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An Analytical and Numerical Study on Effect of Thickness and Concrete Type of Panels on Behavior of Composite Steel Plate Shear Walls

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ABSTRACT: The composite steel plate shear wall (CSPSW) is an innovative lateral load-resisting system that is comprised of reinforced concrete (RC) panels attached to one or both sides of the system using shear connectors. Accordingly, in the CSPSW, the RC panels prevent buckling of the steel plate, and thus, the shear capacity of the plate improves by the shear yielding limit of the plate instead of tension in the direction of the diagonal tension field. Subsequently, this study is aimed to analytically and numerically investigate the effect of thickness and concrete type of panels on the behavior of the CSPSW. To this end, 27 numerical models of CSPSWs with varying thickness of steel plate and concrete panels as well as width-to-height (W/H) ratios of 0.75, 1 and 1.5 have been built using ABAQUS software and then, analyzed through the pushover analysis method. The results indicate that in all W/H ratios, the energy absorption of the models with a plate thickness of 6mm surpasses the others. Importantly, it was found that the response modification factor of the CSPSW is estimated to be 13.5. Lastly, a semi-empirical relationship was proposed to calculate the thickness of the RC panel based on that of the steel plate so that plate buckling could be prevented.

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1- Introduction

Passive energy dissipation systems have always been one of the most attractive and practical options for reducing the risks of natural disasters. In designing such systems, the general idea is that the energy-consuming device or member surrenders to incoming loads earlier than other load-bearing members, thus activating the energy dissipation mechanism and protecting the structure from serious damage [1-3]. Among energy dissipation systems, steel shear wall is mentioned as one of the economically viable options that has a high ability to absorb energy and provide resistance to lateral loads [4-10]. In the initial designs for this wall, high-thickness sheets or high hardeners are used for the steel sheet in order to prevent buckling outside the sheet plate before shear yield [11].

2- Methodology

Table 1 presents the dimensions of sheet and concrete used as well as the length to height ratio of 27 models of composite steel shear walls. In this table, b is the width of the frame, b/d is the ratio of width to height, t_0 is the thickness of the sheet and tc is the thickness of the concrete cover on the sheet.

It should be noted that the height of all models is 530 mm, which is equal to the laboratory model.

According to Figure 1, it is inserted 3 times to the end of the models and the bottom of the model is modeled. Bolt element with a diameter of 20 mm has been used for connection between the steel sheet and concrete cover. The number of studs is considered for models with a ratio of 0.75 and 1 equal to 4 and for models with a ratio of 1.5 to 8.

Three-dimensional continuous element (S4R) is used to model the steel sheet. This element has the ability to study the behaviors of two thick and thin shells. Three-dimensional elements (C3D8R) are used for concrete coating due to the desire to actually see cracks and deformations, in which longitudinal and transverse reinforcements are defined separately in one layer.

The S4R element has six degrees (three transitions and three rotations) of freedom, while the C3D8R element has three degrees of freedom (three degrees of transition). Therefore, a contact element was used to match the middle layer of the steel sheet and the concrete wall. Three-dimensional beam element has been used to model the cutters (bolts). In the beam element, the specifications of the cutting section can be entered into the software.

Three-dimensional elements have been used to model the boundary elements in the above system. These elements are able to estimate stresses and deformations compared to three-dimensional beam elements more accurately. It is also possible to observe local deformations more favorably in this type of element than one-dimensional elements. The beams were connected to the columns by Merge and the steel sheet was tied to the beams and columns in knots.

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Table 1. Model specifications

no. model	b (mm)	b/d	t_p (mm)	t_c (mm)
1	397.5	0.75	2	20
2	397.5	0.75	4	20
3	397.5	0.75	6	20
4	397.5	0.75	2	30
5	397.5	0.75	4	30
6	397.5	0.75	6	30
7	397.5	0.75	2	50
8	397.5	0.75	4	50
9	397.5	0.75	6	50
10	530	1	2	20
11	530	1	4	20
12	530	1	6	20
13	530	1	2	30
14	530	1	4	30
15	530	1	6	30
16	530	1	2	50
17	530	1	4	50
18	530	1	6	50
19	795	1.5	2	20
20	795	1.5	4	20
21	795	1.5	6	20
22	795	1.5	2	30
23	795	1.5	4	30
24	795	1.5	6	30
25	795	1.5	2	50
26	795	1.5	4	50
27	795	1.5	6	50

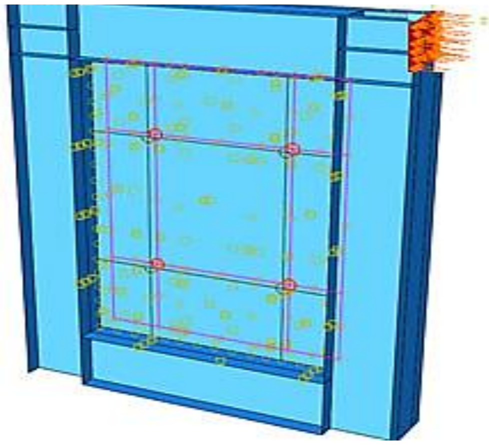

Fig. 1. Boundary conditions of model floor trapping and loading method

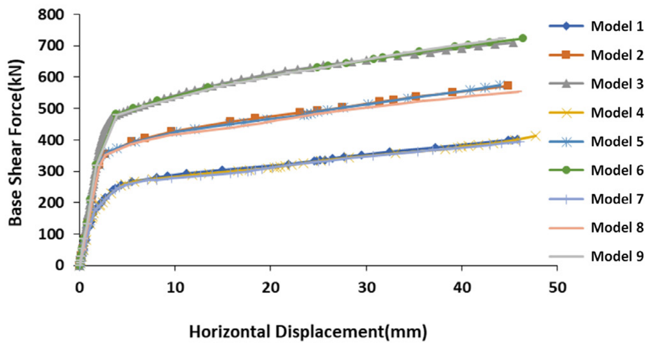

Fig. 2. Base cut-displacement diagram of 9 models of the first group (b / d = 0.75)

3- Results and Discussion

Figure 2 shows the base-shear displacement diagram of the 9 models of the first group (b/d = 0.75). As can be seen, the energy absorption in models 3, 6 and 9 (with a sheet thickness of 6 mm) is higher than other models. Also, by keeping the thickness of the sheet constant and changing the thickness of the concrete, there is no noticeable change in the incremental load diagram. In fact, it can be concluded that changing the thickness of concrete will not affect the bearing capacity of the structural model. As can be seen, due to the fact that the concrete cover is far from the members of the beam and column and only prevents the buckling of the sheet, so it has no effect on the bearing capacity of the frame. The highest coefficient of behavior is related to models 4, 1 and 7 (with a sheet thickness of 2 mm), respectively.

4- Conclusions

- In the ratio b / d = 0.75; Energy absorption in models 3, 6 and 9 (with a sheet thickness of 6 mm) is higher than other models. Also, by keeping the thickness of the sheet constant and changing the thickness of the concrete, there is no noticeable change in the incremental load diagram. In fact, it can be concluded that changing the thickness of concrete will not affect the bearing capacity of the structural model.
- In the ratio b / d = 0.75; The highest coefficient of behavior is related to models 4, 1 and 7 (with a sheet thickness of 2 mm), respectively.
- In the ratio b / d = 1; Energy absorption in models 12, 15 and 18 (with a sheet thickness of 6 mm) is higher than other models. Also, by keeping the thickness of the sheet constant and changing the thickness of the concrete, there is no noticeable change in the incremental load diagram. The highest coefficients of behavior are related to models 10, 13 and 16 (with a sheet thickness of 2 mm), respectively. In addition, energy absorption in models 21, 24 and 27 (with a sheet thickness of 6 mm) is higher than other models. Also, by keeping the thickness of the sheet constant and changing the thickness of the concrete, there is no noticeable change in the incremental load diagram.
- In the ratio b / d = 1.5; The highest coefficients of behavior are related to models 22, 25 and 19 (with a sheet thickness of 2 mm), respectively.
- Energy absorption in models 21, 24 and 27 (with a sheet thickness of 6 mm and a ratio of b / d = 1.5) is higher than other models.
- The highest coefficient of behavior is related to model 4

(with a sheet thickness of 2 mm, concrete thickness of 30 mm and a ratio of b / d = 0.75), respectively.

- The value of the average behavior coefficient for b / d ratios; 0.75, 1 and 1.5 are 13.5, 13.37 and 12.84, respectively. Also, the value of the overall average behavior coefficient is 13.24.

- The proposed relationships for determining the thickness of the cover sheet in terms of the thickness of the steel sheet in terms of the aspect ratio of the frames were presented and validated.

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