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An investigation of dynamic behavior of coupled steel plate shear walls using cross stiffener under uniform load

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Abstract

In recent decades, the coupled Steel plate shear wall system is considered as an efficient lateral force resisting system by engineers and researchers. Different parameters affect the nonlinear behaviour of Coupled Steel plate shear wall system. Other models are produced according to the base model. After verifying the nonlinear behaviour of this system by cross stiffeners on the Coupled Steel plate shear wall, an increase in the thickness of the stiffeners and the thickness of the Coupled Steel plate shear wall have been evaluated. In this study, the effect of the parameters on the initial stiffness, ultimate strength, and energy absorption by the samples have been compared with each other and the base model. The cross stiffeners on the Coupled Steel plate shear wall have also increased the sample's initial stiffness, ultimate strength, and energy absorption. However, the use of stiffeners does not significantly affect the energy absorption by the samples. Stiffeners increase the sample's initial stiffness, ultimate strength, and energy absorption, which has little effect on the energy absorption by the sample.

Keywords: Coupled Steel plate shear wall, Cross stiffener, Plate thickness, Stiffener thickness, Energy absorption
2020 MSC: 82Mxx, 74H80

1 Introduction

The steel plate shear wall system is a lateral force-resisting system for earthquake and wind forces. The steel plate shear wall system (SPSW) includes a steel frame and several steel panels with flexible beam to column connection or rigid connection and steel plates. Steel web plates can be with or without stiffener and have several holes or openings. Also, the steel frame of the Steel plate shear wall system can be flexible. In a Steel plate shear wall system, the lateral stiffness of the structure is the criterion when the shear is dominant, while if the bending is dominant in the structure, this causes significant axial forces, which causes the bending locations to change. Steel plate shear walls use only boundary columns against overturning, which causes the system to be challenged in cases where bending is prevalent. One of the most effective solutions to increase the strength of the Steel plate shear wall is to split this wall into two connecting walls. The Steel plate shear wall system consists of two separate Steel plate shear walls connected by a link beam at floor level, it is called the C-SPSW, coupled steel plate shear wall system.

Sabouri-Ghomi and Roberts performed several experiments on steel shear walls without stiffeners and different thicknesses. In all these experiments, the ductility and S-shape stable cycle loop were obtained, and the energy

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absorbed in each cycle with maximum amplitude was obtained. In this study, circular opening in shear panels is considered, which is one of the advantages of the research to study and test circular opening [10, 12]. Astaneh examined two models using stiffeners and without stiffeners, conducted a comprehensive study of the design of Steel plate shear walls, and stated that solid plates should be used without stiffeners unless required [3]. In 2008, Saburi and Gholhaki placed two samples of the ductile shear wall at a scale of one-third under cyclic loading. The results showed that the beam to column connection affected ductility, strength, and energy absorption but did not have a significant effect on stiffness. It was assumed that the steel plate completely surrendered at the plastic strength level of the structure, and therefore the frame elements around the steel plate were designed based on the final capacity of the plate, and due to the presence of the connection beam, most of the floor shear was carried by the elements around the steel plates, which resulted in the thinner steel plates [11]. In 2011, Fahnestock and Borello designed several six-story structures, and it was assumed in the design that the steel plate completely surrendered to the plastic strength level of the structure, so the frame elements around the steel plate were designed based on the final capacity of the steel plate. As a result, the sections of beams and columns remained in the elastic range and showed enough strength to lateral loads. They were also thinner steel [4]. In 2012, Hosseinzadeh and Tehranizadeh presented models with opening and without opening, and structures with and without opening were compared. The results showed that although the initial stiffness of the two models with and without opening was very close, because of increasing drift and stiffeners around the opening, the model with an opening had more stiffness than the model without an opening [6]. In 2012, Cheng and lin proposed a model to consider the behaviour and design of a coupled Steel plate shear wall. After examining a sample, experimental results show that the behaviour of C-SPSW is ductile and wastes a significant amount of hysteresis energy during cyclic loading and shows efficient behaviour. Another result was that the plastic design of the lower columns was developed along, the lower half of the column height [7]. In [1], Alavi and Nateghi used experimental models and finite element models to investigate the effect of opening and diagonal stiffeners based on the results, they found that the use of stiffeners in this method causes the shear strength of the system with an opening to be closer to the shear strength of the system without an opening and the system with the opening is about 14% stiffer than the model without opening [1]. Jin-yu Lu and Lu-nan Yan evaluated the seismic behaviour of a steel shear wall and specimens of slit shear walls were provided. Based on the results of the pushover analysis on a series of steel slit wall specimens, the effects of the slit parameters, such as $b/h, l/h, h/t$, and m, on the behaviour of the steel slit wall were conducted. The results showed that the simplified model can correctly predict the mutual effects of the bearing wall and the frame, which must be accounted for in the design [8]. Tao Xu and Jian Hua Shao evaluated Multi-Story Steel Plate Shear Walls Designed by Different Methods. Based on two different design methods given in "Technical specification for steel structure of tall buildings" and the shear-bearing capacity method for infilled shear plates, two designed specimens of the steel plate shear wall were built and tested under the static monotonic pushover and low horizontal cyclic loading conditions is ordered to investigate the structural behaviours of the shear wall when exposed to a severe earthquake. A comparative analysis of different mechanical seismic performances was carried out and the following conclusion was obtained both specimens had satisfactory seismic performance in terms of overall drift angle. They could continue to carry loads after the structure behaves beyond the elastoplastic displacement limit specified by the national standards. However, the load carried by the thick SPSW is always greater than that of the thin SPSW. Under the test conditions, the design of the thick SPSW appeared to be overly conservative, while the design of the thin SPSW is rather economical and reasonable [14]. Yousufu Ma and Jeffrey W. Berman evaluated three samples of coupled steel plate shear walls under cyclic loading and different coupling beam-to-column connections, namely a welded moment connection, a bidirectional bolted connection, and a cantilever endplate connection were employed. Different injury patterns for CBs and their connections were observed from three samples. CBs CSPSW-W failed due to weld fracture at the CB-to-VBE junction, While CSPSW-W and CSPSW-E CBs had ductile shear yield. This is followed by the rupture of the CB fibers. The power of the CSPSW-W sample was smaller than the other two samples. However, the initial stiffness of the CSPSW-W specimen was highest because of this Higher rotational stiffness of the CB-to-VBE connection. power and the stiffness reduction of the three samples were similar and stable [9]. The primary research has been focused on the observed of this type of instrumental system, while various factors have influenced the nonlinear behaviour of such a system that the effect of some factors in previous studies is less considered. Factors include the thickness of the shear wall, the use of stiffeners and the effect of the thickness of the stiffeners, which obviously cannot be investigated by an experimental study because of many numbers of models and economical barriers. ABAQUS is a finite element software that has been used for numerical simulation in this research. The reason for using ABAQUS finite element software is the cost of experimental work and the possibility of robust software simulation provided. For this purpose, first, the simulation is performed in the software according to [7]. After validation by changing the mentioned parameters, the nonlinear behaviour of the Coupled Steel plate shear wall is evaluated using the energy absorption curve, initial stiffness, ultimate strength, and the nonlinear behaviour of the samples are compared with the base model [7].

2 Description of Coupled Steel Plate Shear Wall System

The steel plate shear wall system relates to pin-ended elements and is subjected to lateral loading, then, only the central elements transfer axial loadings, and each wall acts separately against the lateral forces applied to them. However, When the walls are connected by a joint and connected utilizing a beam, then in comparison with the previous state, it acts continuously and is adjusted to the extent of $TA/2$ from the anchors in the previous state where T is the force of connection of two walls and A is the distance. These forces are divided between the columns. The Coupled Steel plate shear wall system consists of two or more separate Steel plate shear walls connected by steel beams at the level of the roof on each floor, called the link beam. One of the numerical and experimental studies performed on this type of lateral force resisting system is mentioned in [7]. Figure 1 shows the schematic of the Coupled Steel plate shear wall. This system consists of the main columns of the frame, the main beams of the frame, the coupled beam, and the plate of the wall.

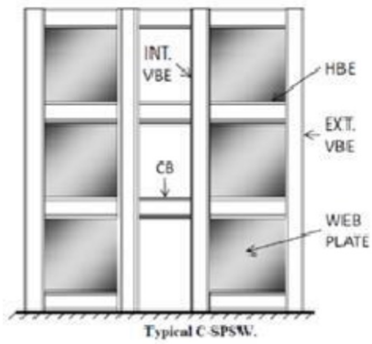


Figure 1: Schematic of Coupled Steel plate shear wall

2.1 Details of the validation model

In this study, the numerical results are compared with the results of a valid experimental sample to reveal the accuracy of the modelling. Therefore, the experimental sample of Lee., in 2012 at the University of Taiwan [7] has been selected. It is worth mentioning that using a six-story prototype, a sample with a scale of 40% was made for the lower 2.5 floors of the coupled Steel plate shear wall using a plate with low yield stress. Figure (2-a) shows the main plan of a six-story building, and Figure (2-b) shows a sample plan made with a scale of 40%.

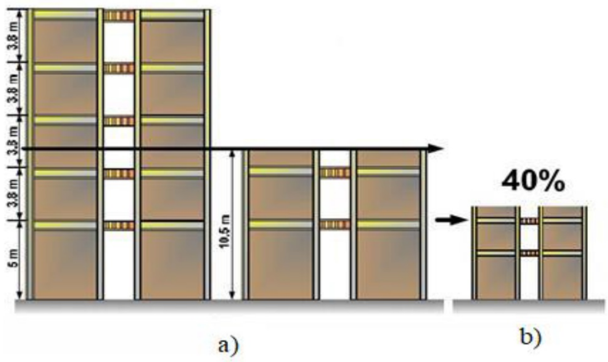


Figure 2: a. six-story main structure. b. Model built with a scale of 40%

Table 1 provides general specifications for structural elements, including the main column, main beam, and link beam.

In this model, the beam-to-column connection is assumed to be rigid. The height of the columns on the first, second, and third floors is 1520, 2000, and 820 mm, respectively. It should be noted that all beam and column elements are controlled by AISC (2005) [2]. Also, at the beam to column connection, 100 mm wide, 204 mm long, and 10 mm thick stiffeners are installed to prevent the sudden entry of compressive forces in the beam flange to the web connection. The Coupled Steel plate shear wall details are shown in Table 2. The loading beam was used for loading.

Table 1: Specification of structural elements of an experimental model

Element	Web (mm)	Flange (mm)	Web thickness (mm)	Flange thickness (mm)
Main column	204	200	16	24
Main beam	170	120	7	10
Link beam	170	160	7	22

On top of each Steel plate shear wall on the floor, a transfer beam is introduced, each shear wall is connected to the transfer beam, and the transfer beam is connected to the loading beam to simplify the loading conditions.

It is a cross beam with a box cross-section with a width and length of 50 and 60 mm. The main beam in the frame is also defined using a reduced cross-section to create a plastic hinge away from the brittle weld metal in the designer's desired location [7].

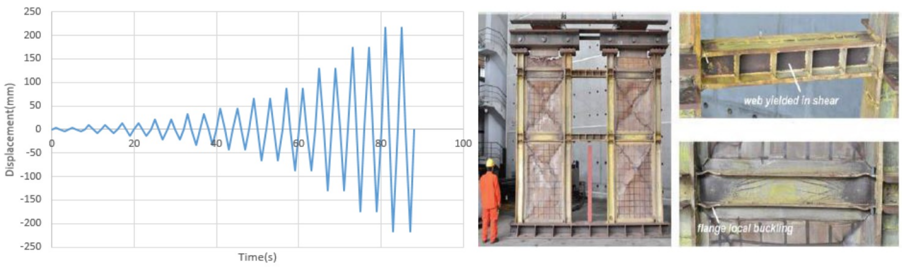
Table 2: Specification of structural elements of an experimental model

Element	Floor	Length (mm)	Width (mm)	Thickness (mm)
Steel plate	1	1835	1116	3.5
Steel plate	2	1270	1116	3.5
Steel plate	3	1116	290	3.5

In the present study, two types of materials are used in general, which are A572gr50 and LYS, mechanical specifications of steels for each member of the structure are listed in Table 3. 4-node shell element (S4R) is used for a grid with two-way curvature and reduced integration. To apply load on the sample, a hydraulic jack has been used, which according to the instructions provided in [5], the necessary forces have been applied to the samples with the displacement control method; the sample loading protocol is shown in Figure (3-a), and the desired shear wall is shown in Figure (3-b) [7].

Table 3: Mechanical characteristics of steels used in the finite element model

Element	E (MPa)	v	Fy (MPa)	Fu (MPa)
Column flange	200000	0.26	350	450
Column web	200000	0.26	415	564
Boundry beam flange	200000	0.26	430	505
Boundry beam web	200000	0.26	400	515
Coupled beam flange	200000	0.26	365	495
Coupled beam web	200000	0.26	400	515
Stiffeners	200000	0.26	220	288
Steel plates	200000	0.26	220	288
Loading and transfer beam	200000	0.26	220	288



a) Cyclic loading protocol b) experimental model of Steel plate shear wall [8]

Figure 3: loading protocol and experimental sample

Displacement equal to 1 mm is multiplied by the first buckling mode's node displacement and applied to the model as the initial condition (initial deformation) before analysis. This value is so significant that it creates a diagonal tensile field immediately after the start of the analysis. As shown in chart 4, the hysteresis chart obtained after analysis is in good agreement with the hysteresis chart of the [7]. A comparison of the numerical model and the experimental sample shows that in the model [7], the ultimate strength of 1540 kn and the ultimate strength of the numerical model of this research are 1710 kn. Comparing the results of chart 4, the initial stiffness of the numerical sample is slightly higher than the initial stiffness of the experimental model. Also, the ultimate strength of the two samples is slightly different from each other. Among the factors of this error are the imperfections and residual stresses in the experimental model and the error in the measuring instruments available in the experimental, so it can be concluded that the results of numerical analysis are in good agreement with the experimental results and the modelling process can be used to investigate the other parameters in this study.

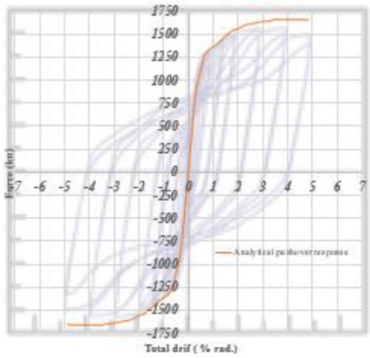


Figure 4: Comparison of experimental cyclic and analytical pushover responses

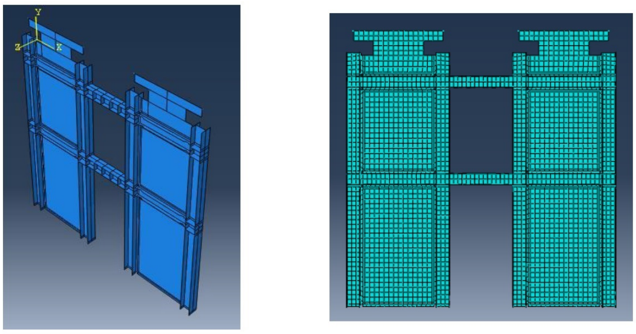
2.2 Details of research models

As mentioned in the previous section, to evaluate the accuracy of the finite element model results, a sample of Coupled Steel plate shear wall of Lee [7] has been modelled and examined in ABAQUS software. It can be stated that the validation model was initially been produced based on the [7]. In the following, the model specifications (without redesign) are changed, and the parameters studied in the numerical models of this paper, including (1) change in the thickness of the steel plate of the shear wall, (2) the use of stiffeners and (3) changes in the thickness of the stiffeners are presented. The specifications of each model are presented in Table 4. The components created for this Coupled Steel plate shear wall in the Part module include a link beam, main columns, main beams, Coupled Steel plate shear wall, and the stiffeners, each of which is modelled according to the model designed by Lee [7]. with a scale of 40% compared to the actual model. Figure (5-a) shows the model in the Assembly module, and Figure (5-b) shows the meshed model before analysis.

Table 4: Characteristics of samples

Model number	Coding	Changes to the base model
Base model	CSPSW-PL 3.5 mm	–
1	CSPSW-PL 5 mm	Using a 5 mm thick plate
2	CSPSW-PL 7 mm	Using a 7 mm thick plate
3	CSPSW-PL 3.5 mm with STIFF 3.5 mm	Using a 3.5 mm thick cross stiffener on the plate
4	CSPSW-PL 3.5 mm with STIFF 5 mm	Using a 5 mm thick cross stiffener on the plate
5	CSPSW-PL 3.5 mm with STIFF 7 mm	Using a 7 mm thick cross stiffener on the plate
6	CSPSW-PL 3.5 mm with STIFF 10 mm	Using a 10 mm thick cross stiffener on the plate

The elasticity properties of the materials are isotropic, and their modulus of elasticity is the same in all respects. The modulus of elasticity intended for materials is equal to 200,000 MPa, and Poisson's coefficient equals 0.26. To introduce the properties of elasticity, a two-line curve (stress-strain) is used. The properties of materials defined in the property module are for shear wall web plate, link beam web and flange, the flange and web of the main beam, and the flange and web of the main column and for all stiffeners. Implicit analysis in ABAQUS is used to obtain the wall response to the lateral displacement applied because it can simulate nonlinear behaviour. For meshing, the four-node shell element (S4R) is used for the web and flange of the main column, coupled beam, and stiffeners. S4R can model nonlinear geometric and nonlinear behaviour of materials and numerical integration in the direction of shell thickness.



a) the model in the Assembly module b) the meshed model

Figure 5: assembled model with meshed model

To apply the load, the target displacement model of 220 mm has been used. The sample modelled in the laboratory is connected to a rigid floor, so in ABAQUS finite element Software, all Transitional and rotational degrees of freedom of the end of the columns and the Steel plate is completely closed so that the experimental conditions can be applied to the modelled sample. At the top of the frame, a beam is modelled as a loading beam in the software. This beam is constrained to the top of the frame, and the displacement of the previously mentioned target is applied to the loading beam. The charts for pushover and energy absorption are drawn, and (1) ultimate strength, (2) energy absorption, and (3) initial stiffness of each of the mentioned models are compared with the base model and each other.

3 Discussion

In this part of the article, comparison charts are presented to examine the factors in Sections 2.2 and Table 4. The von Mises stress contour distribution is used to show the points with the most critical stress concentrations. Pushover versus single load-displacement control to determine the ultimate strength and initial stiffness of the models in the software, and an energy absorption chart for the energy absorbed by each sample is provided. To draw the final force-displacement curve of the coupled steel plate shear wall, first, the force-displacement curve of the steel plate and its surrounding frame is determined, and then the result is obtained by combining these two diagrams. figure 6 shows the force-displacement diagram of the plate. In this diagram, there are two main points called C and D, where C is the point corresponding to the buckling limit and D is the point corresponding to the yield stress of the plate. The critical stress and stiffness for the steel plate are obtained from the equations (3.1) and (3.2).

$$\tau_{cr} = \frac{K\pi^2 E}{12(1-\mu^2)} \cdot \left(\frac{t}{b}\right)^2 \leq \frac{\sigma.}{\sqrt{3}} \tag{3.1}$$

$$K = \begin{cases} 5.35 + 4 \times \left(\frac{b}{d}\right)^2 & for\ \left(\frac{d}{b}\right) < 1 \\ 5.35 \times \left(\frac{b}{d}\right)^2 + 4 & for\ \left(\frac{d}{b}\right) \geq 1 \end{cases} \tag{3.2}$$

t: thickness of steel plate

E: Elastic modulus of steel plate

μ : Poisson's ratio

b: plate width

d: plate height

It is noteworthy that the higher the b/d ratio, in fact, the stiffness of the steel plate increases, and the shear dominates the bend. Using equations (3.3) and (3.4), the amount of force and critical displacement represented by F_{wcr} and U_{wcr} can be obtained.

$$F_{wcr} = \tau_{cr} \cdot t \cdot b \tag{3.3}$$

$$U_{wcr} = \frac{\tau_{cr}}{G} d \tag{3.4}$$

G: shear modulus

According to the above, point C is obtained in the diagram and according to Figure (6-a), point D can be determined.

$$F_{wu} = bt(\tau_{cr} + \frac{C_{m1}}{2}\sigma_{ty} \cdot \sin 2\theta) \tag{3.5}$$

$$U_{we} = \left(\frac{\tau_{cr}}{G} + \frac{2C_{m2}\sigma_{ty}}{E\sin 2\theta}\right). \tag{3.6}$$

In the equations (3.5) and (3.6), θ is the angle of the tensile field with the horizon and σ_{ty} is the tensile stress, which is obtained from the von Mises equations and C_{m1} and C_{m2} are coefficients that depend on items such as the rigidity of the columns and the type of beam connection to the column, where C_{m1} is a number between 0.8 to 1 and C_{m2} is a number between 1 and 1.7. And now if we get the stiffness of the steel plate, we get the force-displacement diagram of the steel plate. Equation (3.7) is used to calculate the curve of the steel plate, and it should be noted that for convenience, the OD line can be drawn instead of the OC and CD lines.

$$K_w = \frac{\left(\tau_{cr} + \frac{C_{m1}}{2}\sigma_{ty} \cdot \sin 2\theta\right)}{\left(\frac{\tau_{cr}}{G} + \frac{2C_{m2}\sigma_{ty}}{E\sin 2\theta}\right)} \cdot \frac{bt}{d}. \tag{3.7}$$

Now the force-displacement diagram of the steel plate is obtained as Figure (6-a). In the next step, the force-displacement diagram for the frame must be drawn, in which there is a main point called E to obtain Bringing it, equations (3.8) and (3.9) should be used.

$$F_{fu} = \frac{4M_{fp}}{d} \tag{3.8}$$

$$U_{fe} = \frac{d * dM_{fp}}{6E_{If}} \tag{3.9}$$

M_{fp} : Plastic bending moment of column

E_{If} : Inertia moment of column

Finally, force-displacement diagram of frame is plotted as Figure (6-b). At last, by using force-displacement diagrams of steel plate and frame, interaction of steel plate and frame is determined. Figure (6-c) shows the force-displacement diagram based on the interaction of the steel plate and the frame.

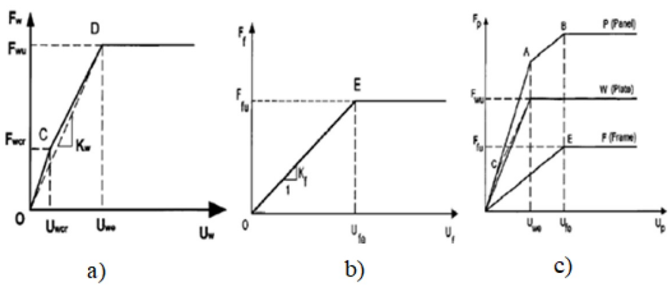
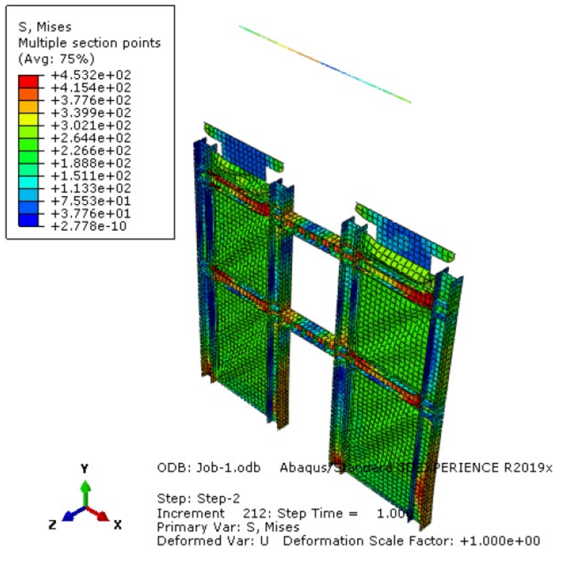


Figure 6: a) force-displacement diagram of steel plate. b) force-displacement diagram of frame. c) force-displacement diagram based on interaction between plate and frame [13]

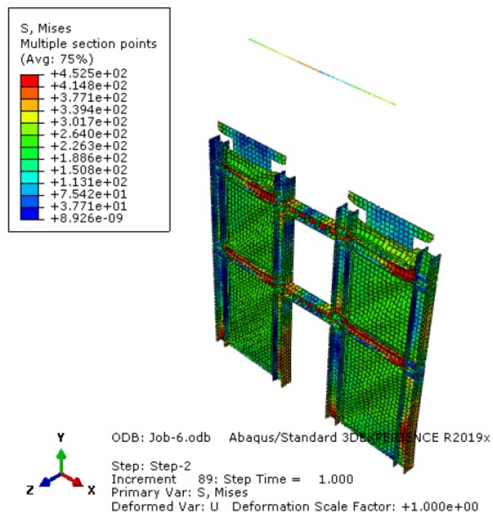
3.1 Effect of increasing the thickness of the Coupled Steel plate shear wall

To investigate the effect of thickness of Coupled Steel plate shear wall, three models of CSPSW-PL 3.5 mm (validation model with a plate thickness of 3.5 mm), CSPSW-PL 5 mm, and CSPSW-PL 7 mm have been considered. Except for the change in the thickness of the Coupled Steel plate shear wall and the loading method (loading by target displacement method), the rest of the model conditions follow the base model [7] entirely. Figure 7 shows the von Mises stress contours for the CSPSW-PL 3.5 mm, CSPSW-PL 5 mm, and CSPSW-PL 7 mm models in megapascals.

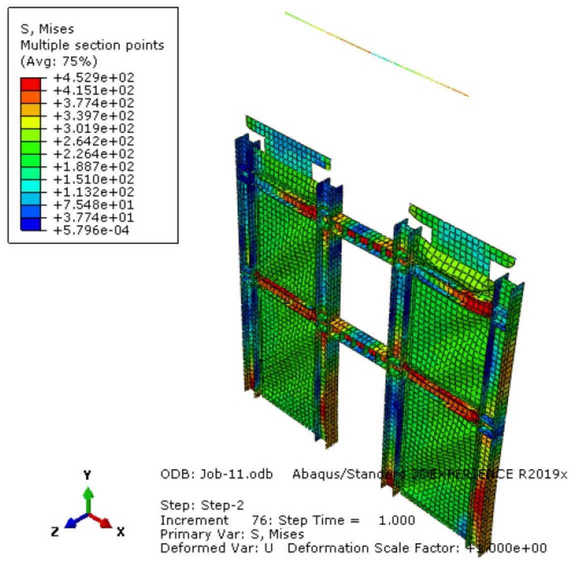
According to Figure 7, it is observed that the maximum stress has occurred in the main beam web and the end of the main columns, and the coupled beam web. In charts (8-a), the pushover graph is presented in the form of a comparison chart, and the chart of the energy absorbed is in the chart (8-b) and compared with each other. The results obtained from the study of pushover and energy absorption are presented in chart 9.



a) von Mises stress (MPa) CSPSW-PL 3.5 mm



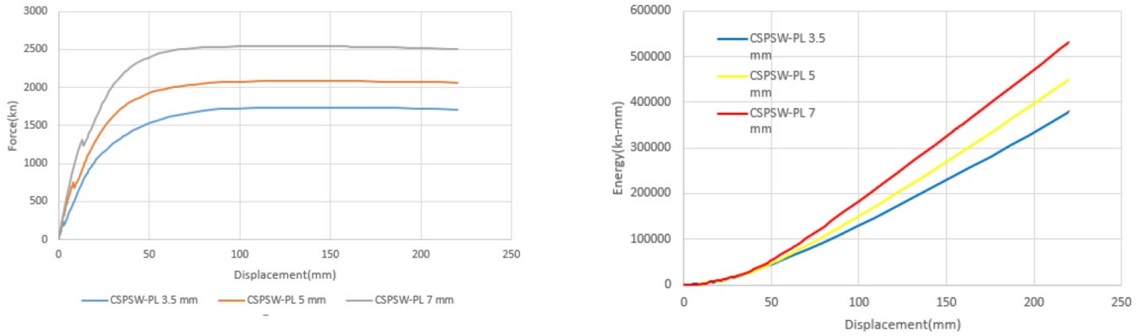
b) von Mises stress (MPa) CSPSW-PL 5 mm



c) von Mises stress (MPa) CSPSW-PL 7 mm

Figure 7: Effects of increasing the thickness of the Coupled steel plate shear wall on von Mises stress

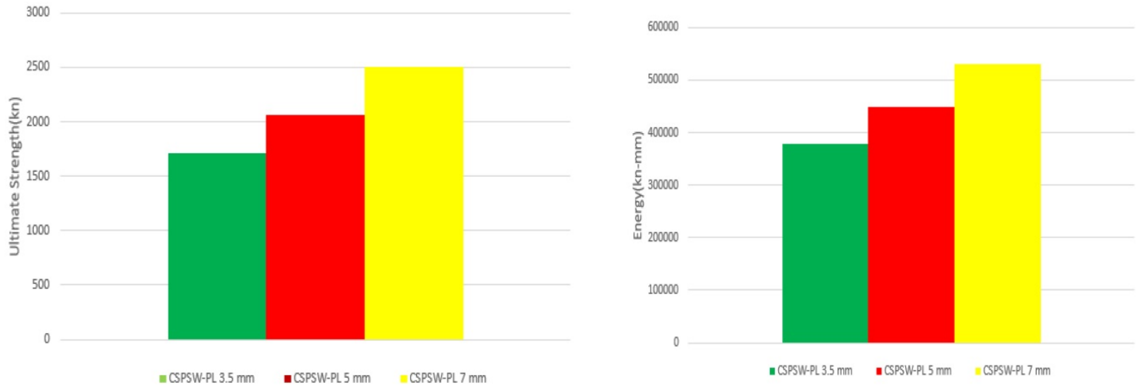
According to the results presented in chart 8 and 9, it can be concluded that with increasing the thickness of the web plate of the coupled Steel plate shear wall from 3.5 mm to 5 mm, the ultimate strength increases by 20% and the ultimate strength increases by 46% with the increase in plate thickness to 7 compared to the base model of CSPSW-PL 3.5 mm. in addition given the force-displacement chart, the initial stiffness of CSPSW-PL 7 mm is more than the CSPSW-PL 5 mm and initial stiffness of the CSPSW-PL 5 mm is more than the base model, which indicates an increase in the initial strength and also the higher chart with a thickness of 7 mm and 5 mm plate indicates an increase



a) pushover curve

b) Energy absorption curve

Figure 8: Effect of increasing the thickness of the Coupled Steel plate shear wall on the pushover and energy absorption curve



a) Comparison chart of the ultimate strength of the samples

b) Comparison chart of the energy absorption of the samples

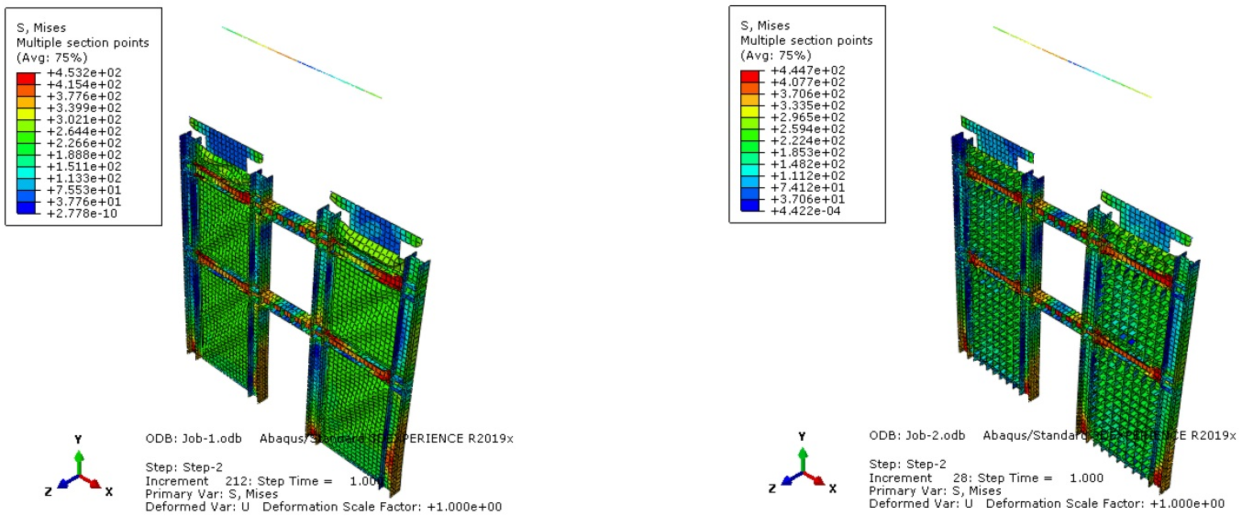
Figure 9: Comparison of the ultimate strength and the energy absorption by the samples

in the ultimate strength. By examining the energy absorption curve in the mentioned models, the energy absorption in the model with 5 mm plate thickness increased 18% compared to the base model, and the energy absorption in the model with a thickness of 7 mm increased by 40% compared to the base model.

3.2 The effect of stiffeners

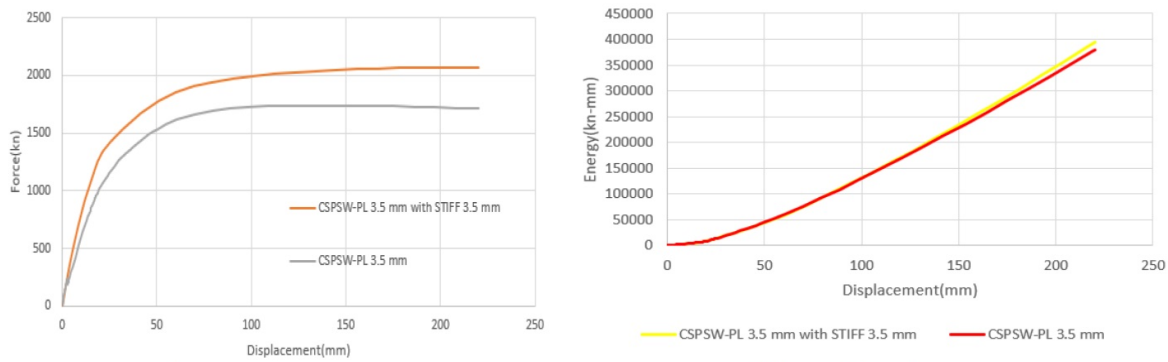
To investigate the effect of stiffeners on the coupled Steel plate shear wall, two models of CSPSW-PL 3.5 mm and CSPSW-PL 3.5 mm with STIFF 3.5 mm have been considered. Except for the use of cross stiffener on the web plate of the coupled Steel plate shear wall and the method of loading (loading by the method of target displacement), the rest of the model conditions are entirely following the base model [8]. The von Mises stress contour is shown in Figure 10 for the CSPSW-PL 3.5 mm and CSPSW-PL 3.5 mm with STIFF 3.5 mm in megapascals. According to Figure 10, in the CSPSW-PL 3.5 mm model, distortions have occurred on the web plate of the Coupled Steel plate shear wall. The stress concentration is created at the bottom of the columns, the web and flange of the main beam, and the Coupled beam, but in the CSPSW-PL 3.5 mm with STIFF 3.5 mm, these distortions and deformations have occurred on the stiffeners and the focus of stress is on the column web and the main beam and the Coupled beam web. Comparison charts are presented, ultimate strength and each model's energy absorption is presented in chart 11. The ultimate strength and energy absorption of each sample are compared in chart 12.

The ultimate strength of the CSPSW-PL 3.5 mm with STIFF 3.5 mm has increased by about 19% compared to the base model. By examining the force-displacement chart, the initial slope of this chart in CSPSW-PL 3.5 mm with STIFF 3.5 mm is greater than the slope of the CSPSW-PL 3.5 mm chart, which indicates an increase in initial stiffness due to the use of cross stiffeners. Also, the higher chart for the CSPSW-PL 3.5 mm with STIFF 3.5 mm indicates an increase in the energy absorption compared to the base model of about 4%.



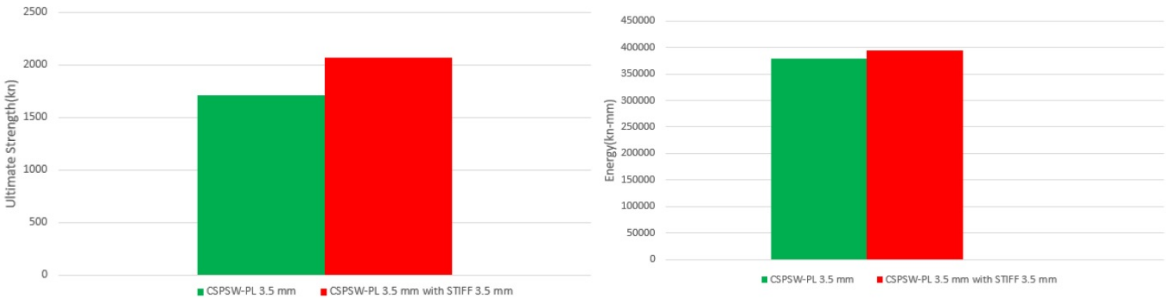
a) von Mises stress (MPa) CSPSW-PL 3.5 mm b) von Mises stress (MPa) CSPSW-PL 3.5 mm with STIFF 3.5

Figure 10: Effect of cross stiffener on the web plate of coupled Steel plate shear wall on von Mises stress



a) pushover curve b) Energy absorption curve

Figure 11: Effect of increasing the use of cross stiffener on the web plate of coupled steel plate shear wall on the pushover and energy absorption curve

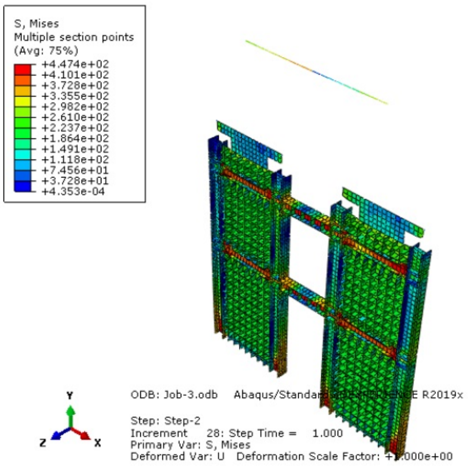


a) Comparison chart of the ultimate strength of the samples b) Comparison chart of the energy absorption of the samples

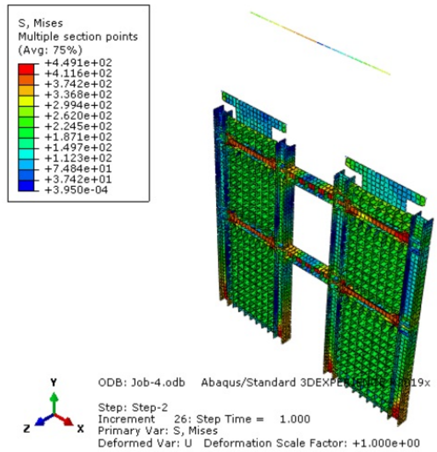
Figure 12: Comparison of ultimate strength and energy absorption of samples

3.3 Effect of increasing the thickness of stiffeners

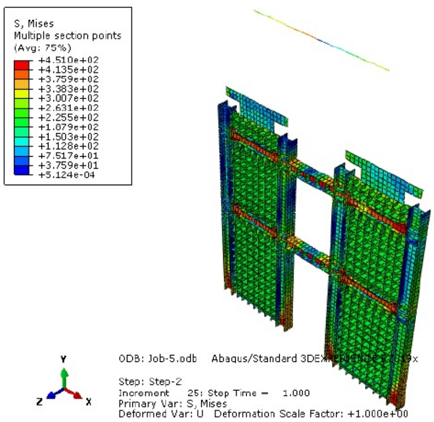
To investigate the effect of the thickness of stiffeners, 3 models of CSPSW-PL 3.5 mm with STIFF 5 mm and CSPSW-PL 3.5 mm with STIFF 7 mm, and CSPSW-PL 3.5 mm with STIFF 10 mm have been considered. Except for the change in the thickness of the stiffeners on the web plate of the coupled Steel plate shear wall and the loading method (loading by target displacement method), the rest of the model conditions are entirely following the base model [7]. Figure 13 shows von mises stress of CSPSW-PL 3.5 mm with STIFF 5 mm and CSPSW-PL 3.5 mm with STIFF 7 mm and PL 3.5 mm with STIFF 10 mm. In the chart (14-a), the ultimate strength of mentioned models is presented and the energy absorption of the models is presented in the chart (14-b) and compared with each other. Each of the pushover and energy absorption charts of models is compared with each other in chart 15.



a) von Mises stress (MPa) CSPSW-PL 3.5 mm with STIFF 5



b) Von Mises stress (MPa) CSPSW-PL 3.5 mm with STIFF 7 mm



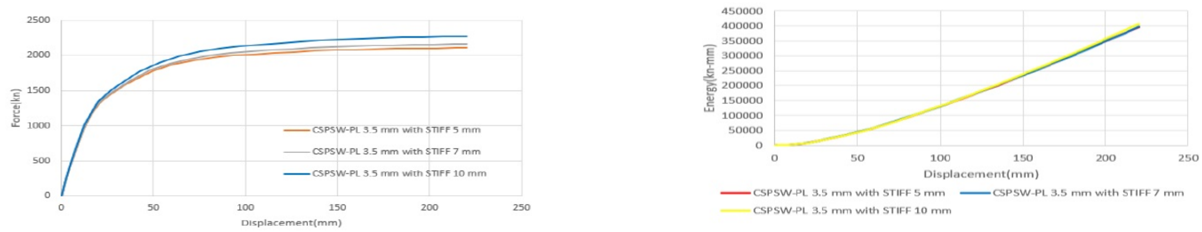
C) Von Mises stress (MPa) CSPSW-PL 3.5 mm with STIFF 10 mm

Figure 13: Effect of increasing the thickness of cross stiffeners on the web plate of the coupled Steel plate shear wall on Von Mises stress

It should be noted that the ultimate strength of the models of CSPSW-PL 3.5 mm with STIFF 5 mm, CSPSW-PL 3.5 mm with STIFF 7, and CSPSW-PL 3.5 mm with STIFF 10 mm increases by 21, 24, and 30% compared to the base model and by examining the force-displacement chart of each model CSPSW-PL 3.5 mm, CSPSW-PL 3.5 mm with STIFF 5 mm with STIFF 7 mm and CSPSW-PL 3.5 mm with STIFF 10 mm, an increase in the slope of these charts is evident, which indicates an increase in initial stiffness. According to the base model, the energy absorption has increased by about 4.4, 7.4, and 6.9%.

4 Conclusion

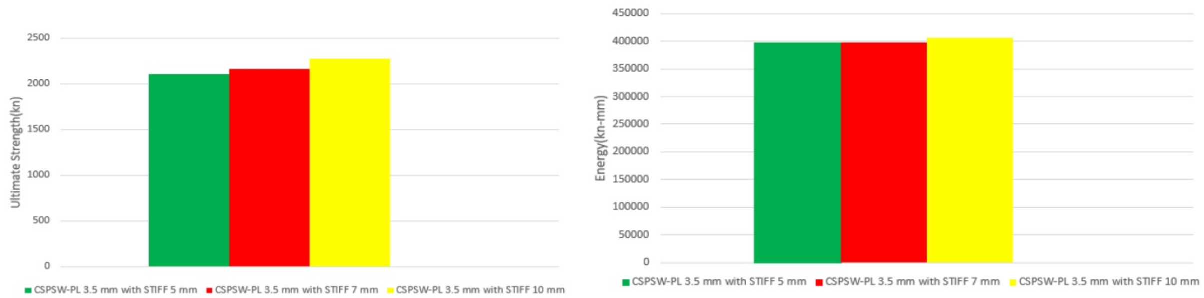
There are rare studies on coupled Steel plate shear wall and the influential factors such as the thickness of the web plate of the coupled Steel plate shear wall, the stiffeners, and an increase in the thickness of stiffeners on the



a) pushover curve

b) Energy absorption curve

Figure 14: Effects of increasing the thickness of cross stiffeners on the web plate of Coupled Steel plate shear wall on the pushover and energy absorption curve



a) comparison chart of the ultimate strength of the samples b) Comparison chart of the energy absorption of the samples

Figure 15: Comparison of the ultimate strength and the energy absorption of the samples

ultimate strength, energy absorption, initial stiffness, and von Mises stress. Due to this reason, further studies are needed. It is necessary to know more about this system. Because of the high cost of fabrication of the sample in the experimental analysis, the use of simulation capability in ABAQUS finite element software is an optimal and appropriate method. The nonlinear behaviour of C-SPSW was studied by changing the mentioned variables. In this study by considering various parameters such as plate thickness, using cross stiffeners and thickness of cross stiffeners, the dynamic behaviour of coupled steel plate shear wall was evaluated. Increasing the thickness of the steel plate, using cross stiffeners and increasing thickness of cross stiffeners caused to the improvement of the dynamic behaviour of coupled steel plate shear wall. These parameters have effects on ultimate strength, initial stiffness and energy absorption and cause to increase in all of them, however, their effects of them on energy absorption are littler than the effects of them on ultimate strength and initial stiffness. According to the assumptions and models of this research, the following results can be presented.

1. Increasing the thickness of the web plate of the coupled Steel plate shear wall from 3.5 mm to 5 and 7 mm increased the initial stiffness, ultimate strength, and energy absorption so that the ultimate strength increased compared to the base model by about 20% and 46% and the energy absorption in the models increased 18% and 40%.
2. The use of cross stiffeners on the web plate of the Coupled Steel plate shear wall with a thickness of 3.5 mm caused an increase in the initial stiffness, the ultimate strength, and the energy absorption in the model by a cross stiffener of a thickness of 3.5 mm. In this sample, the ultimate strength and energy absorption increased by about 19 and 4% compared to the base model.
3. Increasing the thickness of cross stiffeners from 3.5 mm to 5, 7, and 10 mm caused to increase in the initial stiffness, the ultimate strength, the energy absorption in the samples and the ultimate strength in the models compared to the base model increased about 21, 24 and 32%. In addition, the energy absorption also increased by 4.4, 4.7, and 6.9%.

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