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Analytical Study of Cold Formed Steel Shear Wall Panels Under the Influence of Lateral Load

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Abstract— **This study examines lateral load-bearing capacity of the cold-formed steel framed wall panels. Computer models are used to numerically examine one lateral load bearing option for this purpose, and the outcomes are compared. One of lateral load bearing alternative is flat strap X-bracing on wall surfaces. Aspect ratio, stud thickness, bracing number, wall frame flat strap diagonal area, and other criteria are examined, and the outcomes are assessed. The lateral load delivered to the frame is somewhat increased, and the corresponding load is considered as the frame's lateral load capacity in the event that one of the components (studs, tracks, or bracing) fails. The calculation of stiffness involves dividing the lateral load capacity by the corresponding displacement at the node where the end stud, upper track, and diagonal brace link. All the analysis and member checks are done by SAP2000 software.**

Keywords— **Flat strap X-bracing, wall frame flat strap diagonal area and aspect ratio**

1.INTRODUCTION

1.1 General

Thin short steel products are extensively used in building industry, serve as basic building elements for prefabricated frames or panels. These thin steel sections are cold-formed, i.e. their production technique is cold-forming steel pieces from uniformly thick steel sheets. Other names for them include Cold Rolled Steel Sections, Cold Formed Steel Sections, and Light Gauge Steel Sections.

Manufacturers produce CFS sections purchase steel coils of 1.0 to 1.25 m width, slit them longitudinally to the correct width appropriate to the section required and then feed them into a series of roll forms. As the sheet is run through these rolls, its form is progressively changed to the desired profile because they are organized in pairs and move in opposing directions. These rolls include male and female dies. We refer to this as cold-rolling. The number of pairs of rolls, often referred to as stages, ranges from five to fifteen and is determined by the cross sectional shape's intricacy. At the end of the rolling stage, a flying shearing machine cuts the member into the lengths. An alternative method of forming is by press-braking, which is limited to short lengths and for relatively simple shapes. In this process, short lengths of strip are pressed between a male and a female die so fabricate one fold at a time and obtain the final required shape of the section. Cold rolling is used when large volumes of long products are required and press braking is used when small volumes of short length products are produced.

1.2 Components of a Cold Formed Steel Structures

A cold formed steel panel consists of top and bottom track, studs, nogs (blockings), bracing and sheathing. Sections of cold-formed steel fabrication range in thickness from 0.7 mm to 2.0 mm. Lip-shaped C-sections are used as studs, whereas lipless C-sections are utilized as tracks. Pneumatically driven steel rivets or self-drilling screws are used to join frame members. Cold formed steel houses are composed of wall. ceiling and roof panels, floor joists and roof trusses. The majority of the walls are load-bearing, while diaphragms on the roof and floor transfer lateral stresses to shear walls. The sheathed light gauge steel wall panels provide significant shear values against lateral forces caused by earthquake and wind loads. The shear walls are anchored to foundation by hold-down anchors and the shear couple is transferred to ground.

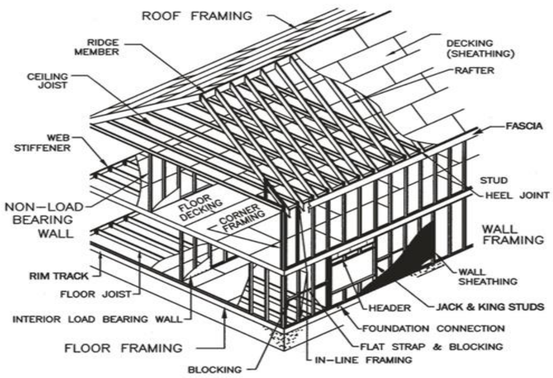

Figure 1.1: Overall views of residential steel framing and the Basic components

1.3 Bracing Types used in Cold Formed Steel Residential Structures

In cold formed steel residential structures. the shear walls can be designed with structural panel sheathing, flat steel sheathing, flat strap diagonal steel bracing, vertical truss wall section or combination of these methods (Fig 1.2). There is no lateral load capacity in the frame itself; bracing techniques are

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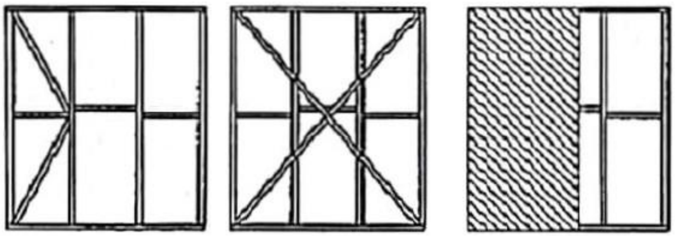
used to provide all of the capacity. The two most popular bracing techniques are flat strap diagonal steel bracing and structural panel sheathing.



K Bracing Steel Cross Bracing Full panel Bracing

Figure 1.2: Bracing Types Used in Light Framed residential structures, Serrette (1997)

1.4 Load Bearing Mechanism of Cold Formed Steel Residential Structures

Shear walls are the primary elements that give a light-gauge steel home its earthquake performance. By using vertical shear walls and horizontal roof and floor diaphragms, a light gauge cold formed steel framed residential building can withstand lateral loads brought on by wind or earthquakes. The diaphragms on the roof and floor absorb the story shear and transfer the load into the shear walls. The shear walls parallel to the force absorb the lateral force and transfer the load into the foundation. (Fig 1.3).

Pin connections are used to join the members of a cold-formed steel frame. This results in frame with no lateral stiffness so all the lateral stiffness is provided by bracing elements. The frame tends to become parallelogram when subjected to lateral stress, but the encased panel resists this. This resistance is provided only if the structural panel is sufficiently connected to frame (Fig 1.4). Originally intended to support vertical loads, the walls are converted to shear walls by adding bracing sections. These components may be structural panel sheathing or flat strap diagonal bracing. Before being transported into the sheathing panels, the story shear in structural sheathing is attached to the top track of the shear wall via the screws holding the plate to the frame. After that, the bottom plate is moved into the foundation. using anchor bolts and the shear is transferred to the bottom plate using screws. Typically, the end studs are made up of back-to-back studs to prevent overturning and to provide the screws at the diagonal's ends adequate room. It is evident that all of the shear force is passed from the frame into the panel mostly by perimeter screws, with the top and bottom tracks transferring the lateral shear force and the end studs transferring the vertical shear force. The screws connecting the panel to frame along internal studs do not transfer high level of shear force and mainly inhibit out of plane buckling of panel.

Furthermore, in order to avoid any elevation in the frame and any bending moment in the bottom track, the anchoring at the end studs needs to be strong enough to transfer the tension force that occurs in the studs. Depending on the forces in the studs, either chemical or mechanical anchor bolts can be employed. To transfer the tension stress into the foundation, hold-down anchors are employed at the ends of shear walls (Fig 1.5). When the tension load surpasses the stud-bottom track connection capability, the stud separates from the bottom track if the hold-down parts are not utilized. The wall breaks too fast as a result of this disruption in the shear wall behavior. Additionally, bending occurs between the end studs and the first anchor bolt due to the lack of mechanical hold-downs. In two-story structures, the upper-story shear walls must be secured to the first-story walls using two hold-down members: one at the top of the first-story wall and one at the bottom of the upper-story shear wall.

A shear wall's performance under lateral force is influenced by a number of factors. Since all of the shear force is transmitted from the frame into the panel by the screws, the sheathing-framing connection is the most crucial factor in a shear wall. A shear wall's lateral load capacity can be increased by increasing the number of screws since this will increase the amount of shear force that is transmitted from the frame onto the plate.

In residential applications all the external walls are covered by single or double layers of gypsum board from internal side. The gypsum board covering makes the shear walls more robust.

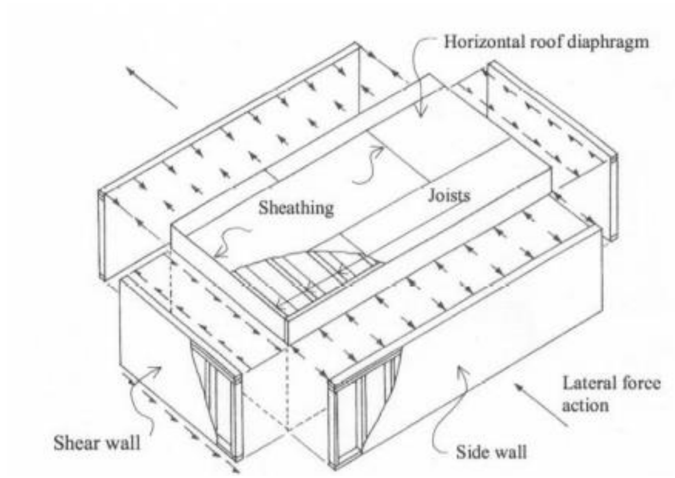


Figure 1.3: Lateral Load Carrying Mechanism of Light Framed Building, Bredel (2003)

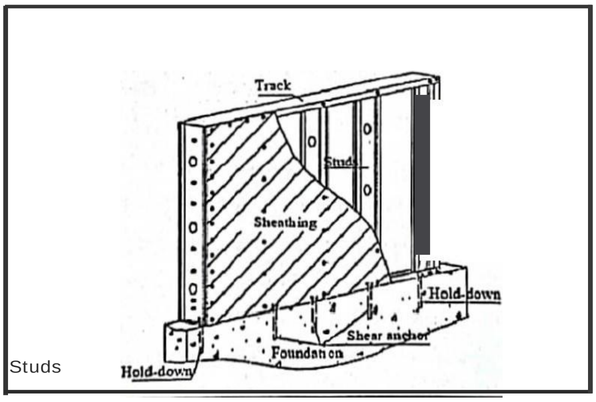


Figure 1.4: Typical Cold Formed Steel Shear Wall, Zhao and Rogers (2002)

Figure1.5: Typical Hold-down Members

1.5 Scope of Study

Even in nations where the construction industry has historically been driven by traditional structural solutions, the use of Cold Formed Steel (CFS) systems is now dramatically growing. In recent years, CFS housing has gained appeal all over the world because it offers an excellent solution to the requirement for reasonably priced, high-performance dwellings. The light weight of the systems, the excellent quality of the finished goods, and the flexibility provided by the large range of shapes and section sizes that can be created using the cold rolling process are just a few advantages of this construction technique. Additionally, because of their dry architecture, the CFS systems offer a reduced execution time. CFS can also benefit from a high strength-to-weight ratio, low maintenance over time, and cost-effective handling and transportation. CFS systems also adhere to sustainability guidelines. Indeed, their adverse environmental consequences are lessened by the use of recyclable and lightweight materials, system flexibility, dry construction, and the capacity to reuse components at the end of their life cycle. Because of these features and their speedy completion time, CFS houses can be the best choice for restoration projects caused by natural disasters like earthquakes, floods, landslides, etc

1.6 Objective of the Study

The overall objective is to investigate analytically the lateral load capacities of shear walls used in CFS framed residential buildings. The specific objectives are as follows:

- To determine the influence of flat strap diagonal area, stud thickness, aspect ratios and
- To determine the number of diagonal bracing on stiffness and wall shear capacity.

1.7 Methodology

The research work will be completed with the following set of methodology.

- Different papers and research works regarding the lateral load bearing capacity of CFS Shear Walls shall be studied
- Four different cases shall be studied.

➢ Same Frame and Varying Flat Strap Diagonal Area: Stiffness vs. Diagonal Area curve shall be obtained

➢ Same Strap Diagonal Area and Varying Stud thickness: Stud Thickness vs. Wall Shear Capacity Curve shall be obtained.

➢ Same Frame Members and Varying Aspect Ratios: Unit Wall Shear Capacity vs. Aspect Ratio curve shall Stiffness vs. Aspect Ratio curve shall be obtained

➢ Same Frame Members and Varying Number of Diagonal Bracing: Stiffness vs. Number of Bracing curve and Wall Shear Capacities vs. Aspect Ratio curve shall be obtained.

- All the analysis shall be done on SAP 2000 software. The properties of Cold Formed Steel shall be as per ASTM A653 (SS Grade 33). The analysis shall be done as per the code AISl-ASD-1996.
- Evaluation and Analysis of the performance of CFS shear wall shall be done and the results shall be interpreted

2.LITERATURE REVIEW

Before proceeding with this project, it is important to have an understanding of previous research on cold formed steel structures. A large number of experimental research programs have been performed to study the structural behavior of cold formed steel stud shear walls (CFSSSW) laterally braced with sheathings and/or with diagonal steel straps. This chapter contains a review of the main tests concerning the structural behavior of CFSSSW.

The study of Tarpy & Girard (1982), [4] Was performed in response to a need to develop design criteria for steel stud shear wall panels with different construction details and sheathing materials. The materials used for the sheathings were GWB (Gypsum Wall Board), GSB (Gypsum Sheathing Board) and PLY (Plywood). The experimental program was based on the testing of fourteen specimens under monotonic load following the requirements of ASTM E 564-76 (1976).

Tissell (1193), [2] conducted for the American Plywood Association eight monotonic loading tests on walls that were sheathed with either OSB (Oriented Strand Board) or PLY and that had various frame thicknesses

Serrette (1997), [2] described the failure mechanism of cold formed steel shear wall panels with the results of the full scale and small-scale tests. The mode of failure of OSB sheathed panels is bend breaking of material around screw followed by screws pulling out at the end of material.

Selenikovich *et al*.. (1999), [3] presented the results of monotonic and cyclic tests on sixteen full size shear walls with and without opening. The Authors observed that the predominant failure mode was head pull through of sheathing screws and bending of frame elements. They concluded the following: that, Long, fully sheathed walls were significantly stiffer and stronger but less ductile than walls with openings. The predictions of the PSW design method were conservative at all levels of monotonic and cyclic loading. Cyclic loading did not influence the elastic behavior of the walls but reduced their deformation capacity. The strength of fully sheathed walls was affected more significantly by cyclic loading than walls with openings. Adding of GWB panels increased the shear strength and stiffness of fully sheathed walls under monotonic load.

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Kawai, Kanno , Uno, Sakumoto (1999), [1] later on, suggested the storey drift angle limits of light gauged steel framed houses to have safety against earthquakes encountered in Japan. The design methods of steel-framed houses were proposed based on the direct evaluation of seismic resistance by seismic response analyses. Holding the maximum storey drift angle to 1/50 rad in a severe earthquake was proposed as a criterion for steel-framed houses. The Nominal Shear displacement of earthquake resistant elements in low-rise buildings is typically specified as a maximum storey drift angle of 1/30 to 1/50 rad. In addition, storey angle of 1/60 rad is applied as a repairable displacement limit for houses

After these studies on displacement limit, Zhao anti Rogen (2002), [5] describes the lateral force resisting mechanism of a cold formed steel residential structure. Under seismic ground motion, horizontal inertia forces develop at the roof and floor levels as a result of the accelerations experienced by the building mass. To resist these lateral loads the structure may include diagonal steel bracing, plywood sheathing, oriented strand board sheathing. gypsum wallboard or sheet steel sheathing in the walls. These structural shear wall systems maintain the structural integrity of the building by transferring the seismic loads from the diaphragms at the roof and floor levels to the foundations.

3.0 ANALYTICAL MODEL OF X-BRACED SHEAR WALLS.

3.1 General Description

X-type flat strap diagonal bracing is one of the most used bracing techniques in cold formed steel frame construction (Figure 3.1). Only tension is carried by the flat strap bracings, which are excessively weak under compression. Self-drilling screws are used to create the bracing-stud connection, and the quantity of screws needed to achieve the necessary connection strength must be decided. To transfer the tension stress, the hold-down component must secure the frame's comer, which is linked to the frame by flat strap bracing, to the foundation (Figure 3.2). The bracing tension force must be supported by the anchorage's robust construction.

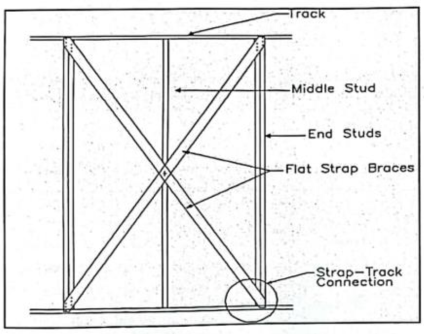

Figure 3.1: General Drawing of Frame with X-Bracing

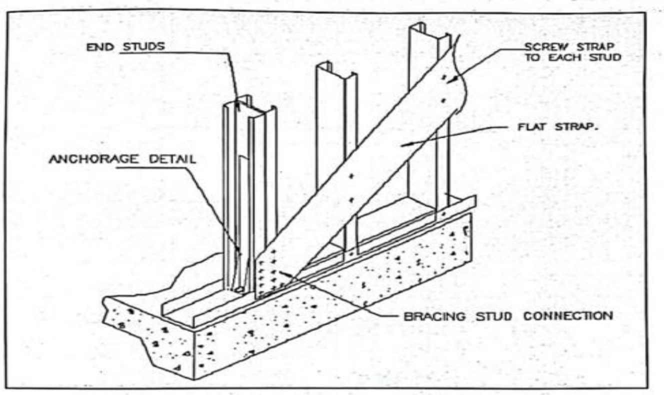

Figure 3.2: Bracing-Frame Connection Detail

3.2 Design Parameters

There are many parameters that affect the lateral load capacity and stiffness of a wall. The most important parameters are frame section geometry, diagonal area, aspect ratio and number of bracings. These parameters are investigated in this study and result are tabled and compared below.

3.2.1 Frame Section Dimensions

The thickness of studs changes from 0.88 mm to 1.81 mm and the thickness of the tracks are 0.84 mm and 1.15 mm.

Section Dimension(mm)	Stud 1	Stud 2	Stud 3	Stud 4	Track 1	Track 2
Height	89	89	89	89	89	89
Flange	41.2	41.2	41.2	41.2	32	32
Lip	12.5	12.5	12.5	12.5	0	0
Thickness	0.88	1.15	1.44	1.81	0.84	1.15
Radius	1.9	1.8	2.15	2.71	1.9	1..9

Table 3.1: Dimensions of sections used in analysis

(End studs are back to back)

Flat straps having six different areas are used in the analysis with different widths and thickness (Table 3.2)

Strap Dimension (mm)	Bracing Type 1	Bracing Type 2	Bracing Type 3	Bracing Type 4	Bracing Type 5	Bracing Type 6
Width(mm)	114	114	114	190	190	190
Thickness(mm)	0.88	1.15	1.44	1.15	1.44	1.81
Area(mm^2)	100.32	131.1	164.16	218.5	273.6	343.9

Table 3.2: Dimensions of X-bracing used in analysis

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3.3 Material Properties
Mechanical properties of steel used in analysis.

Yield Strength of Steel: Fy = 33 ksi (Fy = 228 MPa)

Tensile Strength of Steel: Fu = 45 ksi (Fu =310 MPa)

3.4 Analysis Method
All supports are shown as pins, and moments are released at the frame member connections.
Since flat strap is extremely weak under compression, the diagonal that is subjected to compression is ignored in the model to make computations easier. When one of the components (studs, tracks, or bracing) breaks, the corresponding load is regarded as the frame's lateral load capacity. The lateral stress placed on the frame has increased noticeably. By dividing the lateral load capacity by the corresponding displacement at the node where the diagonal brace, upper track, and end stud join, stiffness is determined. SAP2000 software performs all member inspections and analysis.
Nominal member capabilities are utilized in member stress testing because the program assigns the factor of safety values to be one

3.5 Case Studies
3.5.1 Case-1: Same Frame and Varying Flat Strap Diagonal Area
In this case, the 1.22 x 2.44 m frame (Figure 3.3) is analyzed with six different type flat strap bracing (Table 3.3) and the effect of flat strap areas to stiffness is investigated

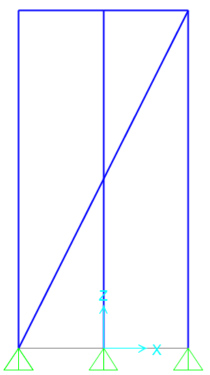

Figure 3.3: SAP2000 Model of Frame

Frame Height: 2.44 m
Frame Width: 1.22 m
Stud Type: Stud 4
Track Type: Track 2
Diagonal Bracing Type: Bracing Type 1,2,3,4,5

	Stud	Track	Bracing Type	Diagonal
Model-1	Stud	Track 2	Bracing Type 1	100.32
Model-2	Stud	Track 2	Bracing Type 2	131.10
Model3	Stud	Track 2	Bracing Type 3	164.16
Model-4	Stud	Track 2	Bracing Type 4	218.50
Model-5	Stud	Track 2	Bracing Type 5	273.60
Model-6	Stud	Track 2	Bracing Type 6	343.90

Table 3.3: Frame member properties of different models for Case-1.

	Shear Capacity(KN)	Displacement (mm)	Stiffness(KN/mm)
Model-1	6.22	4.59	1.36
Model-2	6.22	3.61	1.72
Model-3	6.22	2.97	2.09
Model-4	6.22	2.34	2.66
Model-5	6.22	1.96	3.17
Model-6	6.22	1.65	3.77

Table 3.4: Shear Capacities, Displacements and Stiffnes values of different Models

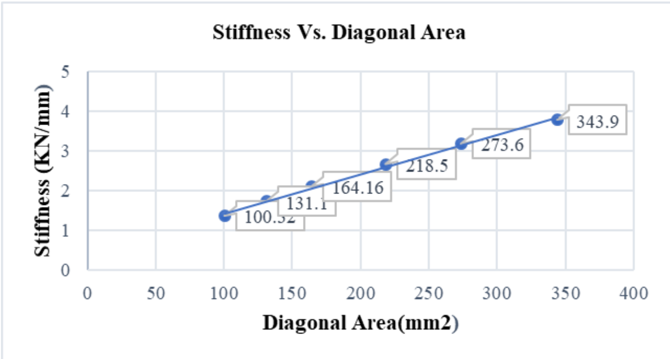

Figure 3.4: Stiffness vs. Diagonal Area curve
In each analysis, the wall shear capacity is same because the axial load capacity of stud governs the wall capacity (Table 3.4). As the diagonal area increases, the displacement decreases and stiffness increases. The area of flat strap increases 3.43 times and the stiffness increases 2.77 times. In this case it is observed that (Figure 3.4), if the axial load capacity governs the design, increasing the diagonal bracing only increases the stiffness but no effect on wall shear capacity.

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3.5.2 Case-2: Same Strap Diagonal Arta and Varying Stud Thickness

In this case, the 1.22 x 2.44 m frame is analyzed (Figure 3.5) with same diagonal bracing area and 4 different stud thicknesses (Table 3.5) and the effect of stud thickness to wall shear capacity is investigated.

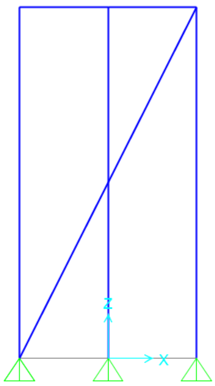

Figure 3.5: SAP2000 Model of Frame

Frame Height:2.44 m
Frame Width: 1.22 m
Stud Type: Stud 1,2,3,4
Track Type: Track 1, Diagonal Bracing Type: Bracing Type 6

Table 3.5: Frame Member Properties and Shear Capacities of different Models

	Stud	Track	Bracing Type	Stud Thickness	Shear Capacity	Unit Shear Capacity(KN/m)
Model 1	Stud 1	Track 1	Br.Type 6	0.88	1.98	1.62
Model 2	Stud 2	Track 2	Br.Type 6	1.15	3.04	2.49
Model 3	Stud 3	Track 3	Br.Type 6	1.44	4.61	3.78
Model 4	Stud 4	Track 4	Br.Type 6	1.81	6.23	5.11

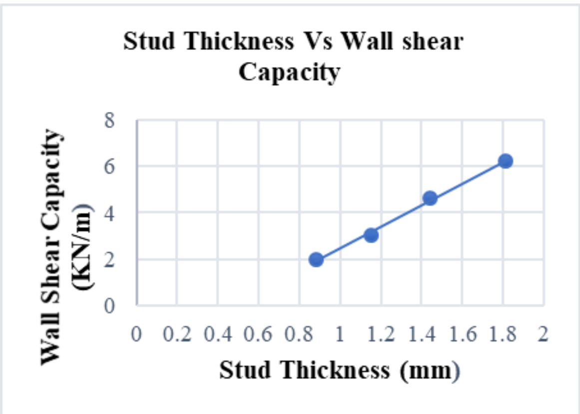

Figure 3.6: Stud Thickness vs. Wall Shear Capacity curve

As the stud increases, the shear capacities of walls increase the axial land capacity of stud governs the wall capacity. The stud thickness increases 2.06 times and the wall shear capacity increases 3.15 times (Figure 3.6). In this case it is observed that, increasing the stud thickness linearly increases the lateral shear capacity of the frame when axial land capacity of the stud governs the design.

3.5.3 Case-3: Same Frame Members and Varying Aspect Ratios

In this case, the frames with same sections but in different sizes (Table 3.6) are analyzed and the effect of aspect ratio to wall shear capacity is investigated (Figure 3.7).

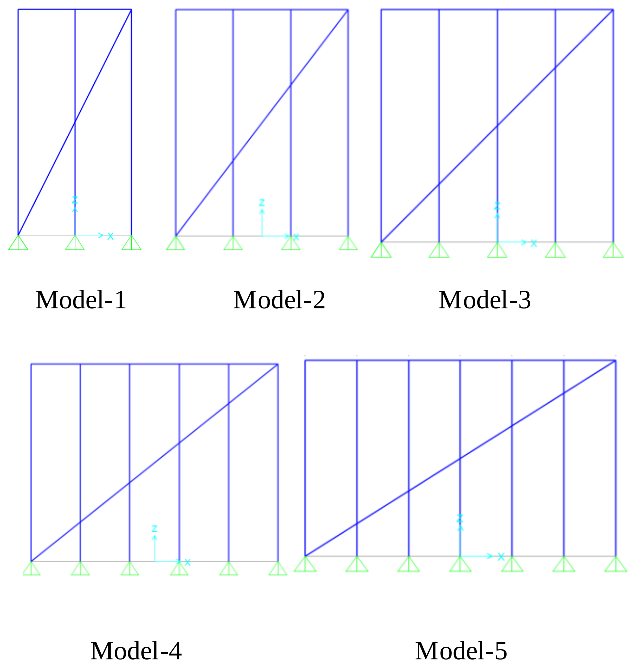

Figure 3.7: Analytical Models of Shear Wall with X-Bracing with different Aspect Ratios

Table 3.6: Frame Member Properties and Aspect Ratios of different Models

	Frame Members	Panel width(m) (w)	Panel Height(m) (h)	Aspect Ratio (h/w)
Model 1	Stud 3, Track 1, Br.Type 6	1.22	2.44	2.00
Model 2		1.83	2.44	1.33
Model 3		2.44	2.44	1.00
Model 4		3.05	2.44	0.80
Model 5		3.66	2.44	0.67

Table 3.7: Shear Capacities, Displacements and Stiffnesses of frames with different Aspect Ratios

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	Total Shear Capacity(KN)	Unit Shear Capacity (KN/m)	Displacement (mm)	Stiffness(KN/mm)
Model 1	4.67	3.83	1.31	3.57
Model 2	7.01	3.83	1.12	6.26
Model 3	9.34	3.83	1.12	8.34
Model 4	11.68	3.83	1.25	9.34
Model 5	14.01	3.83	1.4	10.01

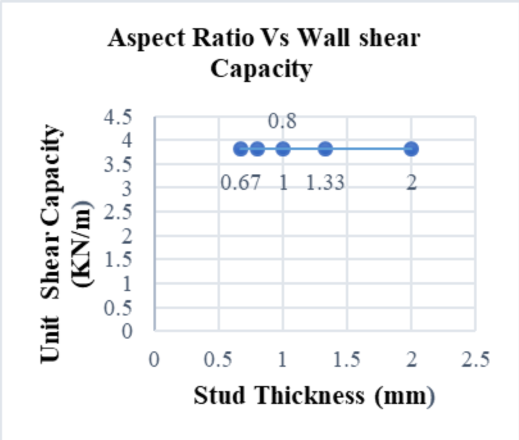


Figure 3.8: Unit Wall Shear Capacity vs. Aspect Ratio curve

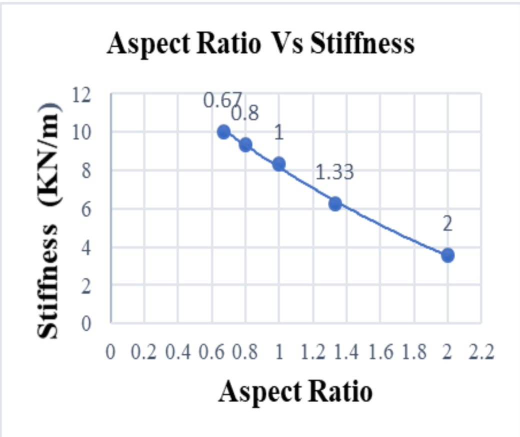
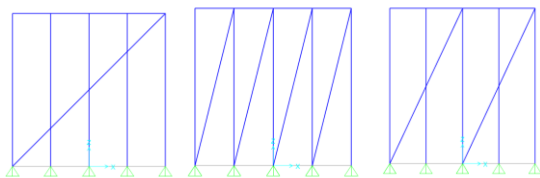


Figure 3.9. Stiffness vs. Aspect Ratio curve

As the aspect ratio of walls increases there is no change in unit shear capacity of walls. The total shear capacity of wall is increases but the shear capacity of unit length is same. On the other hand, as the aspect ratio increases stiffness decreases. Stiffness decreases 2.8 times where aspect ratio changes from 0.67 to 2. In this instance, it is found that the wall's aspect ratio considerably alters the stiffness but has no discernible impact on the unit wall's shear capacity. (Figure 3.9).

3.5.4 Case-4: Same Frame Members and Varying Number of Diagonal Bracing

In this case 2.44 m x 2.44 frames with same sections but having different number of diagonal bracings (Table 3.8) are analyzed and the effect of bracing number to wall shear capacity is investigated.



Model-1 Model-2 Model-3

	Shear Capacity (KN)	Shear Capacity (KN/m)	Displacement (mm)	Stiffness (KN/mm)
Model 1	5.98	2.049	0.71	8.423
Model 2	7.18	2.943	1.07	6.71
Model 3	7.18	2.943	2.08	3.452

Figure 3.10: Analytical Models of Shear Wall with different number of X-bracings.

Frame Height: 2.44 m
Frame Width: 2.44 m

Table 3.8 Frame Member Properties and Number or Bracings of different Models.

	Frame Members	No. of Bracings
Model 1	Stud 3,Track 1,Bracing Type 6	1
Model 2		2
Model 3		4

Table 3.9: Shear Capacities, Displacements and Stiffnesses of frames with different number of Bracings

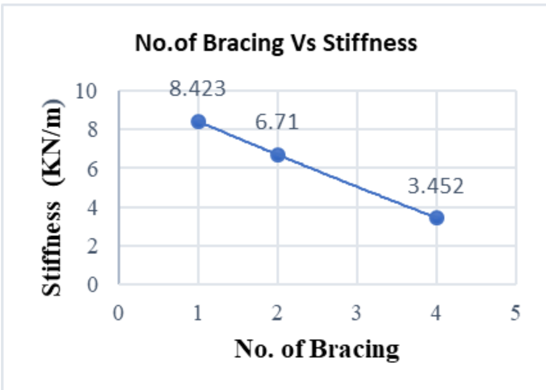


Figure 3.11: Stiffness vs. Number of Bracing curve

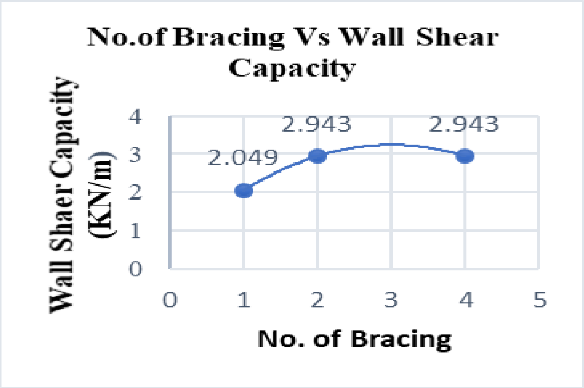


Figure 3.12: Wall Shear Capacity vs. Number of Bracing curve

As the number of bracing increases, there is nearly no change in shear capacity of walls (Table 3.9). On the other side, as the number of bracings increases, stiffness decreases. Stiffness decreases 2.44 times where bracing changes from one to four (Figure 3.11)

CONCLUSIONS

On the basis of the result obtained from analytical study of this thesis work, following conclusion scan be drawn.

1. Stiffness of X-braced wall frames increase if the flat strap bracing with larger area is used, but it does not make significant change in the lateral load capacity of the frame. As the area of flat strap bracing is increased 3.43 times, the stiffness increases 2.77 times
2. As the stud thickness increases making other parameters constant, the shear capacity of wall also increase. With 2.06 times increase in thickness, the walls shear capacity increase 3.15 times.
3. Aspect ratio of the X-braced shear walls does not make any significant change in the lateral load capacity of unit length but as the aspect ratio increase from 0.67 to 2, the stiffness decrease 2.8 times.
4. Number of bracings for a shear wall with constant dimensions does not change the lateral load capacity, but stiffness decreases as number of bracing increases. Hence, it can be concluded that the lateral capacity is governed by the capacities of studs rather than the size and the number of bracings

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