Nonlinear Finite Element Analysis on Seismic Performance of Steel Corrugated Shear Wall

Xiaotong Peng, Chen Lin, Tingting Zhang and Xu Zhang

1 School of Civil Engineering and Architecture, University of Jinan, Jinan 250022, China.
2 School of Architecture and Landscape Design, Shandong University of Art & Design, Jinan 250014, China.
Email: pengxito@163.com

Abstract. In order to study the seismic behavior of corrugated steel shear wall, a three dimensional nonlinear FEM of steel corrugated shear wall was established by use of ABQUS software. Based on that, the bearing capacity of the corrugated steel shear wall under the monotonic loads and its hysteretic behavior under the cyclic loads were analyzed. The results indicate that the corrugated steel shear wall could decrease storey drift and improve lateral bearing capacity and stiffness of steel frames dramatically; the corrugated steel shear wall has better seismic performance than steel plate shear wall.

1. Introduction
Steel plate shear walls (SPSWs) are widely used and efficient lateral force resistant system. However, it is prone to buckle under lateral load. Although stiffened steel shear walls and composite steel plate shear walls are produced by Alinia and Shafaei respectively [1-2] to delay the buckling of steel plates, the effect is not satisfactory. The corrugated steel plate is quailed as shear walls in steel frame for its large initial stiffness and shear yield strength. It can reduce the out-of-plane deformation of shear walls and improve lateral stiffness of steel frames. Thus, tanking corrugated steel plates as shear walls was proposed by Hossain and Wright [3]. Then the buckling performance of steel corrugated plate shear walls (SCSWs) was studied by Li Feng et al [4-6]. Li Guo qiang [5] studied the influence of waveform on SCSWs shear capacity, and Zhu Wei [6] found that the shear wall has the best lateral resistant performance when corrugations placed horizontally. Non-linear finite element analysis of SCSWs was conducted by Liu Ying [7] to study its hysteretic behavior.

Based on the research above, two models of SCSW and SPSW were produced taking a 6-story office building as a prototype. ABAQUS 6.14 software was used to analyze the seismic behavior of SCSWs and SPSWs, and its lateral resistant behavior and hysteretic performance under monotonic and cyclic loading were compared.

2. Corrugated Steel Plate and Flat Steel Plate
Two models of SCSW and SPSW was designed based on the 3-4 stories in the central area of the 6-story office building prototype (Figure. 1). The span of the model is 7800mm, the storey height is 3600mm, the section size of the beam, column and ground beam is 400×8×280×18mm, 500×14×320×18mm, and 1200×75×900×75mm respectively. The corrugated steel plate in SCSWs adopts type YX-51-250-750 with 1 mm in thickness. It is composed of two parallel-connected trapezoidal corrugated steel plates formed honeycomb shape. Flat steel plate used in SPSW is 2mm in thickness. The beams and columns are connected rigidly. The infill steel plate is separated from the
columns with a distance of 30 mm. whereas the infill steel plates are welded to flanges of beams by connection plates.

![Figure 1. Model Dimensions](image)

3. **Nonlinear Finite Element Analysis**

In order to analysis the seismic behavior of steel corrugated plate shear walls, SCSW and SPSW were compared. Besides the infill steel plate, the modeling methods for frame size, element type, meshing, boundary conditions and loading history used in the two models is the same.

3.1. **Finite Element Models**

S4R shell elements are adopted to simulate beams, columns, and flat steel plate or corrugated steel plate, which can realize the buckling deformation under stress accurately. The rigid joints are achieved by the 'merge' option in assembly function module. The welded connections are achieved by 'tie' option. The steel frame and the steel plate and connection used Q345 and Q235 steel respectively (Table. 1).
Table 1. Material Properties

|                | $E$ (N/mm$^2$) | $f_y$ (N/mm$^2$) | $f_u$ (N/mm$^2$) |
|----------------|----------------|-----------------|-----------------|
| Steel frame(Q345) | 204000         | 310             | 460.3           |
| Infill plate(Q235) | 203000         | 210             | 323.2           |

- $E$ is the elastic modulus.
- $f_y$ is the yield strength.
- $f_u$ is the ultimate strength.

The models are meshed in a simple and regular way using free meshing with quadrilateral element (Figure 2). The accuracy and calculating time are influenced by meshing density directly. To ensure accuracy of calculating results and save computer time, the meshing size is 50mm for beams, and 100mm for columns, ground beams, flat steel plates, corrugated steel plates and fishplates.

![Figure 2. Free Meshing Partition](image)

The boundary conditions are set as follows: the nodes of the ground beam lower flanges are constrained fully to realize the fixed end. The load is applied in the Z-axis direction with X and Y axes degrees constrained (Figure 3). In order to avoid stress concentration and local buckling at the loading point, an infinite rigid plane is placed on the loading point to ensure the transfer lateral load uniformly.

![Figure 3. Boundary Condition](image)
The static and cyclic loading scheme is controlled by peak displacement, which is applied along the Z-axis direction. The amplitudes of elastic loading history at each level are 2mm, 4mm, 6mm, 8mm, 10mm, 12mm, and 14mm, with each loading level recycled only once (Figure 4).

![Loading History](image1)

**Figure 4. Loading History**

3.2. *Finite Element Analysis*

The lateral deformation of both structures increased gradually under the monotonic loads (Figure. 5). The end of elastic stage of the SPSW is represented by horizontal load of 4550 kN, while that of the SCSW is 5564 kN. The ultimate bearing capacity of the SPSW is 6858KN with a displacement of 66.36mm, while the bearing capacity of the SCSW is 7490KN. It indicates that within the elastic stage, the peak drift of the SCSW is smaller but its ultimate bearing capacity is 9.2% higher than that of the SPSW.

![Load-displacement Curves](image2)

**Figure 5. Load-displacement Curves**

In order to study the hysteretic behavior in the elastic stage, the cycling loading is applied in elastic stage with displacement in 14mm. Figure. 6 shows the hysteretic curves of the SCSW and the SPSW under cyclic loading. They are both spindle shaped and plump indicating both models have good energy dissipation performance. Moreover, the energy dissipation performance of the SCSW is better than that of the SPSW, since hysteretic loop areas of the SCSW is obviously larger than that of the SPSW.
Figure 6. Hysteretic Curves

Within the elastic stage, buckling waves are formed diagonally in first and second floors of SPSW (Figure 7). The steel frame mainly yields around joints, and the out-of-plane deformation occurs in the flange of columns. As for the SCSW, buckling waves are formed in steel plate area near the upper and lower beams on second floor and no buckling waves are observed on the steel plate of first floor. Only a small part of the steel around the connection reaches ultimate strength, no deformation is observed on the flange of columns.

There is a large part of steel plate around the top of column in SPSW yields, while only a small range on the top of the column in SCSW yields. The corrugated steel plate of the SCSW absorbs most parts of the lateral loads of the structure, and shares the lateral loads that columns subjected to.

(a) SCSW Model
4. Conclusions
(1) Under the monotonic loads, compared to the SPSW, the SCSW has better lateral stiffness and bearing capacity.

(2) Under the cyclic loads, the SCSW has a better hysteretic behavior in the range of displacement amplitude (14mm). The corrugated steel plate has made great contributions in increasing lateral stiffness, improving energy dissipation capacity and delaying the premature buckling of steel plates.

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References
[1] Alinia M.M and Shirazi R.S On the design of stiffeners in steel plate shear walls 2009 Journal of Constructional Steel Research 65 2069-77.
[2] Shafaei S, Ayazi and Farahbod F The effect of concrete panel thickness upon composite steel plate shear walls 2016 Journal of Constructional Steel Research 117 81-90.
[3] Chan C.L, Khalid Y.A and Sahari B.B Finite element analysis of corrugated web beams under bending 2002 Journal of Constructional Steel Research 58 1391-1406.
[4] Li F and Zhao L Elastic Bucking Analysis of Transverse Honeycomb Shaped Section Steel Plate Shear Wall 2014 Steel Construction 29 59-62.
[5] J.W. Berman and M. Bruneau. Experimental Investigation of Light-Gauge Steel Plate Shear Walls 2005 Journal of Structural Engineering 131 259-267.
[6] Yanlin Guo, Qinglin Zhang and Xiaoyan Wang. A Theoretical and Experimental Study of the Shear Strength of H-Shaped Members with Sinusoidal Corrugated Webs 2010 China Civil Engineering Journal 10 45-52.
[7] Li G, Zhang Z and Sun F Shear Strength of H-beam with Corrugated Webs 2009 Journal of Tongji University/Natural Science 37 709-14.
[8] Zhu W and Mei H Analysis of Lateral Force Performance of Corrugated Steel Plate Shear Wall 2013 Development orientation of building materials 5 20-2.
[9] Liu Y 2012 Nonlinear Finite Element Analysis of Semi-rigid Composite Steel Frame with Profiling Steel Plate Infill Wall China Steel construction Society Lodge of Structural stability and Fatigue
[10] Yu A, Zhao J, Jiang A 2006 Ductility Steel Folded Plate Shear Wall China Steel construction Society Lodge of Structural stability and Fatigu