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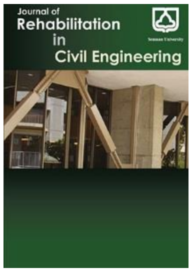

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Effects of the Opening on the Behavior of Composite Steel Plate Shear Wall (CSPSW)

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ABSTRACT

Due to architectural, mechanical and even structural considerations, in some cases there is need to create some openings in the composite steel shear walls. Presence of the openings can considerably affect the wall behavior. Therefore, in this study, the effects of the opening on the behavior of composite steel shear walls are investigated. For this purpose, first an experimental specimen without opening is developed and tested. The outcomes of the experimental study are verified by existing data Then three series of the CSPSW specimens (four specimens in each series) with opening are built and tested. Accuracy and precision of these experimental outcomes is verified by twelve numerical models which are developed using ABAQUS software. Therefore, general behavior of the CSPSWs with opening are investigated according to the attained outcomes from numerical and experimental tests. In addition, some methods are proposed to reduce the negative effects of the opening on the behavior of CSPSW. Then a parametric study is performed to evaluate effects of different parameters namely concrete cover thickness, steel plate thickness, thickness of the strengthening plate installed around the opening and bolt spacing on general behavior of the CSPSW. In addition to study the effects of opening in behavior of CSPSW, in this paper a thorough investigation about the influence of different parameters on drift of the system is performed .Finally, a formula is proposed based on the developed numerical models to compute lateral displacements of the composite shear walls with openings. This formula can be utilized for deriving an intensification factor which can be applied to calculate displacement of the composite shear wall with openings from the responses of a wall without openings.

1. Introduction

Steel plate shear wall (SPSW) is a structural system consisting of a steel frame and an infill steel plate. This structural system resists lateral loads by combination of bending stiffness of the boundary frame elements and the developed tension field in the buckled infill plate. Accordingly, this structural system is designed based on the post-buckling behavior of the steel plate. Extensive past researches on the SPSW

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system demonstrated its satisfactory performance in resisting lateral loads due to severe ground motions or wind loads [1]. In spite of its numerous advantages, SPSW system has its own shortcomings. First of all, like the other steel structures, SPSW requires protection against fire. Moreover, low out of plane stiffness and therefore out of plane buckling is a major problem against the impact loading [2]. In addition, the buckling of infill steel plate has significant negative effect on shear strength and energy dissipation capacity of the overall system [3].
Composite steel plate shear wall (CSPSW) is a relatively novel structural system that is proposed to improve performance of steel plate shear walls by addition of one or two layers of concrete to the infill plate. The concrete covers are connected to the steel plate by means of shear studs or bolts. The role of the concrete cover(s) is to prevent buckling of the infill steel plate. In the case of CSPSWs with only one concrete layer, the concrete cover plays the role of stiffeners in an stiffened steel plate shear wall and hinder early local as well as global buckling of steel plate. In this manner, the shear yielding of the steel plate occurs, which results in higher lateral load bearing capacity. Accordingly, the CSPSW provides greater lateral stiffness and shear strength and also demonstarates more ductile behavior in comparison with the SPSW, while thinner infill plate is needed [4].
Zhao and Astaneh-Asl performed the first study on the CSPSW structural system [3]. Based on the presence of a gap between the concrete cover and the boundary steel elements, they categorized CSPSWs in two groups, namely with and without gap. The CSPSWs with the gap are sometimes termed as innovative composite shear walls. Zhao and Astaneh-Asl found that however both types demonstrate ductile behavior with stable post buckling performance, but less damages under relatively large displacement cycles are reported for the innovative walls. According to the studies of Zhao and Astaneh-Asl, a design guideline were included in the AISC 341-10 [1].
Since inclusion of this system in the AISC-341, various studies are performed in different aspects of the CSSPWs. For example, Rahaei and Hatami investigated effect of bolt spacing on the performance of the system by means of both analytical and experimental approaches [6]. Gou et al found that connecting of the steel plate to the concrete cover using mechanical connectors increases ductility and energy dissipation capacity of the system [7]. Moreover, they showed that despite major role of the infill plate in bearing lateral loads, effect of the boundary steel members is also significant. Shafaei et al. studied effects of opening on the behavior of composite steel plate shear walls and showed that increasing size of opening is accompanied by linear degradation of the elastic stiffness and ultimate capacity of the system [10]. In another study, Arabzadeh et al. showed that inclusion of the opening in the corners of the wall results in further strength reduction [11].
Despite the previous researches, further investigations are required to accurately identify the influential parameters on the performance and seismic design of composite steel plate shear walls. One of the important topics that is neglected is the optimum design of the CSPSW details in the presence of openings. Accordingly, in the present paper, this topic is further researched experimentally and numerically. For this purpose, first a series of CSPSW specimens with and without openings are constructed and tested. The outcomes of the specimen

without opening is compared with those attained previously by Arabzadeh et al. [12]. Moreover, numerical models are developed using ABAQUS finite element package to verify results attained form the tests. To study effects of the opening on the performance of the system, the attained results from the specimens without opening are compared with those including an opening. In addition, various strategies are proposed to reduce negative effect of the opening and effectivity of these strategies is evaluated experimentally. Finally, a parametric study is performed to evaluate effect of different parameters like of concrete cover, thickness of steel infill plate, thickness of the strengthening plate installed around the opening and bolt spacing on the general behavior of the CSPSW system.

2. Experimental Model Verification

To verify the developed experimental model, a specimen without opening is casted. Hereafter, this model is referred as the control specimen. This accuracy of the attained results for the control specimen is ascertained by comparing the derived experimental results with those reported by Arabzadeh et al. for a similar test [10]. The properties of steel and concrete material are identical with the Arabzadeh et al. [10] model. These characteristics are reported in Tables (1) and (2). The specimen tested by Arabzadeh et al. and the test setup are depicted in Fig. 1, and Fig. 2 demonstrate the developed control specimen in this study.

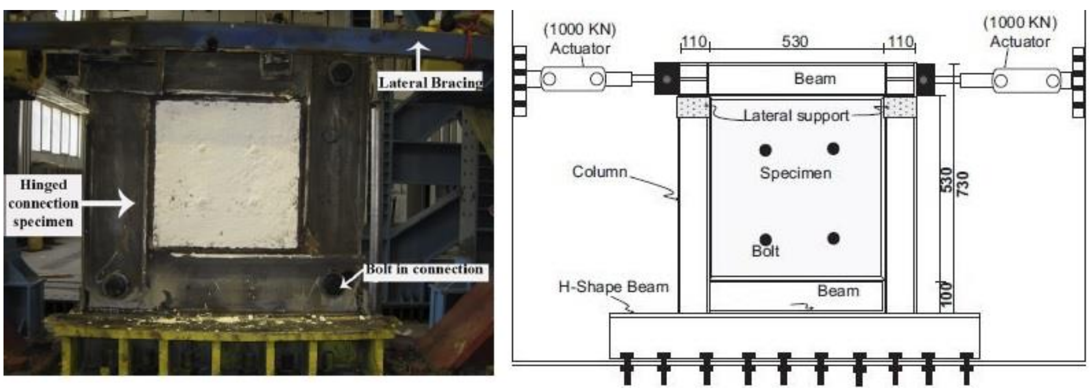

Fig. 1. Arabzadeh et al. specimen before loading and the test setup [3].

Table 1. Properties and dimensions of the steel members in experimental specimens.

Component	Dimensions (mm)	Yield stress (MPa)	Ultimate strength (MPa)	Modulus of elasticity (MPa)
Columns	2IPE100+2PL100×5	361	510	203000
Beams	2IPE100	361	510	203000
Steel plate shear wall	t=2 mm	268	415	203000
Fish plate	PL 40×5	297	406	203000
Bolts	Ø20	336	492	203000
Rebar	Ø3	361	510	203000

The obtained load-displacement hysteresis curves are demonstrated in Fig. 3. It is evident that the control specimen is slightly stiffer than the Arabzadeh et al. specimen [10].

This can be attributed to experimental errors and perhaps this difference can be reduced by casting and testing more than one specimen. Nevertheless, the experimental outcomes are in good agreement with each other and this finding verifies accuracy of the control specimen.

Fig. 2. Control specimen.

Table 2. Properties and dimensions of the standard 28-day concrete components in experimental specimens.

Component	Dimensions (mm)	Compressive strength of the cylindrical specimen (MPa)	Compressive strength of the cylindrical specimen (MPa)	Modulus of elasticity (MPa)
Concrete cover	t=30 mm	43	47	30819

3. Evaluation of Opening Effect

Now that the developed numerical model is verified, four specimens including a rectangular opening with the dimensions of 2×1.5 m (which is for example dimensions of a door) are modeled to investigate effects of opening on the performance of CSPSW system. In order to provide an opportunity to compare the attained results with those derive by Arabzadeh et al. [10] for the walls without opening, similar geometrical dimensions and material properties are assumed for the four developed models. In the first model of the CSPSWs without opening, no strengthening method is applied to retrofit the system, while in the other three specimens, three different strengthening strategies are undertaken. In one of the models, 45-degree rebar are placed at the corners of the opening to prevent diagonal cracking and improve shear strength of the concrete cover. To compensate the stiffness loss of the system due to presence of the opening, in the third model additional strengthening steel plates are installed around the opening boundary. Finally, in the third retrofitted model, the previously mentioned techniques are applied simultaneously. Therefore, the following convention is used for naming the developed models: The model containing opening without special strengthening method is called CSWO1 hereafter. The model in which 45-degree rebar are utilized is called CSWO2. The third model in which peripheral steel plates are installed around the opening boundary is termed CSWO3, and finally CSWO4 is the fourth model in which both 45-degree rebar and strengthening steel plates are used.

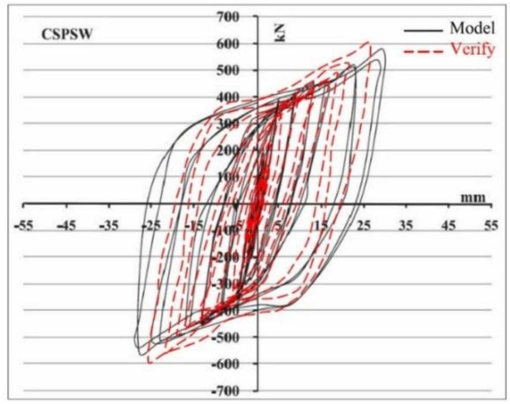

Fig. 3. Load-displacement hysteresis curves of reference specimen and Arabzadeh et al. specimen.

3.1 Loading

The displacement control ATC24 loading protocol is used to load the developed models [6]. The lateral displacement of the story is the control parameter in this approach.

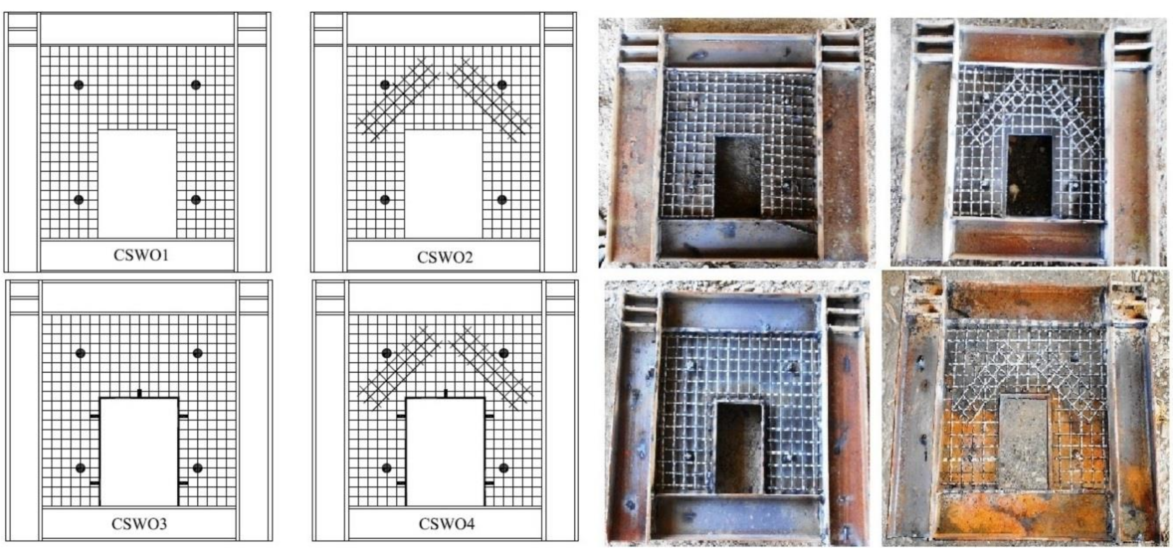

Fig. 4. The developed models for CSPSWs with opening.

Table 3. Properties of the first series of experimental specimens [10].

Specimens	CS1-1	CS1-2	CS1-3
Columns (mm)	2IPE100+2Pl100×5	2IPE100+2Pl100×5	2IPE100+2Pl100×5
Foundation beam(mm)	2IPE100	2IPE100	2IPE100
Roof beam(mm)	2IPE100	2IPE100	2IPE100
Steel wall plate thickness(mm)	2	2	2
Fish plate(mm)	40×5	40×5	40×5
Number of bolts	4	4	4
Bolt diameter(mm)	6	6	6
Type of bolt	10.9	10.9	10.9
Rebar diameter(mm)	3	3	3
Reinforcement ratio	1%	1%	1%(45,135) deg
Concrete thickness(mm)	3	3(both side)	3
Free space around concrete (gap) (mm)	11.25	11.25	11.25

Fig. 5 depicts the utilized loading history. In this loading protocol, Δ is the yield lateral story displacement, that is derived approximately using the experimental models.

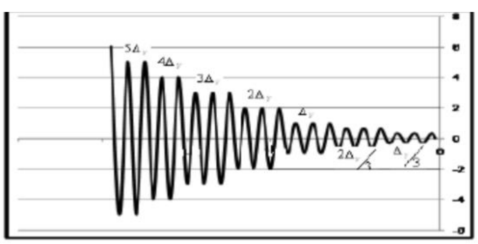

Fig. 5. Loading history.

3.2 First Series of Experimental Specimens

First, three one-story single-bay composite steel plate shear walls with the scale of 1:4 were casted. Characteristics of the first specimen which is named CS1-1 are presented in Table 3. In this specimen, only one side of the infill steel plate is covered with concrete panel. In the second specimen, CS1-2, the concrete panel is utilized for both sides of the steel plate and in the third specimen, CS1-3, the inclined rebar arrangement is used in the RC panels. Each of these specimens are modeled four times according to the four different models defined previously and the opening is also included in these developed specimens.

The models were loaded according to the ATC24 loading protocol. The attained hysteresis curves are demonstrated in Figs. 6 to 8. As it was expected, inclusion of opening increases the displacement and reduces the energy absorption capacity of the CSPSWs. When no strengthening method is applied, presence of the opening results in about 30% and 35% increases in lateral displacements and decreases in energy absorption capacity, respectively. On the condition that 45° rebar are installed at the corners of the opening, performance of the CSPSW with opening is enhanced by about 3%. This enhancement is because of the rebar that prevents diagonal cracking in concrete. In contrast with the slight improvement achieved by using 45-degree rebar, utilization of the strengthening steel frame around the opening position, improves the seismic behavior considerably.

Finally, when combination of the two previous strengthening methods is used, the lateral displacement of the system only absorption capacity reduces about 20%. increases about 11% and the energy.

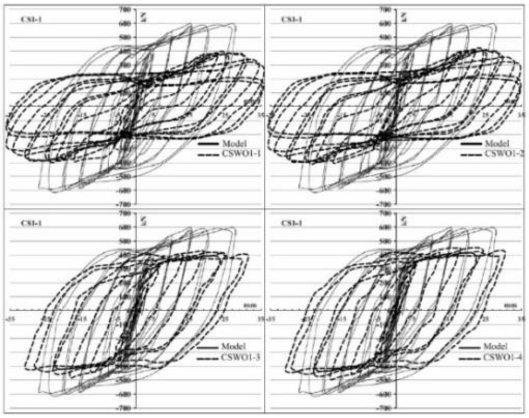

Fig. 6. The load-displacement curve of experimental specimen CS1-1 without opening vs. the four experimental specimens containing opening.

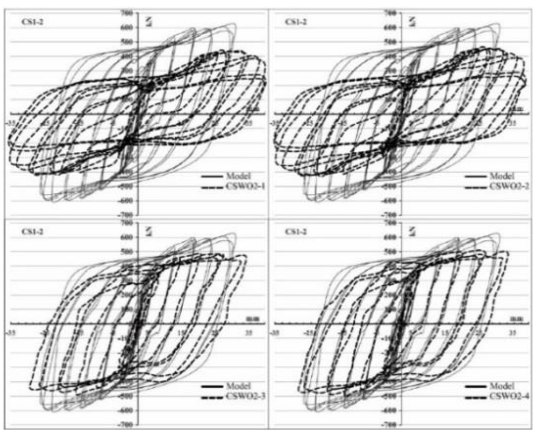

Fig. 7. The load-displacement curve of experimental specimen CS1-2 without opening vs. the four experimental specimens containing opening.

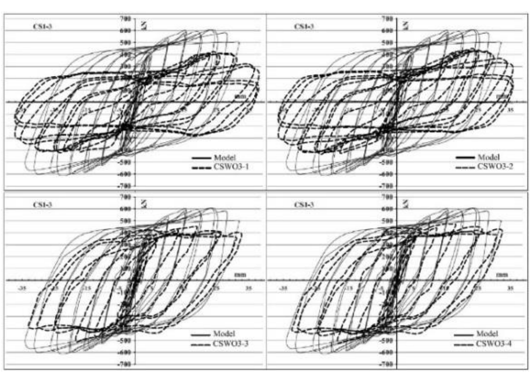

Fig. 8. The load-displacement curve of experimental specimen CS1-3 without opening vs. the four experimental developed specimens containing opening.

4. Second Series of Experimental Specimens

4.1 Model Verification

To verify accuracy of the attained experimental results, they are compared with the outcomes of the test conducted on CSWO3. In order to mitigate the possible errors and achieving more accurate responses, only the steel plate shear wall is modelled and analysed in the first step. When the developed model is confirmed by evaluating its outcomes, the composite shear wall specimens are modelled numerically by simply adding the reinforced concrete panels to the steel shear wall model.

Eight-node three-dimensional Solid elements (C3D8R) are used to boundary elements and the concrete cover. The Solid elements are used for meshing the concrete cover to facilitate simulating the contact between concrete panel and the boundary elements. Shell elements of the type S4R are utilized for the infill steel plate. Finally, the shear connectors are modelled by using Beam elements, B31. Note that the fish plates which are usually used to connect the steel plate to the boundary element are not models in this study. Previous studies showed that using this assumption in developing numerical models does not vary behaviour of the models considerably [11].

All the degrees of freedom at the bottom of the lower beam are fixed in all directions.

High strength concrete is used mainly in order to minimizes cracking of the concrete cover. The volume ratio of rebar is about 0.01 percent of the concrete volume and they are placed in a single layer. The “Rebar Layer” is used to model the rebar in the software. In addition, high strength bolts are used in order to remain elastic and due not undergo any plastic deformations. The nonlinear static or

Pushover is used. In this approach, increasing lateral displacement is applied to the specimen at the upper beam level.

The behavior of the developed numerical model for specimen containing opening is compared with the corresponding experimental observations in order to verify accuracy of the ABAQUS model. Fig. 9 demonstrates this specimen (CSWO3) and the utilized mesh of finite elements for this specimen in the ABAQUS model.

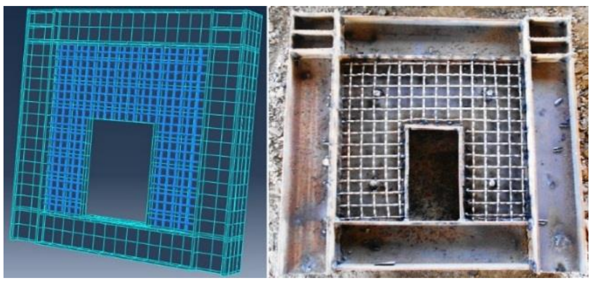

Fig. 9. the developed ABAQUS model and the experimental specimen before loading (cswo3).

The derived experimental and numerical load-displacement hysteresis curves from are demonstrated in Fig. 10. It is evident that the numerical model is slightly stiffer than the experimental specimen performs a bit more flexible than the developed numerical model. One probable justification for this behavior can be the utilized meshes in the numerical analysis. In spite of the mentioned difference, the numerical results are in good agreement with the experimental outcomes. These observations verify precision of the developed model.

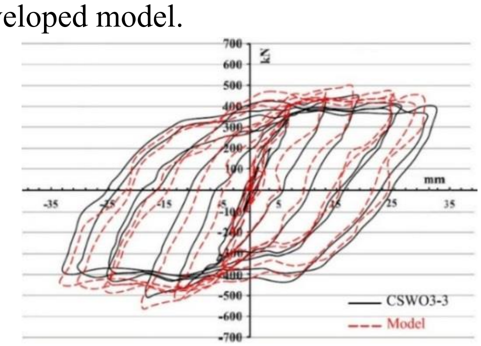

Fig. 10. Experimental vs. numerical load-displacement hysteresis curves.

4.2 Second Series of the Specimens

The Second series of the specimens are there series one bay-three story CSPSWs (four specimens in each series as in fig 4) with scale of 3:1. The variable parameters in the specimens were infill plate thickness, dimensions of beams and columns and width to span ratios. The first specimen (CS3-1) is a CSPSW with rigid beam to column connection. The characteristics of the utilized steel and concrete are presented in Tables (1) and (2). Thickness of the steel plate in this specimen is equal to 30 mm and the gap between RC panels and the boundary elements are also 30 mm. The second specimen (CS3-2) is similar to the first one with this difference that there is no gap between RC panels and the frame members. Existance of a 30 to 80 mm gap between the steel frame and the concrete panel has considerable effect on the performance of the system and leads to increase ductility and reduction of the damages to the concrete cover, while slight reduction in the total strength of the wall is neglibile in comparison with the mentioned improvements.

In the CSPSWs without the gap, increasing thickness of the concrete cover results in increase in the wall stiffness, but in the system containing gap, no remarkable change in stiffness occurs, because the concrete panel and frame have no contact to each other.The third experimental specimen is same as the first one, but the steel plate thickness is changed to 3 mm. the bolts utilized in this specimen also different with the other two specimens. Summary of the specimens' properties are listed in Table 5.

Again, a rectangular opening is introduced in these specimens ad they were modeled by considering the four different models proposed to reduce the negative effects of the opening. The models were loaded according to the mentioned loading history. One of the developed models for these series are depicted in Fig. 11 shows the deformed CSPSWs after analysis. The computed load-displacement curves for the models with opening in comparison to the experimental outcomes derived for the specimens without opening are presented in Figs. 12 to 14

Again, it is evident that existence the opening results in lower wall stiffness and consequently, the lateral displacements of the system will be increased and the energy absorption capacity of the system would be reduced. On the condition that no strengthening technique is used, the lateral displacements of the wall increases 45% about by inclusion of opening, and the energy absorption capacity decreases about 50%. Same as the previous outcomes for the one story system, utilizing 45° rebar at the corners of the opening, improves behavior of the system about 2%. On the other hand, application the strengthening steel frame in the opening position, results in only 25% increase in the lateral displacement of the system and the energy absorption only reduces about 20%. It is not surprising that the most efficient strengthening method is combination of the two mentioned schemes. This approach is utilized in the fourth model.

Table 5. Properties of the second series of experimental specimens [10].

Specimens	CS3-1	CS3-2	CS3-3
Columns (mm)	2IPE160	2IPE160	2IPE160
Foundation beam(mm)	L=840 ,IPE140	L=840 ,IPE140	L=840 ,IPE140
First and second story beam(mm)	IPE140+2PL100×8	IPE140+2PL100×8	IPE140+2PL100×8
Roof beam(mm)	2IPE140	2IPE140	2IPE140
Steel wall plate thickness(mm)	2	2	3
Fish plate(mm)	60×5	60×5	60×5
Number of bolts	27	27	27
Bolt diameter(mm)	10	10	12.5
Type of bolt	8.8	8.8	8.8
Rebar diameter(mm)	8	8	8
Reinforcement ratio	1%	1%	1%
Concrete thickness(mm)	40	40	40
Free space around concrete (gap) (mm)	30	-	30

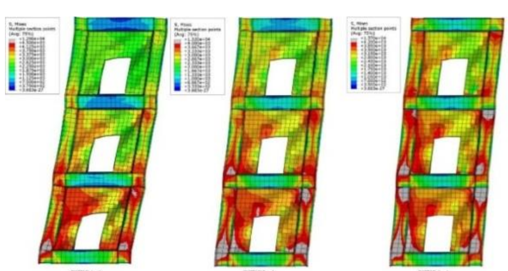

Fig. 11. Deformed shape of the second series of specimens after numerical analysis.

5. Parametric Study

In This section, a parametric study is performed to investigate effect of four different model variables on the drift ratio of the system. These variable parameters are bolt distances (d), thickness of the steel plate (t_w), thickness of the strengthening plate (t_o) and concrete panel thickness (t_c). Fig. 15 demonstrate these parameters.

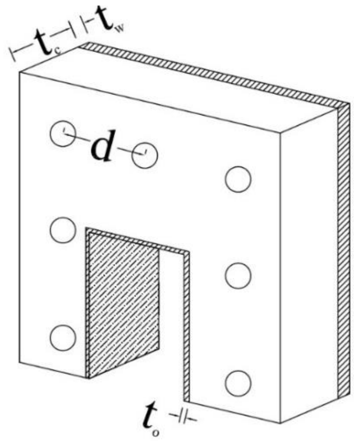

Fig. 12. The considered variable parameters

To evaluate effects of these parameters, different models with different values of this parametersare developed. The outcomes obtained from analysis are presented in the following sub-sections.

5.1 Influence of the Bolt Distance/Concrete Thickness on Drift

Fig. 16 shows change of the lateral drift ratio with respect to the variation of the bolt distances/concrete thickness. The outcomes are normalized with respect to the case of bolt distances equal to 10 cm and concrete panel thickness equal to 10 cm. it is evident that increasing bolt distances or concrete panel thickness does not have considerable effects on drift ratio.

5.2. Effects of the Steel Plate Thickness on Drift

The variation of story drift with respect to the thickness of infill plate for three three-story specimens are demonstrated in Fig. 17. In this diagram, the drifts are normalized by the drift of a specimens with 2 mm steel plate. It can be seen that increasing the infill plate thickness beyond 6 mm has no considerable effect on drift reduction and therefore would not be economical.

5.3. Effects of the Strengthening Steel Plate Thickness on Drift

Finally, the trend of variation in the drift ratio with respect to the thickness of the strengthening steel plate installed around the opening are depicted in Figure 18. It should be noted that in this diagram, the values are normalized with respect to the values of the 2 mm thick strengthening steel plate. According to the trend of variations, it can be concluded that the 5 mm thick plate is the optimum option for strengthening of the model after inclusion of opening.

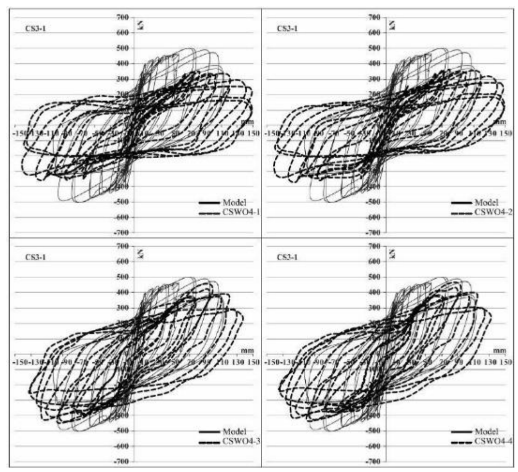

Fig. 13. The experimental load-displacement curves of specimen CS3-1 without opening [10] vs. the four experimental models with opening.

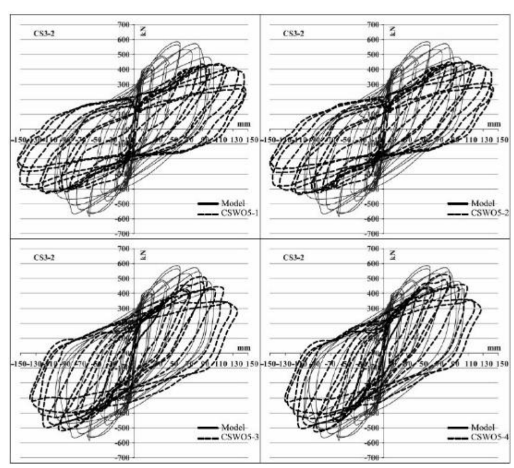

Fig. 14. The experimental load-displacement curves of specimen CS3-2 without opening [10] vs. the four experimental models with opening.

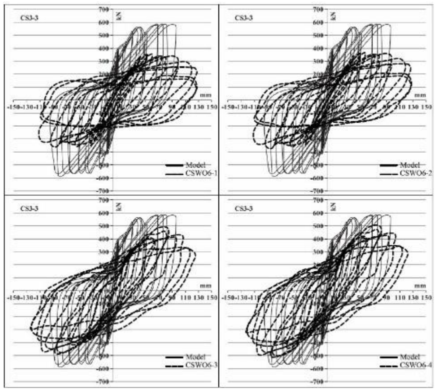

Fig. 15. The experimental load-displacement curves of specimen CS3-3 without opening [10] vs. the four experimental models with opening

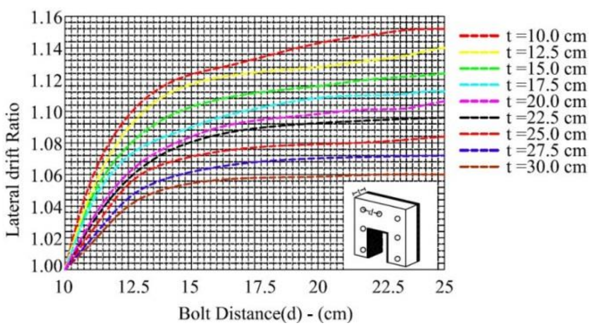

Fig. 16. Effect of bolt distances and concrete panel thickness on drift ratio.

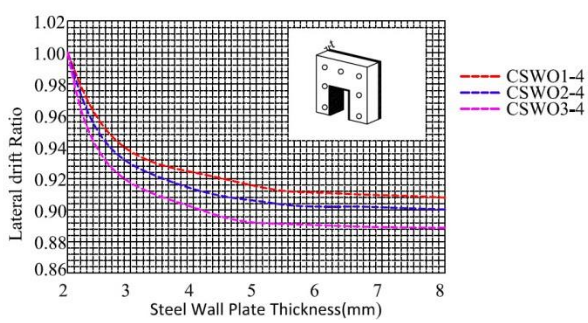

Fig. 17. Effect of thickness of infill steel plate on drift ratio.

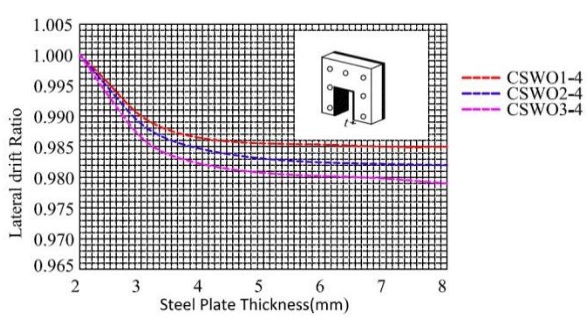

Fig. 18. Effect of thickness of strenghtening steel plate on drift ratio.

6. Proposition of a Predictive Relation for Lateral Displacement of the CSPSWs Containing an Opening

To propose an empirical model for prediction of the lateral displacements of composite shear walls with openings, the first step is to consider the probable effective parameters and assuming a predetermined range of variations for them as follows: wall and opening dimensions (α, β=0.3~0.36, λ=0.6~0.5 L,H=700~750mm), concrete and steel properties(E_c=245872.12~252909.61 kg/cm^2, E_s=1.9~2.1E06 kg/cm^2,f_c=240~260 kg/cm^2 , f_y=2400 kg/cm^2) dimensions and characteristics of the beams (IPE14~IPE16) and columns (2IPE14~2IPE16), concrete thickness (tc=100mm) and wall plate (tp=6mm) (Fig. 23). I

In the next step, 1000 numerical models with different model properties are developed using ABAQUS software, by varying effective parameters in a wide range of practical values.

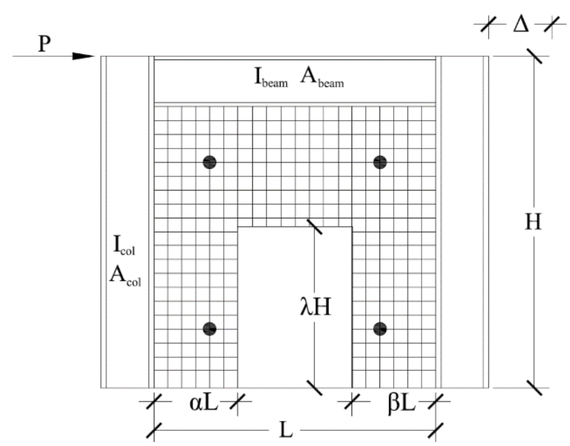

Fig. 19. The variable dimensions

The attained results of the model parameters are used as the input data for proposing predictive empirical relationship and its numerical evaluation.

Table 6. Possible models for the empirical relationship.

1	$\Delta=\sqrt{(r\frac{\lambda^{a}f_c{}^{b}P^{c}A_{col}{}^{d}\,A_{beam}{}^{e}}{\alpha^{f}\beta^{g}H^{h}L^{i}t_{plate}{}^{j}t_{concrete}{}^{k}I_{col}{}^{l}\,I_{beam}{}^{m}E_c{}^{n}E_s{}^{o}})}$
2	$\Delta=log(r\frac{\lambda^{a}f_c{}^{b}P^{c}A_{col}{}^{d}\,A_{beam}{}^{e}I_{col}{}^{l}\,I_{beam}{}^{m}}{\alpha^{f}\beta^{g}H^{h}L^{i}t_{plate}{}^{j}t_{concrete}{}^{k}E_c{}^{n}E_s{}^{o}})$
3	$\Delta=\sqrt{log(\frac{\lambda^{a}f_c{}^{b}P^{c}A_{col}{}^{d}\,A_{beam}{}^{e}}{\alpha^{f}\beta^{g}H^{h}L^{i}t_{plate}{}^{j}t_{concrete}{}^{k}I_{col}{}^{l}\,I_{beam}{}^{m}E_c{}^{n}E_s{}^{o}})}$
4	$\Delta=r\frac{\lambda^{a}f_c{}^{b}P^{c}A_{col}{}^{d}\,A_{beam}{}^{e}}{\alpha^{f}\beta^{g}H^{h}L^{i}t_{plate}{}^{j}t_{concrete}{}^{k}I_{col}{}^{l}\,I_{beam}{}^{m}E_c{}^{n}E_s{}^{o}})$

The nonlinear regression is performed on the proposed general models using 750 selected data points, and the unknown coefficients and powers are computed such that to minimize average error of the models. The derived values are reported in Table (7).

Table 7. Calculated coefficients and powers for the suggested models.

Model	1	2	3	4
a	1.19704	0.53006	0.52094	1.01155
b	1.22098	0.07745	0.01500	0.24579
c	0.09608	0.58854	0.67690	1.00494
d	19.41075	0.28660	3.97914	32.33260
e	0.87293	0.04604	11.36370	6.14901
f	1.59729	0.27779	0.27448	0.55549
g	1.11954	0.29753	0.29482	0.59522
h	1.98918	0.27952	0.18510	0.63964
i	1.27895	0.66398	0.66462	1.31296
j	2.64557	0.10492	0.10080	0.21169
k	0.43159	0.17791	0.15568	0.37944
l	0.78339	0.30786	0.32472	0.55292
m	1.07729	0.38251	0.18997	1.13204
n	1.99865	0.01077	1.71611	13.38310
o	45.98293	0.01141	5.34137	2.90370
r	1.70155	8.40926	0.00000	1.30565

Now the remaining data, including 250 sets of numerical simulations, are utilized in order to calculate average error of the suggested models. In the present study, two different error measures namely Mean Absolute Relative Error and Square Root of Sum of Square errors are used for this purpose. The Mean Absolute Relative Error (MARE) is derived by taking advantage of the following equations are used:

$$MARE = mean(\frac{|\Delta_{Relation}-\Delta_{Numerical}|}{\Delta_{Numerical}}) \qquad (1)$$

In this equation, $\Delta_{Numerical}$ and $\Delta_{Relation}$ are the predicted displacements by the proposed relations and the outcomes of the developed numerical model, respectively.

The next error measure is the Square Root of Sum of Square errors (SRSS). This measure is calculated using the subsequent equation:

$$SRSS\ Error = \sqrt{\frac{\sum_{i=1}^{n}(\Delta_{Relation}-\Delta_{Numerical})^2}{n}}) \qquad (2)$$

where, n is the number of experimental test results. The calculated error criteria for assumed models are reported in Table (8).

Table 8. The average errors of the proposed models.

model	SRSS error	MARE error
1	4.57	0.28
2	1.83	0.43
3	1.67	0.28
4	1.58	0.16

Based on the calculated error measures, which are reported in table (8), Model No. 4 is the most accurate with the average SRSS error about 1.5%. Therefore, this model which has the following form, is suggested for calculating lateral displacement of a CSPSW including an opening.

$$\Delta=r\frac{\lambda^{a}f_c{}^{b}P^{c}A_{col}{}^{d}\,A_{beam}{}^{e}}{\alpha^{f}\beta^{g}H^{h}L^{i}t_{plate}{}^{j}t_{concrete}{}^{k}I_{col}{}^{l}\,I_{beam}{}^{m}E_c{}^{n}\ \ E_s{}^{o}}$$

7. Conclusion

This study is performed mainly in order to investigate effect of openings on the behavior of CSPSW system. According to the attained results and observations, the following conclusions can be made:

1. Undoubtedly, incorporation of an opening in CSPSW reduces stiffness and energy dissipation capacity of the system. Consequently, the displacements will also increase. The degree of these variations depends on the opted remedial approaches to decrease the negative influences of openings on the performance of the system.

2. utilizing thicker infill and strengthening plate up to 6 and 5 mm thickness, respectively, results in drift reduction. Beyond the mentioned values, further increase in the thicknesses has no considerable effect on drift reduction of CSPSW system.

3. In the cases that no remedial provision is undertaken, introduction of the opening increases lateral displacements about 45%, while installing a metal strengthening frame in the location of the opening, increases the lateral displacement of the system only up to 25%.

4. Addition of strengthening rebar in 45-degree direction at the corners of the opening to avoid diagonal cracking can reduce the negative effects of openings to some extents.

5. Application of strengthening plates around the opening is more operative and prevent some of the stiffness loss. However, using 45-degree rebar, when the strengthening plates are also installed, would not provide considerable improvement, because of this fact that the steel plate prevents cracking of the concrete cover, by itself.

6. On the condition that the RC panel rebar are placed in 45 degree, using additional 45 degree rebar is not effective.

7. In high concrete panel thicknesses, increase in bolt distance has almost no influence on the drift.

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