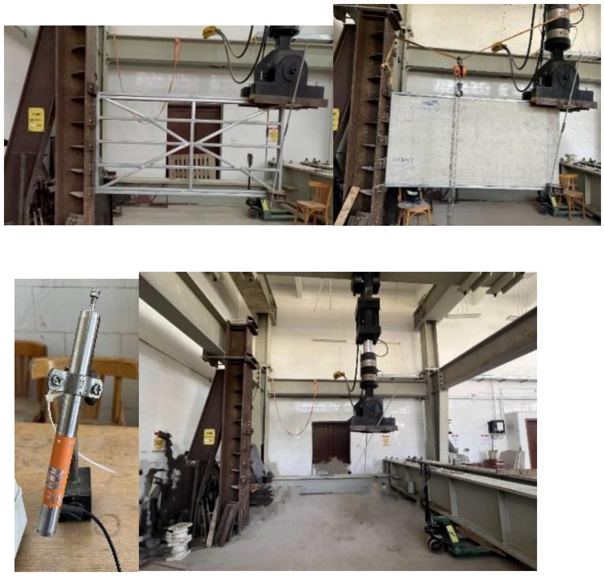


Figure (10): Loading Frame Setup and Data acquisition

3. EXPERIMENTAL STUDY

The shear walls framing with different types of sheaths, stud spacing, screw spacing, bracing types and hold down details are illustrated in Figures (11), (12), (13) and (14).

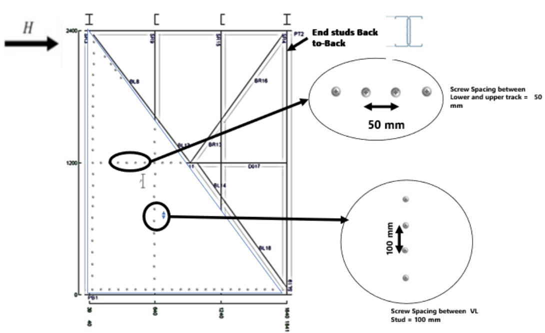


Figure (11): Shear Wall (1800*2400 mm) Sheath with Fiber Cement Board 10 mm.

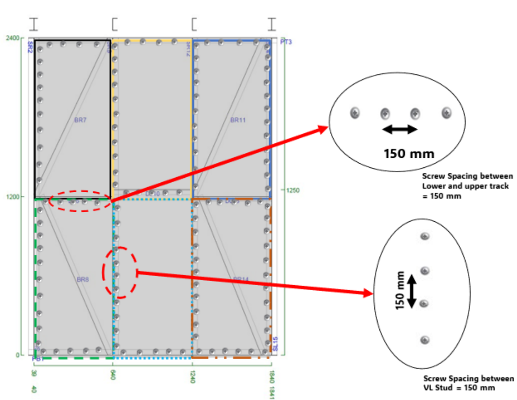


Figure (12): Shear Wall (1800*2400 mm) Sheath with Thermal Board 20 mm.

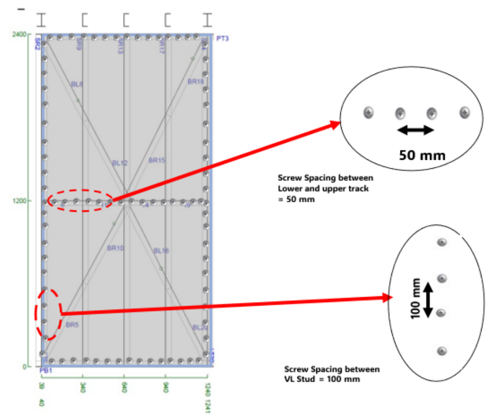


Figure (13): Shear Wall (1200*2400 mm) Sheath with Fiber Cement Board 10 mm.

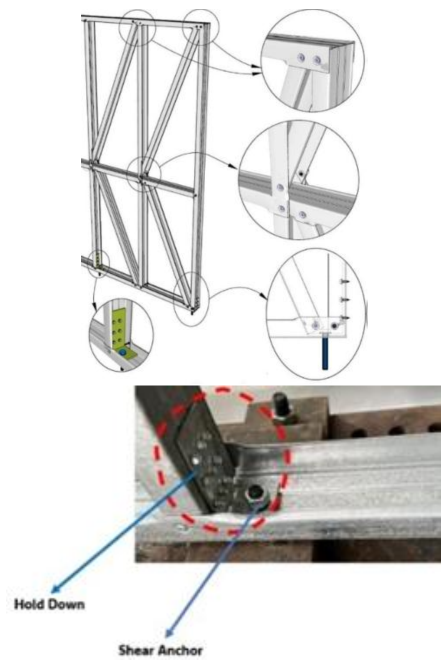


Figure (14): Shear wall frames details before sheath.

Table (1) and (2) show the details for all shear walls with varying dimensions and different gauges used experimentally.

Table 1.
Details of shear wall Size (1200*2400 mm).

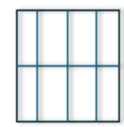
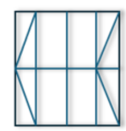
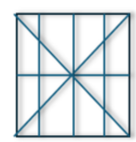
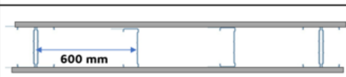
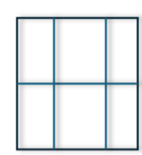
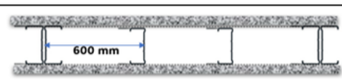
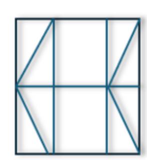
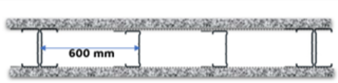
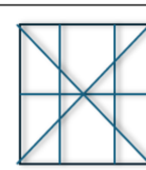
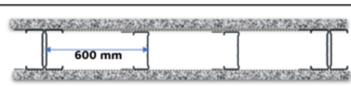
Specimen Size	Test Specimen	Wall framing details	Sheathing Type	Bracing Type	Screw Spacing mm (Track-Nogging/ Stud)	Schematic draw	Steel Gauge
1200 mm*2400 mm	SW 01		Without board	None	——		G 350
	SW 02		10 mm Fiber Cement Board Double side		50/100		
	SW 03- K		Without board	K-Bracing	——		
	SW 04- K		10 mm Fiber Cement Board		50/100		
	SW 05 -X		Without board	X-Bracing	——		
	SW 06 -X		10 mm Fiber Cement Board		50/100		

Table 2.
Details of shear wall Size (1800*2400 mm).

Specimen Size	Test Specimen	Wall framing details	Sheathing Type	Bracing Type	Screw Spacing mm (Track-Nogging/ Stud)	Schematic draw	Steel Gauge
1800 mm *2400 mm	SW 07		10 mm Fiber Cement Board	None	50/100		G 550
	SW 08		20 mm Thermal Board		150/150		
	SW 09- K		10 mm Fiber Cement Board	K-Bracing	50/100		
	SW 10- K		20 mm Thermal Board		150/150		
	SW 11 -X		10 mm Fiber Cement Board	X-Bracing	50/100		
	SW 12 -X		20 mm Thermal Board		150/150		

4. TEST RESULTS AND OBSERVATIONS.

4.1. Specimen 01 (SW01):

Had a light gauge steel frame without bracing, recording a maximum lateral load of 0.75 KN with a top displacement of 192.56 mm, indicating minimal load-bearing capacity due to lack of support.

4.2. Specimen 02 (SW02):

Constructed with fiber-cement boards, showed a significantly higher load-bearing capacity of 11.3 KN before experiencing a failure at 10 KN due to board tearing and as well as the lower track and self-drill screw being pulled out, resulting in cracks in the board Notably, the board did not experience any crushing. The high uplift force at the tension corner resulted in local buckling in the bottom track.

4.3. Specimen 03 (SW 03- K):

Mirrored SW01 and SW02's dimensions, yielding a maximum force of 2 KN with a lateral displacement of 115.42 mm, failing due to a rivet collapse in the hold-down element.

4.4. Specimen 04 (SW 04- K):

The fourth specimen, SW04, has identical dimensions and configuration as specimen SW02. The structure comprises a wall panel made of 10 mm thick FCB material, which is double-sided and strengthened by K bracing. sustaining a maximum load of 15.38 KN at a 132.68 mm displacement before failing due to buckling and tearing at the hold-down element down before it was modified.

4.5. Specimen 05 (SW 05- X):

Tested and focuses an X-bracing approach, achieving a peak load of 3.38 KN at 40.46 mm, but failing under lateral buckling on the compression side and tilting of the rivets on the tension side of the bracing, due to the absence of fixation screws between the back-to-back studs.

4.6. Specimen 06 (SW 06- X):

Implemented enhancements by adding channels in the tension stud to increase the thickness and reduce the risk of uplift. Additionally, we used a modified hold-down mechanism strengthened with two stiffeners as well as two metal washers to enhance the strength of the shear wall. Furthermore, we have inserted a screw of Tek size (#10 with a length of 1.5 inches) between two studs positioned back-to-back in order to prevent buckling. which led to an improved total load capacity of 22.91 KN at 125.63 mm of lateral displacement before the tearing failed the tension side at 17 KN. Subsequently, the lower track buckled, and the shear resistance of the wall slightly increased to reach 22.9 KN, leading to the failure of the self-drill board screw.

4.7. Specimen 07 (SW 07):

With similar enhancements and for a stiffer design, a stud spacing of 600 mm and a screw configuration of 50 mm in the HL track and 100 mm between VL screw studs. The wall panel is 1800*2400 mm, the steel gauge is G550, and it is sheath with FCB 10 mm sheath. It is free of additional bracing. tested at 23.74 KN at 34.42 mm, failing due to a self-drill screw bearing failure and associated board crushing. Remarkably, after modifying the stud and track and adjusting the hold down, it appeared that there were no damages on the hold down on the tension side. Furthermore, rounded bars were included in the shear walls to represent the effects of gravity loads.

4.8. Specimen 8 (SW 08):

Has screw configuration of 150 mm in the HL track and 150 mm between VL screw studs. The structure comprises a wall panel of 1800*2400 mm G550, constructed with a 20-mm thermal board sheath and without bracing. resulting in a maximum load of 15.24 KN and notable cracking and buckling failures of the top track at 10 KN due to the continuous load increment.

4.9. Specimen 09 (SW 09- K):

Added further modifications, including additional channels within the track and a stud in the hold-down area, this configuration is specified in Specimen SW07. achieving a maximum recorded force of 28.5 KN which equates to a lateral displacement of 44.42 mm before experiencing crushing, Furthermore, the improved hold-down mechanism demonstrated outstanding strength and remained undamaged without any cases of failure.

4.10. Specimen 10 (SW 10- K):

Displayed similar modifications as SW09, with a maximal force of 23.13 KN corresponding to a lateral displacement of 119.71 mm, characterized by multiple cracks and subsequent buckling of the upper track.

4.11. Specimen 11 (SW 11 -X):

Similarly, the modifications, reaching a tested force of 29.78 KN at 68.41 mm, revealing satisfactory performance under the adjusted configurations.

4.12. Specimen 12 (SW 12 -X):

The analysis indicates that the maximum recorded force is 33.39 kilonewtons (KN), which corresponds to a sideways movement of 167.21 millimeters (mm). The failure modes began with a crack situated on the tension side of the lower board with loads of 2.9, 2, and 12.7 kilonewtons. This eventually resulted in a rapid failure, causing the board to be crushed and the top track to buckle and rivet connection screw tilting, resulting in the appearance of shear damage at a load of 33 kilonewtons.

4.13. Hold Down and Modified Hold down:

Modified Hold downs HD-1 is composed of a bent steel plate as the body of the hold down and two triangular shaped stiffeners are welded at sides and add two washers to increase stiffness of tension side, the hold-down element was strengthened with a 3 mm plate stiffener and two bolt washers with a diameter of 16 mm, serving as supports Fig (14).

Failures Modes of specimens are shown in Fig (15,16,17,18,19,20,21&22).

Figure (15) ; The old HD and Modified one with stiffener.

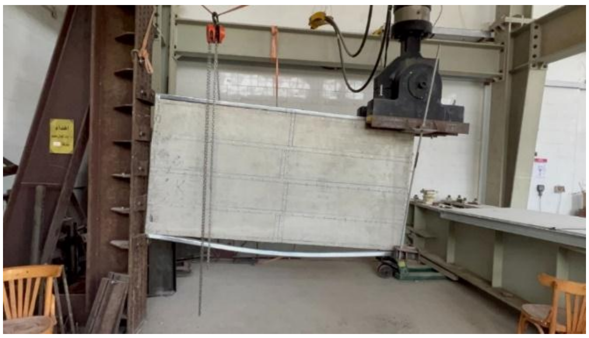
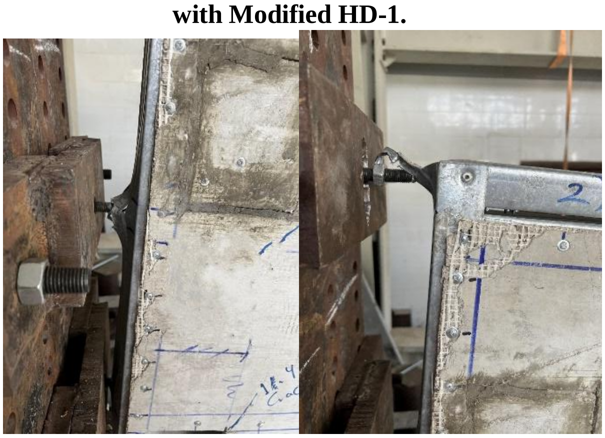


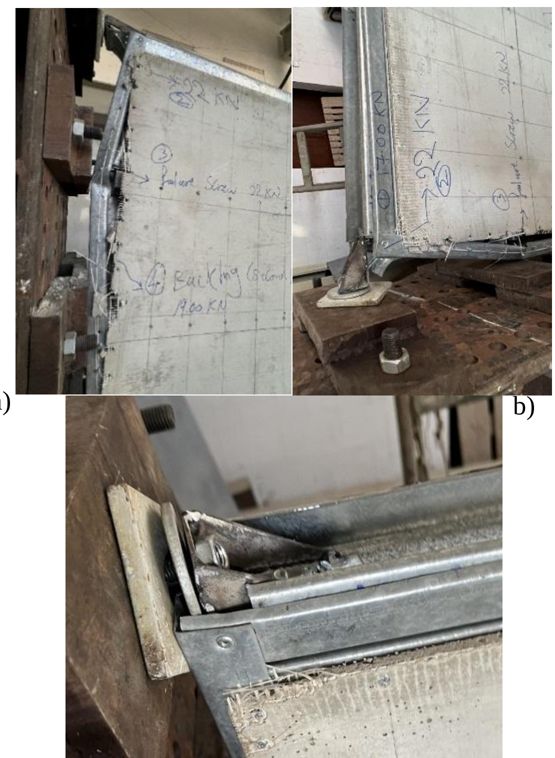
Figure (16): The Shear wall SW04-K after the test under monotonic test before strength the lower track with Modified HD-1.



(a) Pull out HD before modified. (b) Uplift and pull-out tension stud.

Figure (17): Failure modes of Specimen SW04-K

Figure (18): Failure modes of Specimen SW05-X.

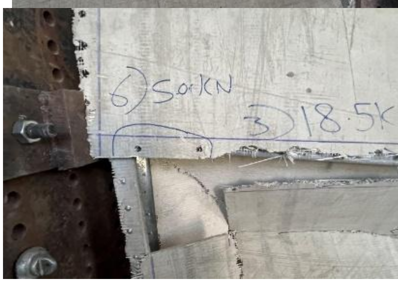


a) b) c)

a) buckling lower track and screw pull through
b) tear out lower track
c) modified HD with two washers an additional stud inside b2b stud.

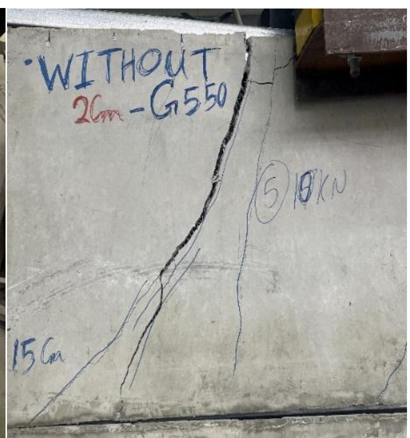
Figure (19): Failure modes of Specimen SW06-X.

a) 

b) 

a) Cracks FCB.
b) Crushing FCB and screw bearing.
Figure (20): Failure modes of Specimen 07

a) 

 b)

c) 

a) buckling upper track, b) Thermal board cracks
c) rivet tilting
Figure (21): Failure modes of Specimen SW08

a)

b) 

a) board cracks b) top track buckling
Figure (22): Failure modes of Specimen SW10-K


a) b)

c) 

d) 

a) split screw board b) crushing board
c) Total crushing board d) buckling in X – bracing
Figure (23): Failure modes of Specimen SW11-X

5. EVALUATION OF EXPERIMENTAL RESULTS:

5.1. Results and discussion:

5.1.1. Effect of bracing to the steel framing elements without sheath aspect ratio 2:1:

1- The ultimate lateral load in case of SW01 is 0.75 KN with corresponding lateral displacement is 192.56 mm, This case is without any type of bracing.

2- The ultimate lateral load in case of SW 03- K is 2 KN with corresponding lateral displacement is 115.422 mm . This case is with K bracing. This indicates that using K-strap bracing increases the shear resistance by **167%** than the steel frame.

3- The ultimate lateral load in case of SW 05- X equals 3.378KN with corresponding lateral displacement is 40.463 mm. This case is with X bracing. This indicates that using X-strap bracing increases the shear resistance by almost **350%** compared to the steel frame.

- As seen in the diagram, the CFS wall without any bracing or cladding exhibits noticeably reduced stiffness compared to the other forms of CFS walls.

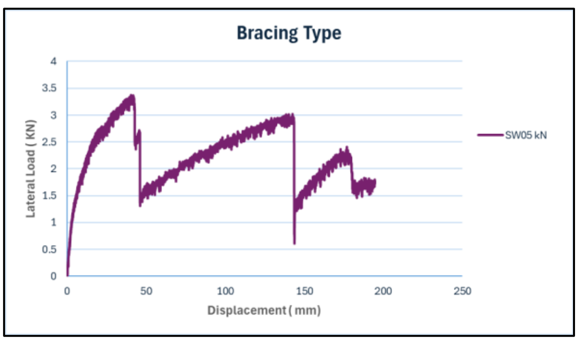


Figure (24): Effect of bracing on SW05 specimen.

5.1.2. Effect of bracing and Sheathing on steel framing elements:

<u>For Steel frame Size (1.2 m *2.4 m) with 10 mm FCB :</u>

1- The ultimate lateral load in case of SW02 is 11.293 KN with corresponding lateral displacement is 97.485 mm. This case is without any type of bracing and sheath with 10 mm Fiber Cement Board (FCB).

2- The ultimate lateral load in case of SW 04- K is 15.382 KN with corresponding lateral displacement is 132.676 mm. This case is with K bracing and sheath with FCB. This indicates that using K-strap bracing and FCB increases the shear resistance by **36%** than steel frame.

3- The ultimate lateral load in case of SW 06- X equals 22.910 KN with corresponding lateral displacement equals 125.631 mm. This case is with X bracing and sheath with FCB. This indicates that using X-strap bracing and FCB increases the shear resistance by almost **100%** compared to the steel frame.

- As seen in the diagram, the CFS wall without any bracing noticeably reduced stiffness compared to the other forms of CFS walls.

-

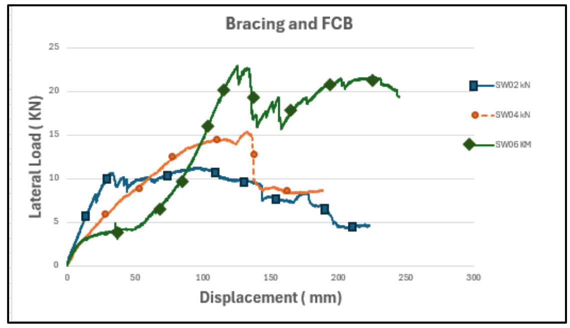


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Figure (25): Effect of bracing and FCB (SW02, SW04, SW06) specimens.

a. Effect of Using FCB Cladding 10 mm for the comparable type of bracing (without bracing, K and X):

1- The ultimate lateral load in case of SW01 equals 0.75 KN with corresponding lateral displacement 192.56 mm. This case is without any type of bracing.

2- The ultimate lateral load in case of SW-02 equals 11.293 KN with corresponding lateral displacement 97.485 mm. This case is without any bracing and sheath with 10 mm FCB. This indicates that using FCB sheath increases the shear resistance by **500%** compared to the steel frame without any cladding.

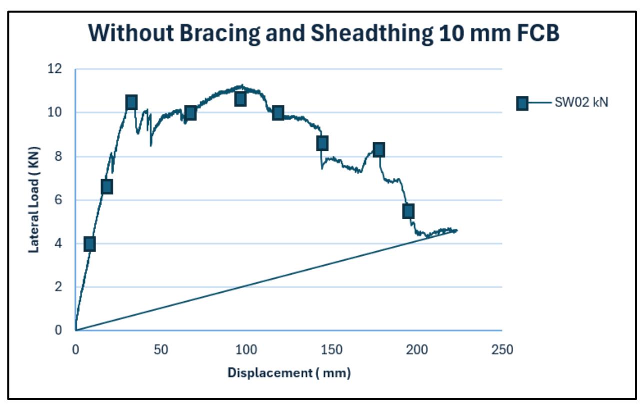


Figure (26): Effect of sheath for SW02 specimen.

3- The ultimate lateral load in case of SW03-K is 2 KN with corresponding lateral displacement 115.422 mm. This case is with K- bracing.

4- The ultimate lateral load in case of SW 04-K is 15.382 KN with corresponding lateral displacement equals 132.676 mm. This case with K- bracing and sheath with 10 mm FCB. This indicates that using FCB sheath increases the shear resistance by **670%** compared to the steel frame without any cladding.

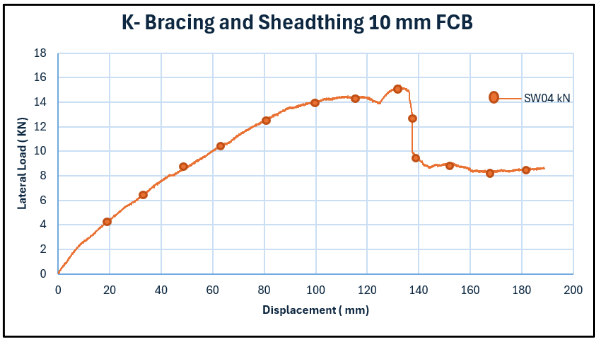


Figure (27): Effect of K-bracing and sheath specimen.

5- The ultimate lateral load in case of SW05-X is 3.378 KN with corresponding lateral displacement is 40.463 mm. This case with X- bracing.

6- The ultimate lateral load in case of SW 06-X is 22.910 KN with corresponding lateral displacement equals 125.631 mm. This case is with X- bracing and sheath with 10 mm FCB. This indicates that using FCB sheath increases the shear resistance by **570%** compared to the steel frame without any cladding.

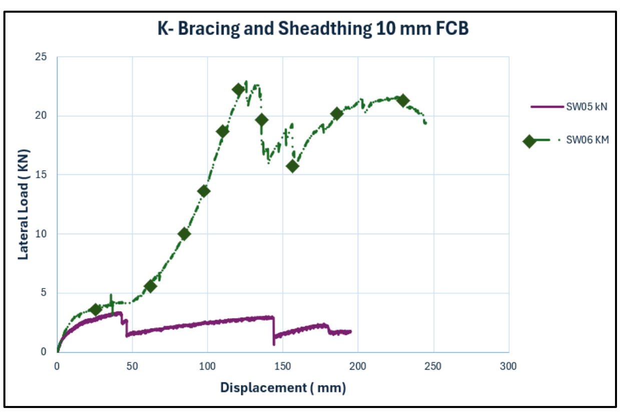


Figure (28): Effect of X-bracing and sheath specimen.

5.1.3. Effect of bracing on steel framing elements for aspect ratio 1.333:1.

b. Effect of Bracing on Steel frame Size (1.8 m *2.4 m) and sheath with 10 mm FCB:

1- The ultimate lateral load in case of SW07 is 23.745 KN with corresponding lateral displacement is 34.42 mm .This case is without any type of bracing and sheath with FCB. The screw spacing is 50 mm between the lower and upper track and 100 mm between the vertical studs.

2- The ultimate lateral load in case of SW 09- K is 28.48 KN with corresponding lateral displacement is 44.42 mm .This case is with K bracing and sheath with FCB .The screw spacing is 50 mm between the lower and upper track and 100 mm between the vertical studs. This indicates that using K-strap bracing increases the shear resistance by **20%** than steel frame.

3- The ultimate lateral load in case of SW 11- X is 29.78 KN with corresponding lateral displacement is 68.41mm. This case is with X bracing and sheath with FCB. The screw spacing is 50 mm between the lower and upper track and 100 mm between the vertical studs. This indicates that using X-strap bracing increases the shear resistance by almost **25%** than the steel frame.

- As seen in the diagram, the CFS wall without any bracing exhibits noticeably reduced stiffness compared to the other forms of CFS walls.

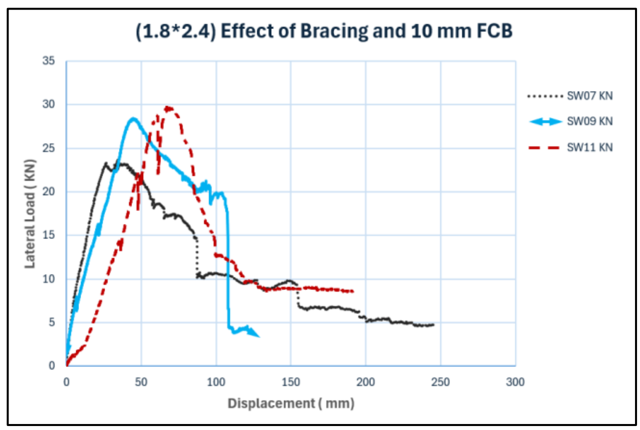


Figure (29) : Effect of bracing and FCB specimen.

c. Effect of Bracing on Steel frame Size (1.8 m *2.4 m) and sheath with 20 mm Thermal Board:

1- The ultimate lateral load in case of SW08 is 15.24 KN with corresponding lateral displacement is 91.09 mm. This case is without any type of bracing and sheath with thermal board. The screw spacing is 150 mm between the lower and upper track and 150 mm between the vertical studs.

2- The ultimate lateral load in case of SW 10-K is 23.13 KN with corresponding lateral displacement is 119.71 mm. This case is with K bracing and sheath with thermal board. The screw spacing is 150 mm between the lower and upper track and 150 mm between the vertical studs. This indicates that using K-strap bracing increases the shear resistance by **52%** than the steel frame.

3- The ultimate lateral load in case of SW 12-X is 33.39 KN with corresponding lateral displacement is 167.21mm. This case is with X bracing and sheath thermal board. The screw spacing is 150 mm between the lower and upper track and 150 mm between the vertical studs. This indicates that using X-strap bracing increases the shear resistance by almost **119%** than the steel frame.

- As seen in the diagram, the CFS wall without any bracing exhibits noticeably reduced stiffness compared to the other forms of CFS walls.

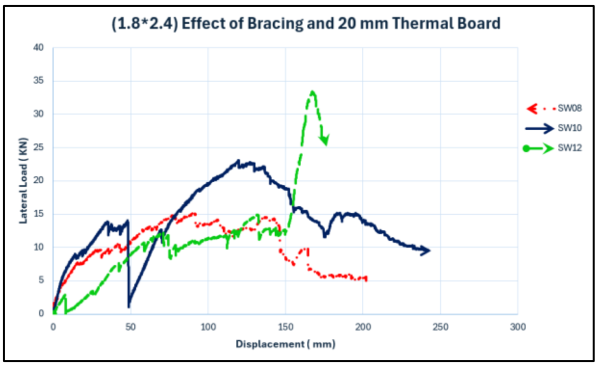


Figure (30) : Effect of bracing and thermal board specimen.

5.1.4. Effect of type of sheath (FCB & Thermal board) on Steel frame Size (1.8 m *2.4 m):

1- The ultimate lateral load in case of SW07 is 23.74 KN with corresponding lateral displacement is 34.42 mm. This case is without any type of bracing and sheath with 10 mm FCB. The screw spacing is 50 mm between the lower and upper track and 100 mm between the vertical studs.

2- The ultimate lateral load in case of SW 08 is 15.24 KN with corresponding lateral displacement is 91.09 mm without any type of bracing and sheath with 20 mm thermal board. The screw spacing is 150 mm between the lower and upper track and 150 mm between the vertical studs.

- <u>This indicates that using Fiber Cement Board 10 mm and screw spacing is 50 mm between the lower and upper track and 100 mm between the vertical studs increases the shear resistance by **50%** than the steel frame with thermal board.</u>

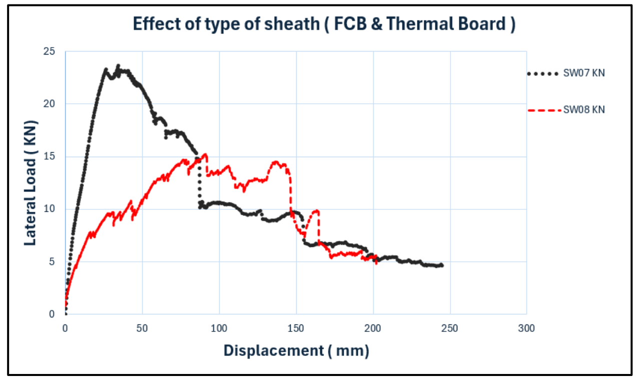


Figure (31): Effect of type of sheath specimen.

3- The ultimate lateral load in case of SW09-K is 28.48 KN with corresponding lateral displacement is 44.42 mm. This case is with K bracing and sheath with FCB. The screw spacing is 50 mm between the lower and upper track and 100 mm between the vertical studs.

4- The ultimate lateral load in case of SW 10-K is 23.13 KN with corresponding lateral displacement is 119.71 mm. This case is with K bracing and sheath with thermal board. The screw spacing is 150 mm between the lower and upper track and 150 mm between the vertical studs.

- <u>This indicates that using Fiber Cement Board and screw spacing is 50 mm between the lower and upper track and 100 mm between the vertical studs increases the shear resistance by **20%** than the steel frame with thermal board .</u>

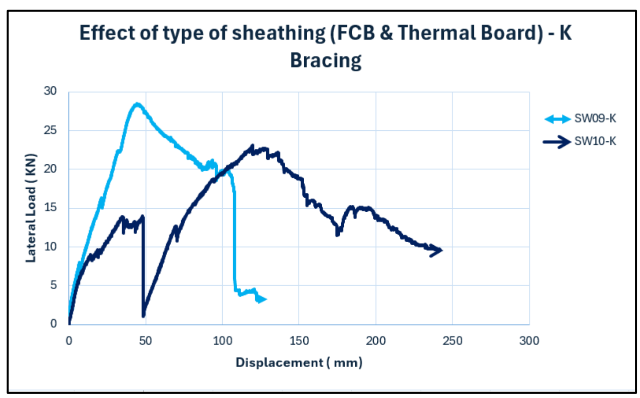


Figure (32): Effect of type of sheath and K- Bracing specimen.

5- The ultimate lateral load in case of SW11-X is 29.78 KN with corresponding lateral displacement is 68.41 mm. This case is with X bracing and sheath with FCB. The screw spacing is 50 mm between the lower and upper track and 100 mm between the vertical studs.

6- The ultimate lateral load in case of SW 12-X is 33.39 KN with corresponding lateral displacement is 167.21 mm. This case is with X bracing and sheath with thermal board. The screw spacing is 150 mm between the lower and upper track and 150 mm between the vertical studs.

- <u>This indicates that using Thermal Board and screw spacing is 150 mm between the lower and upper track and 150 mm between the vertical studs increases the shear resistance by **12%** than the steel frame with FCB.</u>

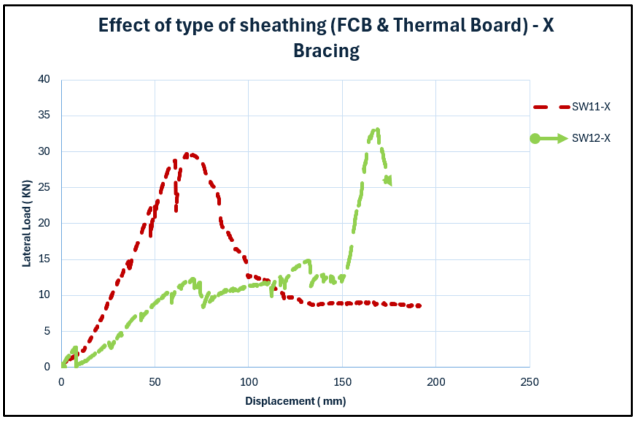


Figure (33): Effect of type of sheath and X- Bracing specimen.

Figure (33): Effect of Shear walls with Aspect Ratio 2:1.

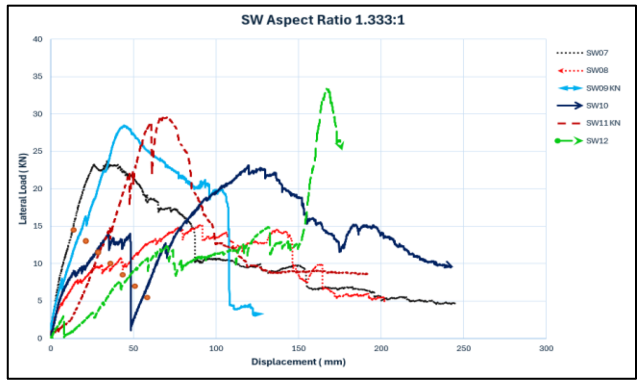
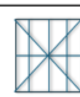


Figure (34): Effect of Shear walls with Aspect Ratio 1.333:1.

Table 3: Shear walls with the same Constant parameter and variable bracing type with aspect ratio 2:1 and 1.333:1.

Specimen Size	Test Specimen	Sheathing Type	Bracing Type	Screw Spacing mm (Track-Nogging/ Stud)	Schematic draw	(Ultimate Lateral Load) KN	(Corresponding Lateral Displacement) MM
1200 mm*2400 mm- Gauge 350	SW 01	Without board	None	———		0.75	192.56
	SW 02	10 mm Fiber Cement Board Double side		50/100		**11.293**	**97.485**
	SW 03- K	Without board	K-Bracing	———		2.000	115.422
	SW 04- K	10 mm Fiber Cement Board		50/100		**15.382**	**132.676**
	SW 05 -X	Without board	X-Bracing	———		3.378	40.463
	SW 06 -X	10 mm Fiber Cement Board		50/100		<u>**22.910**</u>	<u>**125.631**</u>
1800 mm*2400 mm- Gauge 550	SW 07	10 mm Fiber Cement Board Double side	None	50/100		**23.74**	**34.42**
	SW 08	20 mm Thermal Board		150/150		11.293	97.485
	SW 09- K	10 mm Fiber Cement Board Double side	K-Bracing	50/100		**28.48**	**44.42**
	SW 10- K	20 mm Thermal Board		150/150		23.13	119.71
	SW 11 -X	20 mm Thermal Board	X-Bracing	50/100		29.78	68.41
	SW 12 -X	20 mm Thermal Board		150/150		<u>**33.39**</u>	<u>**167.21**</u>

5- CONCLUSIONS AND RECOMMENDATIONS:

The research includes several types of graphs that analyze the influence of multiple variables on the load capacity of walls as part of the experimental examination. The main conclusions derived from the presented parametric investigation are:

- The shear wall with aspect ratio 2:1, The use of **X-Bracing and without any sheath** increases the shear resistance by **350 %** compared to the other forms of CFS walls without bracing.
- For the shear wall with aspect ratio 2:1, the use of bracing with **X-Bracing and sheath with 10 mm FCB** increases the shear resistance by **25 %** compared to the other forms of CFS walls.
- For the shear walls with aspect ratio 2:1 and **sheath with 10 mm FCB** with **X-Bracing** is the most effective wall with shear resistance by **100 %** compared to the other forms of CFS walls (Without bracing and K-bracing).
- For the shear walls with aspect ratio 1.333:1, the case with **X bracing and sheath with FCB,** the screw spacing is 50 mm between the lower and upper track and 100 mm between the vertical studs, increases the shear resistance by almost **25%** than without bracing and K- bracing.
- For the shear walls with aspect ratio 1.333:1 of **X bracing and sheath with 20 mm Thermal board**, the screw spacing is 150 mm between the lower and upper track and 150 mm between the vertical studs, increases the shear resistance by almost **119%** than without and K- bracing with the same constant parameters.
- For the shear walls with aspect ratio 1.333:1 of **X bracing and sheath with 20 mm Thermal board**, the screw spacing is 150 mm between the lower and upper track and 150 mm between the vertical studs, increases the shear resistance by almost **119%** than without and K- bracing with the same constant parameters.
- The hold-down element was strengthened with a 3 mm plate stiffener and two bolt washers with a diameter of 16 mm, serving as supports, enhanced the strength of the shear wall, with a markable increase in the tension side in walls.
- Using Tek screw in hold down of # 10 instead of #8, the connection strength between stud and hold down is about 40%.
- Increasing the lower track resistance of the shear wall that resulted in the increase of the strength between the base and track is about 50%.
- Strengthening the lower track section avoided base deformation and separation, which can lead to enhanced shear wall sheathing materials and reinforcing techniques. These enhancements may raise the system's overall stiffness and lateral load capacity
- Strengthening the hold down element resisted the tension force in the vertical stud which effectively transmitted the tension force from the tension side of the vertical stud to the base of the CFS wall.
- The sheath material, which is a fiber cement board, has the most impact on the CFS's behavior, and enhanced the shear capacity of the sheath wall by using X-strap bracing.
- It is recommended to decrease the screw spacing to be in the range of 5-10 cm as a result of the demonstration results.
- Explore techniques for enhancing the connection between studs and track.
- Examine the shear characteristics of the CFS wall when subjected to cyclic loading.
- Investigate the impact of vertical load on the shear characteristics of the CFS shear wall.

Acknowledgments
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