The Effect of Trapezoidal Corrugated Steel Plates and Coupling Beam Action on the Seismic Behavior of Coupled Steel Shear Wall Systems

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ABSTRACT

Steel shear walls are one of the lateral load resisting systems that have been considered by researchers and designers in the last four decades. Though steel shear walls have proven effective, they are limited due to the opening on their bay. To address this, coupled shear walls can be used. As a result, there has recently been widespread use of corrugated sheets in the steel shear walls for low- and mid-rise buildings. However, there are limited studies on the coupled shear wall. Hence, as a symbol of low- and mid-rise buildings, Abaqus software was utilized in this study to model and analyze samples of coupled steel shear wall 3-, 6-, and 12-story buildings under push over analysis up to 4% roof drift. The effect of the trapezoidal corrugated steel plate with vertical and horizontal waves was investigated on the five key factors: bearing capacity, energy dissipation, degree of coupling, coefficient of behavior and ductility ratio of the coupled steel shear wall. Furthermore, the effect of increasing both the cross-sectional area of the coupling beam and the length of the coupling beam was assessed in this study. The results demonstrate that vertical and horizontal corrugated sheets cause a reduction of three factors: the base shear, degree of coupling, and energy dissipation. In addition, the behavior coefficient and ductility ratio decreases in the vertical corrugated sample and increases in the horizontal corrugated sample. Furthermore, increasing the beam's length or cross-sectional area causes a decrease in four factors: the bearing capacity, coefficient of behavior, ductility, and energy dissipation ratio. The degree of coupling decreases in the vertical corrugated samples and increases in the horizontal corrugated samples. Moreover, the degree of coupling increases in both cases of flat and corrugated steel sheets with increasing the number of stories.

KEYWORDS

Steel plate shear wall, Trapezoidal corrugated steel plate, Degree of coupling, Coupled shear wall, Coupling beam

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1. Introduction

Using the non-elastic zone capacity of structural members allows the seismic lateral-force-resisting systems to be designed for more minor requirements than those predicted by the dynamic elastic analysis. Steel Plate shear walls (SPSW) are new seismic lateral force resisting systems. The SPSW system consists of a steel frame with web plates connected to the beams and columns of each story, referred to as Horizontal Boundary Elements (HBEs) and Vertical Boundary Elements (VBEs), respectively. Due to the current design limitations in the regulations, it is sometimes impossible to create large openings, in which case steel plate shear walls with coupling can be used as a solution to address this problem [1].

The steel plate shear wall with coupling consists of two separate shear walls connected by a coupling beam [1]. One way to stiffen these walls is to improve their buckling behavior by using stiffeners. However, due to the high cost of making stiffened panels and increasing the structure's weight, corrugated steel plates have been suggested as a suitable alternative with a high out of plane resistance, high shear strength, and high ductility (Emami et al. 2013) [2]. In 2017, Hosseinzadeh et al. discovered that in corrugated shear walls, the development of the tension field, wall yield and damage depends on the plate geometry corrugated, which with increasing corrugation angle, wall damage to tear off the sheet expands [3]. In 2016, Gholhaki and Qadaksaz found that raising coupling beam length increases the period and drift of the structure and reduces the base shear [4]. In 2017, Borello and Fahnestock tested two specimens of three-story steel plate shear walls under the cyclic lateral-displacement protocol [5]. One of the specimens had flexural yielding another had intermediate flexural yielding. The results indicated that both specimens got a lateral drift of 4% and excellent performance with high internal stiffness, suitable ductility and high energy absorption.

With attention to the previous studies, further evaluation of using Trapezoidal Corrugated Steel Plates in the steel plate shear wall and coupling beam effect is required. Consequently, in this research, examples of coupling steel shear walls 3, 6 and 12 story symbol of low and mid-rise buildings were modelled in Abacus software. Then, the effect of using a trapezoidal corrugated steel plate with the vertical and horizontal orientation in them was investigated on bearing capacity, energy absorption rate, degree of coupling (DC), coefficient of behavior and ductility ratio, under nonlinear static analysis up to 4% drift roof. In addition, the effect of coupling beam performance was assessed at all three heights.

2. Methodology

In this research, the specifications of the 3-story sample of Borello experiments and the 6 and 12-story samples designed in Borello's doctoral dissertation have been used to model the samples. 9 samples were modelled to analyze the effect of using trapezoidal corrugated sheets with the vertical and horizontal orientation, 6 samples were modelled to study the effect of increasing the beam length, and 6 samples were studied to investigate the effect of increasing the cross-sectional area of the coupling beam. The models' behavior was studied up to 4% drift, which is considered the minimum drift of special moment frames according to AISC 341-16 [6]. Since the 3-story sample is built in Borello's experiment has a scale of 0.43. 6 and 12-story samples were modelled with a scale of 0.43 to have the same scale. A36 steel is used for steel sheets in all samples, and A992 steel is used for other members. Besides, the roof level coupling beam, which was removed in the laboratory model because of limitations caused by the hydraulic jack, has been modelled in all Abacus models based on the initial design specifications. In naming the models in Table 1, the initial numbers show the number of story; the terms P and TC indicate the Planner Steel Plate and Trapezoidal Corrugated steel sheet, respectively. The letters V and H also indicate the Vertical and Horizontal waveforms of the steel sheets, respectively. The terms CL and CB also express Coupling beam Length and the Cross-section of the Beam, and the numbers after it indicate the increase percentage. Other specifications such as beam and column connection, coupling beam stiffener and boundary conditions are like the Borello test model [1].

Table 1. Sample properties

SAMPLE	EXT. COLOUMN	INT. COLOUMN	BEAM	COUPLING BEAM	PLATE TICKNESS	STEEL PLATE
3-P	W8×58	W8×48	W6×12	W6×12	1.16	PLANAR
3-TC-V	W8×58	W8×48	W6×12	W6×12	1.16	CORRUGATED
3-TC-H	W8×58	W8×48	W6×12	W6×12	1.16	CORRUGATED
6-P	W24×279	W24×229	W18×50	W18×50	3.175	PLANAR
6-TC-V	W24×279	W24×229	W18×50	W18×50	3.175	CORRUGATED
6-TC-H	W24×279	W24×229	W18×50	W18×50	3.175	CORRUGATED
12-P	W36×800	W36×652	W18×86	W18×86	5.56	PLANAR
12-TC-V	W36×800	W36×652	W18×86	W18×86	5.56	CORRUGATED
12-TC-H	W36×800	W36×652	W18×86	W18×86	5.56	CORRUGATED
3-CL10	W8×58	W8×48	W6×12	W6×12	1.16	PLANAR
3-CL20	W8×58	W8×48	W6×12	W6×12	1.16	PLANAR
6-CL10	W24×279	W24×229	W18×50	W18×50	3.175	PLANAR
6-CL20	**W24×279**	**W24×229**	**W18×50**	**W18×50**	**3.175**	**PLANAR**
12-CL10	**W36×800**	**W36×652**	**W18×86**	**W18×86**	**5.56**	**PLANAR**
12-CL20	**W36×800**	**W36×652**	**W18×86**	**W18×86**	**5.56**	**PLANAR**

3-CB25	**W8×58**	**W8×48**	**W6×12**	**W6×15**	**1.16**	**PLANAR**
3-CB65	**W8×58**	**W8×48**	**W6×12**	**W6×20**	**1.16**	**PLANAR**
6-CB25	**W24×279**	**W24×229**	**W18×50**	**W18×50**	**3.175**	**PLANAR**
6-CB65	**W24×279**	**W24×229**	**W18×50**	**W18×50**	**3.175**	**PLANAR**
12-CB25	**W36×800**	**W36×652**	**W18×86**	**W18×86**	**5.56**	**PLANAR**
12-CB65	**W36×800**	**W36×652**	**W18×86**	**W18×86**	**5.56**	**PLANAR**

3. Discussion and Results

The values of the maximum base shear, Energy absorption, DC, behavior factor and ductility ratio of the samples are given in Table 2.

Table 1. Results

SAMPLE	BASE SHEAR (KN)	ENERGY ABSORPTION (KJ)	DC	BEHAVIO FACTOR	DUCTILITY RATIO
3-P	914	164	0.534	6.24	5.51
3-TC-V	842	140	0.317	4.95	4.94
3-TC-H	869	152	0.523	7.01	6.82
6-P	818	262	0.609	6.30	5.42
6-TC-V	761	244	0.340	4.42	4.61
6-TC-H	783	250	0.563	6.38	6.64
12-P	131	917	0.741	5.79	3.97
12-TC-V	1656	896	0.393	5.39	3.48
12-TC-H	1689	843	0.673	5.42	4.58
3-CL10	893	157	0.460	5.14	5.12
3-CL20	856	154	0.428	5.88	5.31
6-CL10	804	255	0.563	6.18	4.91
6-CL20	775	251	0.548	6.25	5.01
12-CL10	1695	887	0.689	5.61	3.66
12-CL20	1629	868	0.671	5.68	3.86
3-CB25	879	157	0.560	5.89	5.43
3-CB65	903	160	0.590	5.38	5.39
6-CB25	791	253	0.649	6.13	3.85
6-CB65	804	258	0.672	6.03	5.13
12-CB25	1667	879	0.751	5.73	4.88
12-CB65	1712	912	0.767	5.55	3.53

The results demonstrate that the maximum amount of base shear is reduced by changing the steel sheet from planar to vertical and horizontal orientation. Furthermore, the maximum amount of base shear decreases with increasing the coupling beam's length. As can be seen, increasing the cross-sectional area of the coupling beam in the 3rd, 6th and 12th story samples, a decreasing trend is observed in the amount of reduction of the maximum base shear. In other words, the maximum amount of base shear in the sample with a 25% increase in the cross-sectional area of the coupling beam has a more significant reduction than the sample with a 65% increase in the cross-sectional area of the coupling beam.

4. Conclusion

In this paper, the effect of using vertical and horizontal trapezoidal corrugated steel sheet, the effect of increasing the length and cross-sectional area of the coupling beam on the steel shear wall of 3, 6 and 12 story was researched, and the subsequent results were obtained:

- In all samples, base shear, degree of coupling and energy absorption are decreased by changing the steel plate from planar to vertical and horizontal corrugated, which is more in the panel with vertical corrugation
- In all samples, rising the coupling beam's length, the base shear, degree of coupling, behavior factor, ductility ratio, and energy absorption decrease.
- In all samples with expanding the cross-sectional area of the coupling beam, the base shear, behavior factor, ductility ratio and energy absorption decrease and the degree of coupling increases.
- With increasing height in all three models, including steel plate wall, vertical and horizontal corrugated sheet, the degree of coupling increases.

5. References

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