Seismic Behavior Analysis of New Damping and Energy Dissipating Corrugated Steel Shear Wall System

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Abstract. In order to avoid the premature buckling of steel plate shear walls, the corrugated steel plate walls are used to increase stiffness and the buckling resistance performance, and soft steel dampers are also adopted to improve the energy dissipation capacity. This combined use of the corrugated steel plate wall and the damper leads to a new system: damping energy-dissipating corrugated steel shear wall (DCSW). A numerical simulation model was established to study the seismic behavior of DCSW using the software ABAQUS, in which the material and geometric nonlinear were considered. Based on that, the ultimate bearing capacity, stiffness and ductility were analyzed. The results indicate that the DCSW structure has a high strength redundancy. The strength of DCSW structure is about 18% higher than that of steel.

1. Introduction
Steel structure has become the preferred structural form for high-rise buildings because of its good seismic performance. However, it is prone buckle out of plane, and its lateral stiffness and bearing capacity drop sharply after elastic buckling. James Montgomery [1] increased the plate thickness and added stiffening ribs to the steel plate shear walls to solve this problem, however the economic effect was poor. Guo Yanlin et.al [2] covered steel plates with concrete plates to avoid the premature buckling of steel plates, whereas its fabrication and construction are complicated. Many relevant studies on steel plate shear wall [3-6] indicated that steel plate shear walls are advantageous, and the key point is to avoid premature buckling of steel plate shear walls and improve their post-buckling strength in an economical and simple way.

2. Model Design of DCSW
According to the studies around the world, two design ideas of reinforced steel plate shear wall [7-10] are adopted: (1) Increase the lateral stiffness of shear walls by changing the cross-section shape of steel plate and placing fiber reinforced materials outside the steel plate. (2) Consume the seismic energy by adding energy dissipation devices.
In this paper, new strategies that combine the two methods above are proposed. The section shape of steel plate shear wall is changed, and the natural buckling-resistant shear wall is adopted. The corrugated steel plate shear wall is light in weight and convenient in construction, which will not cause damage to the structure. The soft steel damping is also adopted to absorb the seismic energy (Fig. 1).

![Figure 1. DCSW System.](a) DCSW structure. (b) DCSW structure detail]

3. Nonlinear Finite Element Analysis

In order to analysis the lateral resistance of DCSW system, six models were established. These models share the same frame size, element type, meshing, boundary conditions and loading history but there infill steel plates and dampers are different.

3.1. Finite Element Analysis

Shell elements are adopted in those models. 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 dampers used Q345 steel and Q235 steel respectively (Table. 1).

| Material Type          | E (N/mm²) | ƒ_y (N/mm²) | ƒ_u (N/mm²) |
|------------------------|-----------|-------------|-------------|
| Steel frame (Q345)     | 204000    | 310         | 460.3       |
| Infill plate (Q235)    | 203000    | 210         | 323.2       |

a E is the elastic modulus.

b ƒ_y is the yield strength.

c ƒ_u is the ultimate strength.

S4R shell elements are adopted to simulate beams, columns, and flat steel plate or corrugated steel plate. The models are meshed in a simple and regular way using free meshing with quadrilateral element (Fig. 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 columns, and 100mm for corrugated steel plates and dampers.

The boundary conditions of the finite element analysis model are set up in the initial analysis step. At the bottom of the model, the beam and column are coupled to a reference point, and a completely fixed boundary condition is applied to the reference point: U1=0, U2=0, U3=0, UR1=0, UR=0, UR3=0. The loading scheme adopted is displacement control. X-direction restraint is applied to web of beam and column to avoid out-of-plane deformation of frame. First, the beam section is coupled to a point, and then Z-direction displacement loading is applied to this point.
3.2. Finite Element Analysis

The load-displacement curve of steel frame-shear wall structure is shown in Fig. 3a. The ultimate bearing capacity of flat steel plate shear wall is 3024kN, and that of corrugated steel plate shear wall is 3544kN, which is 18% higher than that of flat steel plate. The ultimate bearing capacity of corrugated plates placed horizontally and vertically is almost the same.

The load-displacement curve of steel frame-damped energy dissipation shear wall structure is shown in Fig. 3b. The ultimate bearing capacity of damped energy dissipation-flat steel plate shear wall is 3081kN, and that of DCSW system is 3508kN. Therefore, adding dampers will have some influence on the lateral resistance of the structure, but the overall trend remains unchanged. The lateral resistance of the damped energy dissipation - corrugated steel plate shear wall is still higher than that of the damped energy dissipation - flat steel plate.

![Free Meshing Partition](image)

**Figure 2.** Free Meshing Partition.

![Load-displacement Curves](image)

**Figure 3.** Load-displacement Curves (Influence of steel plate).
The load-displacement curves of three steel frame-shear wall structures and three steel frame-damped energy dissipation shear wall structures under monotonic loads are shown in Fig. 4. From the figure, it can be seen that the introduction of soft steel dampers has almost no effect on the ultimate bearing capacity of the structure, but the peak points of the structure have been moved back, because the introduction of dampers increases the damping of the structure and improves the ductility of the structure. Observing the initial stiffness of the three groups of curves, we can see that the initial stiffness of the structure decreases slightly after introducing the damper, which is also due to the yielding of the damper at the initial stage of loading, prior to the energy dissipation of the main structure before it enters the yielding stage. Therefore, the rhombic open-hole soft steel damper proposed in this paper is an excellent energy dissipation component, and its application in the structure can improve the ductility and damping of the structure.

(a) Steel plate  
(b) Horizontal corrugated plate  
(c) Vertical corrugated plate

Figure 4. Load-displacement Curves (Influence of dampers).

4. Conclusion
(1) Using corrugated steel plate instead of flat steel plate as shear wall, the ultimate bearing capacity of the structure is increased by nearly 18%, and the lateral stiffness and ductility are also improved. The placing direction (horizontal and vertical) of the ripple has little influence on the lateral resistance of the structure.

(2) The soft steel damper has little effect on the ultimate bearing capacity of the structure. The ductility of the structure is improved because the yielding displacement of the soft steel damper is small, and the energy dissipation occurs before the main structure enters the yielding stage.

(3) DCSW system can avoid the premature buckling of traditional steel plate shear wall, and improves the lateral capacity of the structure. It strengthens the lateral stiffness of steel frame, which reducing the seismic requirements for connections, and provide opportunity to adopt semi-rigid connections for steel frame. This is also a useful exploration of the ideal seismic system.

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