Anti-Seismic Test Study on the Grid-Tube-Type Double Steel Plate and Infilled Concrete Composite Shear Wall

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Abstract. In this paper, three test models were cast about the grid -tube- type double steel plate and infilled concrete composite shear wall, the horizontal low cyclic loading test was carried out, and hysteresis curves and skeleton curves were got under different coaxial compression ratios. The results show that the new composite shear wall has many advantages, such as full hysteresis curve, high bearing capacity, high ductility and high energy dissipation capacity. Under the large displacement angle of 1/25 and cyclic loading of 80 times, the plastic hinge area still maintains the large stiffness and bearing capacity, which can effectively prevent the collapse of the structure under the action of a major earthquake. New composite shear wall has good seismic performance, which can realize the design requirements of high axial compression ratio, high ductility and thin thickness walls.

1. Introduction

High-rise steel structure represents the future development direction of architectural structure. The high-rise buildings have become a symbol of national spirit and the rise of urban economy. With the increase of building height, horizontal load effect on the structure is bigger and bigger \cite{1-3}, in order to ensure the safety of high-rise steel structure building’s aseismic, must be set against the powerful earthquake shear walls to resist lateral force \cite{4-6}.

Currently, high-rise building structure often USES the steel frame - reinforced concrete core tube structure, as the height of the building structure more and more high, in order to guarantee the ductility of the reinforced concrete core tube shear wall, the need to strictly control the axial compression ratio of concrete core tube shear wall, the wall thickness of concrete core tube shear wall will be designed to be very thick, too thick shear wall construction difficulties, not only a waste of space, and increase weight, seismic load force increases \cite{7-9}.

Modern high-rise buildings have proposed the requirement of high axial pressure ratio, high extension line and thin wall \cite{10-12}. Based on the advantages of the composite structure of steel tube concrete, the new idea of the combination shear wall of the grid type double plate concrete is proposed, and the flat steel box girder is placed in the long bar grid steel wall panel, and the hollow cavity of the long fence is made of self-dense concrete, forming the shear wall of the grating double plate concrete.

The new type of composite shear wall has good seismic performance, the concrete is subjected to the multi-axial compression condition of the grating steel pipe, and its performance is obviously improved. Lateral steel plate division formed by internal Rachel a beam tube, internal Rachel has a constraint function of the lateral deformation of steel plate, steel plate fills in concrete can prevent the
steel plate in the bends, fills in the compressive stress of concrete bear all can avoid the outside steel compression flexion, a new type of composite shear wall lateral steel plate has a great ability to resist buckling.

2. Model making

In order to verify the new grille type double steel concrete shear wall has good seismic performance, in this paper, experimental design for three piece of steel concrete composite shear wall specimen grating type, section as shown in figure 1, the number of CSW - 1, CSW - 2, CSW - 3, and they are all width 1400 mm, the thickness 160 mm, the net height is 2800 mm.

Three specimens were divided into 2 groups, the first set of CSW - 1, CSW - 2 the dis-placement control load, axial compression ratio comparison test, the second group of CSW - 3 controlled by displacement loading, as a validation test artifacts, such as for the last level load displacement of symmetric cyclic loading, to further explore energy cumulative fatigue damage situation of plastic hinge, particular case as shown in table 1.

| Axial  | Loading method         |
|--------|------------------------|
| CSW-1  | 0.1                    |
| CSW-2  | 0.6                    |
| CSW-3  | 0.1                    |

Three new grille type double steel concrete strength grade of concrete shear wall specimen design of C40, inside all use 4 mm thick steel plate and the outer steel plate Q235B steel, shear wall at both ends for 160mm common channel steel hot rolling, all connections are welding between steel. Load the beam section size 400*400mm, ground beam section size 500*600 mm, in order to ensure the connection between the bottom of the shear wall and ground beam, on top of the ground beam pass long embedded in the hot-rolled h-beam flange HM350*200.

This experiment was carried out in the civil traffic laboratory in Southeast University, Kowloon lake campus, and the structure was shown in figure 2. The experimental loading method is applied to apply the repeated horizontal load at the top of the cylinder while the shaft is applied to the shaft. Vertical axial force by hydraulic jack, horizontal load is at the top of the manufactured by American
MTS company of hydraulic servo actuator applied, actuators, the maximum static load of 1500 kN, the maximum dynamic load of 1000 kN, range of 500 mm.

3. Test Results Analysis

3.1. The Test Phenomenon
The vertical axial pressure of the test piece csw-1 is 400 kN, the axial pressure ratio is 0.1, and the force displacement control is applied. No abnormal phenomena in the initial loading, the component has a large initial stiffness. Elastic loading phase at the end of the horizontal displacement of the specimens at about 12 mm (interlayer lateral Angle about 1/200), end channel steel stress reaches the yield stress, basic no surface deformation. Specimens using displacement control after the overall yield load, when displacement load to ±84 mm (interlayer lateral Angle about 1/40), there will be 9 cm from the root of the specimens in plates up slightly. When the displacement load to ±114 mm (interlayer lateral Angle about 1/25), the root of the specimen on both sides of the steel plate have obvious, tie-beam concrete affected by extrusion, and beginning to flake pre-embedded anchoring H type steel beam bending deformation, the termination. During the whole experiment, the plate was not buckling and the whole process was the same (see figure 3 for test phenomenon of csw-1 specimen of steel plate shear wall).

![Test Phenomenon](image)

Figure 3. The test phenomenon.

The vertical shaft pressure of the test piece csw-2 is 2400 kN, and the axial pressure ratio is 0.6. Load adoption force - displacement control. Loading specimen no abnormal phenomenon, the early stage of elastic loading at the end of the horizontal displacement of the specimens at about 11 mm (interlayer lateral Angle about 1/225), end channel steel stress reaches the yield stress, specimens using displacement control load after overall yield. When the displacement loading to plus or minus 33 mm (layer between the lateral Angle of about 1/85), 8 cm in steel specimens from the root up slightly, beam end surface concrete has a small amount of peeling phenomenon. When the displacement load to plus or minus 55 mm (interlayer lateral Angle about 1/50), the root of the specimen on both sides of the steel plate have obvious, to tie-beam concrete by extrusion, pre-embedded anchoring H type steel
beam local pull up, the termination. During the whole experiment, the plate was not buckling and the whole process was the same. Csw-2 and csw-1 yield reduced yield and peak displacement, and the yield load and peak load increased significantly.

The vertical shaft pressure applied by csw-3 is 400 kN, and the axial pressure ratio is 0.1. Loading using displacement control when the displacement load to + 108 mm (about 1/25 layer between lateral), load level for the symmetric constant amplitude cyclic loading, when the loop after 20 times, specimen roots steel local ballooning, tie-beam concrete destruction intensified, extrusion and start peeling; But the hysteresis curve overlapping, continuously reflect the stability of the specimen stiffness, after the cycle for the 80th time, plate local buckling, local pull up because of the H steel beam, beam seriously damaged, end of the test. During the whole experiment, the plate was not buckling and the whole process was the same. In order to observe the internal stress distribution of concrete at the end of the test, the specimen positive close to the bottom position, cut the outer steel, concrete core, found that the internal concrete base in good condition, no visible cracks occurred, the mechanical properties show that the new composite shear wall plastic hinge is good.

Tube concrete column, concrete inside three to a state of compression, improved the pipe concrete compressive strength and ductility, effectively avoid the early destruction, makes the new grille type steel concrete composite shear wall can give full play to the seismic resistance of steel and concrete and the energy dissipation capacity. Grille type steel concrete composite shear wall set inside the Rachel across steel plate, steel plate spacing within relatively dense, which can effectively limit the lateral shear the out-of-plane deformation of steel plate and bear all the pressure to avoid the shear steel tube concrete compression, therefore grille type steel concrete composite shear wall has higher ability to resist out-of-plane buckling.

### 3.2. Hysteresis Curve

Drawing the hysteresis curve of the specimen, the result is shown in figure 4. In the early displacement loading specimen at the elastic stage, the bearing capacity of the specimen and the horizontal displacement of approximate linear relationship, and have higher initial stiffness, along with the increase of the load displacement curve of specimen appeared inflection point, the specimen into the elastic-plastic stage, and with the increase of displacement between layers, surrounded by sluggish loopback area is increasing, shape and constantly improve the bearing capacity, the tangent stiffness begins to decrease gradually. From the composite shear wall specimen hysteretic curves of 4, you can see that composite shear wall specimen of the hysteresis curve is full, stable, with good energy dissipation capacity, after entering elastic-plastic stage, after three times per level displacement under cyclic hysteresis curve close to, show that specimens under the displacement at the same level of carrying capacity is stable. The test piece csw-1 is compared with csw-2, and it is found that the bearing capacity of the test shaft is higher than that, the capacity of the bearing capacity will be increased, the energy dissipation capacity will be decreased. The specimen and CSW CSW - 1-3 contrast, find specimen under two different loading modes, its mechanical performance is not much difference, but the yield and yield have slightly difference before and after.

![Figure 4. Hysteresis curve.](image-url)
3.3. Skeleton Curve

The skeleton curve of the composite shear wall specimen is shown in figure 5, which shows that the sample from the loading begins to the damage and goes through two parts. When the applied load is small, concrete cracking, steel plate did not yield, specimen at the elastic stage, the stiffness of the specimens basic remains the same, skeleton curve approximation in a straight line; As the load increases, the test stiffness begins to decrease slowly and accumulates the residual deformation of different degrees. Steel plate yield after load continues to increase, and the skeleton curve appeared an obvious turning point, slope further reduce, the rapid decline in stiffness, specimen soon peak load, the above parts for the rising curve segment. After exceeding the peak load, the curve enters the descending segment. As can be seen from the figure 5 skeleton curve, the specimen after the peak load, the curve fell quite gentle, namely bearing capacity drops slowly, visible steel had good constraint effect on internal concrete, belongs to the ductile fracture.

![Figure 5. Skeleton curve.](image)

(a) Different axial compression ratio  
(b) Different load mode

3.4. Ductility Analysis

The ductility of the structure or component size is usually measured by ductility coefficient, this paper USES simplified ductility coefficient: specimen failure limit to the corresponding displacement ductility coefficient. The characteristic value of the skeleton curve of three specimens is shown in table 2, which determines the yield point using the secant stiffness method. The displacement of the limit displacement is the corresponding displacement of 85% of the peak load. You can see from this table grille type steel concrete composite shear wall in low axial compression ratio has good ductility, and ductility coefficient is close to 9, under high axial compression ratio. The ductility coefficient is close to five. The main reason is the new grille type steel concrete composite shear wall internal self-compacting high-strength concrete, greatly improve the composite shear wall structure of axial compression stress performance, strengthen the strength of this new type of composite shear wall structure and rigidity.

![Table 2. The characteristic point of the skeleton curve.](image)

|          | yield load (kN) | yield displacement (mm) | Peak load (kN) | peak displacement (mm) | limit displacement (mm) | Ductility coefficient |
|----------|-----------------|-------------------------|----------------|------------------------|------------------------|-----------------------|
| CSW-1    | 702.36          | 12.62                   | 929.84         | 69.08                  | 114                    | 9.03                  |
| CSW-2    | 811.11          | 10.78                   | 1082.38        | 30.90                  | 55                     | 5.10                  |
| CSW-3    | 682.72          | 12.32                   | 925.17         | 68.25                  | 114                    | 9.25                  |
3.5. Stiffness Degradation
In the specimen after the inelastic phase, along with the increase in number of load and displacement amplitude increasing, the plastic damage accumulation gradually, wall rigidity showed obvious degradation process.

The stiffness degradation curve of the specimen is basically symmetric about the coordinate axis, and the stiffness of the specimen is obviously reduced by the whole load. The stiffness of the specimen is degraded before and after the yield of the specimen, the stiffness of the specimen is degraded faster, and the stiffness degenerate curve flattens out. When the axial pressure is larger, the initial stiffness is larger and the stiffness degenerates faster. The effect of load mode on stiffness is not very different. The stiffness is gradually decreasing from yield to peak load to eventual destruction. At the beginning of loading, the stiffness decreases faster and the test parts show the better energy dissipation ability, and the stiffness decreases with the increase of displacement (as shown in figure 6).

![Stiffness regression curve.](image)

3.6. Strength Degradation
In the condition that the displacement amplitude is constant, the increase of the structural or structural bearing capacity of the load over and over of the load is called the degradation of intensity. From figure 7 shows that the bearing capacity of the three specimens are relatively stable, although the structural strength in the whole process of the Dutch have taken place in different degree of degradation, but its degradation coefficient were greater than 0.9, shows that the strength of structural bearing capacity of structure has good stability, not the strength of the sudden destruction, under strong earthquakes are still in a relatively long period of the interior of the specimen in higher bearing capacity.

![Sample strength regression coefficient curve.](image)
3.7. Energy Dissipation

Structure or component of energy dissipation capacity refers to the structure or component under the action of earthquake ground motion by using its plastic deformation and energy dissipation of external input ability, it is to measure living structure seismic performance of an important indicator, reflects the nonlinear mechanical properties. Specimen CSW - 1, for example, in stages, the initial stage of the load the specimen at the elastic stage, surrounded by a ring of detention area is lesser, at this stage the basic do not have energy dissipation of specimens; With the increment of external load, stagnant loopback surrounded the area of the specimen increased significantly, when the specimen in yield stage, is preliminary already has the energy dissipation of the specimens, since then, with the continuous increase of the displacement, hysteresis of the specimens loopback area is still a linear growth. Compared with the test piece csw-1 and the test piece csw-2, when the axial pressure ratio is increased, the delay circulation area of the specimen is decreased, the energy dissipation coefficient decreases, and the energy dissipation decreases. In conclusion, the new grille type steel concrete composite shear wall structure of the bearing capacity is relatively stable, hysteretic performance is good, has the high energy dissipation capacity, can effectively prevent the structure collapsed under strong earthquakes (as shown in figure 8).

![Hysteresis loop back area vs. Displacement](image1.png)

(a) CSW-1

![Hysteresis loop back area vs. Displacement](image2.png)

(b) CSW-2

**Figure 8.** Compare the curve of the specimen.

4. Conclusion

This paper designed the three steel concrete composite shear wall specimen grating type, and the test research under low reversed cyclic loading, can draw the following conclusion:

(1) The grille type steel concrete composite shear wall seismic performance is good, under low reversed cyclic loading is a plump hysteresis curve, has advantages of high bearing capacity, ductility and energy dissipation capability is strong, can achieve high axial compression ratio, high ductility and seismic shear walls of the thin wall thickness design requirements.

(2) The concrete composite shear wall of the grid-type steel plate, the concrete in the tube is under three pressure condition, and the compressive strength and ductility of the concrete in the tube are improved. Set spacing was Rachel across steel effectively restrict the lateral shear the out-of-plane deformation of steel tube concrete bear all the pressure to avoid the shear steel pressure, lateral plate has high ability to resist out-of-plane buckling.

(3) The grille type steel concrete composite shear wall is formed by combining multiple steel tube concrete column, concrete inside three to a state of compression, improved the compressive strength and ductility of concrete inside, effectively avoid the early destruction, makes the new grille type steel concrete composite shear wall can give full play to the seismic resistance of steel and concrete and the energy dissipation capacity.

(4) The grille type steel concrete composite shear wall has good stability, bearing capacity under 1/25 displacement Angle, cyclic loading 80 times, the new steel plate shear wall plastic hinge region there is still no obvious damage, in the whole test process without any sound.

(5) With the increase of axial pressure ratio, the bearing capacity of the concrete composite shear wall of grille type plate is increasing, and the ductility and energy dissipation of the wall is decreasing.
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