Dynamic Time Analysis of the Composite Shear Wall on the Grid-tube-type Double Steel Plate Wall with Infilled Concrete

Biqing Li, Jinbao Li and Wenping Xu

1 Jiangsu Southeast Special Technical Engineering Co., Ltd, Nanjing, China, 210008
2 College of Civil Engineering, Southeast University, Nanjing, China, 210096
E-mail: umabank@163.com; jlb1958@vip.163.com; 425616904@qq.com

Abstract. In this paper, based on a 30-story building with frame-core tube structure system, three comparative schemes are established of reinforced concrete core tube construction, steel-reinforced concrete core tube construction and the combined shear wall core tube structure with the grid -tube- type double steel plate wall with infilled concrete are established, and the dynamic elastoplastic time history is analyzed. Research shows that under the influence of a severe earthquake, the lateral strength degradation and stiffness degradation are slow on the Joint structural system of concrete filled steel tubular frame and composite shear wall core tube structure with the grid -tube- type double steel plate wall with infilled concrete, so interlayer shear force and bottom shear force increase, structural lateral stiffness increased significantly, interlayer displacement angle reduces significantly, and it improves the seismic performance of tall building.

1. Introduction

As the crystallization of modern architecture technology, supertall buildings have promoted the image of cities and countries[1-2], and tall buildings have always been an important means for people to demonstrate their achievements [3-4]. As the floor increases, the horizontal load of supertall buildings becomes the key factor for design control. Modern high-rise buildings for the shear wall structure “high axial compression ratio, high ductility, thin wall thickness” requirements[5-8], therefore, high-rise steel structure building needs to be an excellent seismic performance, a new type of composite steel plate shear wall structure[9-11].

Draw lessons from the advantages of steel concrete composite structure[12-13], multiple tie plates are arranged between the outer double steel plates. A rectangular grid steel pipe wall, bar grille self-compacting concrete, high strength steel pipe casting to form a rectangular grid type double steel pipe concrete composite shear wall structure and a new type of composite shear wall, it has many advantages, such as stiffness, high degree of industrialization, construction is convenient, strong ability to resist buckling, high yield load, good ductility, energy dissipation good performance and low cost.

In this paper, a kind of 30 - storey concrete-filled steel tube frame - core tube structure system is accurately analyzed by nonlinear time history, and reveal the new grille type steel concrete composite seismic performance of shear wall structure system, the dynamic characteristics, for this composite shear wall structure system provided a reference for the design and application.

2. The experimental study

2.1 Test model
The experimental design of three grille type concrete composite shear wall is designed, which is csw-1, csw-2, csw-3, and it is 1400mm width, 160mm thickness and 2800mm. Through this new type of shear wall shear wall subjected to low-cyclic pseudo-static experiment was carried out, from hysteresis curves, skeleton curves, ductility, energy dissipation, etc, to study the seismic performance. (as shown in figure 1).

![Test section schematic](image1)

![Test device diagram](image2)

**Figure 1. Test specimen**

Three specimens were divided into 2 groups, the first set of CSW - 1, CSW - 2 the do - displacement 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, the particular case as shown in table 1.

| Axial compression ratio | Loading way     |
|-------------------------|-----------------|
| CSW-1                   | 0.1 Force-dis control |
| CSW-2                   | 0.6 Force-dis control |
| CSW-3                   | 0.1 Constant amplitude loading |

Table 1. Test load condition condition

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 model [16 common channel steel hot rolling, all connections are welding between steel. The loading beam section size is 400*400mm, ground beam section size is 500*600mm, 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 flangeHM350*200.

2.2 Test results analysis
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 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.

![The specimen hysteresis curve](image3)

**Figure 2. The specimen hysteresis curve**

The concrete composite shear wall of the grid-type steel plate, the concrete in the tube is in three to the pressure state, improves the compressive strength and ductility of the concrete in the tube. 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. (as shown in figure 2 and figure 3).
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, ductility coefficient is close to 9, under high axial compression ratio, the ductility coefficient is close to five.

| Specimen | Yield Load (kN) | Yield Displacement (mm) | Peak Load (kN) | Peak Displacement (mm) | Limit Displacement (mm) | Ductility Coefficient |
|----------|-----------------|-------------------------|----------------|-------------------------|-------------------------|-----------------------|
| CSW-1    | 702.3           | 12.62                   | 929.84         | 69.08                   | 114                     | 9.03                  |
| CSW-2    | 811.1           | 10.78                   | 1082.38        | 30.90                   | 55                      | 5.10                  |
| CSW-3    | 682.7           | 12.32                   | 925.17         | 68.25                   | 114                     | 9.25                  |

3. Engineering background and design parameters
A 30 layer of steel frame - core tube structure, structural plane size is 24m * 24m, the height of 4 m, the total height is 120 m, model parameters as shown in table, floor plan model is shown in figure 4. The structure of the structure is 8.5 degrees, and the second type is 0.35 s.

Figure 3. Test skeleton curve

Figure 4. Layout plan of standard floor structure

(a) Section of the steel concrete composite shear wall
(b) The simplified section of the grid-type steel plate concrete composite shear wall

Figure 5. Composite shear wall section
This project adopts the concrete filled steel tubular frame - core tube shear wall structure system, to verify the grille type double steel pipe concrete composite shear wall structure seismic performance, the advantage of establishing three core tube shear wall contrast scheme, plan A for reinforced concrete shear wall core barrel, plan B for steel reinforced concrete core tube structure, program C grille type double shear wall core tube structure of concrete filled steel tube composite structures. The composite shear wall section is shown in figure 5, and the structural parameters are shown in table 3.

| Table 3. The structural parameters |
|-----------------------------------|
| **Steel beam**                    |
| Floor                             | Section (mm) | Concrete grade | Steel grade |
| 1-30                              | 400x600x25x10| Q345           |

| Reinforced concrete column        |
|-----------------------------------|
| Floor                             | Section (mm) | Concrete grade | Steel grade |
| 1-10                              | 800x20       | C50            | Q345        |
| 11-20                             | 700x18       | C50            | Q345        |
| 21-30                             | 600x16       | C50            | Q345        |

| Steel reinforced concrete shear wall |
|--------------------------------------|
| Floor | thickness(mm) | Concrete grade | Steel grade | Reinforcement ratio |
| 1-10  | 400           | C40            | HRB400      | 0.37%               |
| 11-20 | 300           | C40            | HRB400      | 0.46%               |
| 21-30 | 250           | C40            | HRB400      | 0.57%               |

| Steel concrete shear wall          |
|------------------------------------|
| Floor | thickness(mm) | Concrete grade | Steel grade | Reinforcement ratio |
| 1-20  | 300           | C40            | HRB400      | 0.37%               |
| 21-30 | 250           | C40            | HRB400      | 0.57%               |

4. Dynamic time history analysis

4.1 The selection of seismic waves

The elastic-plastic timing analysis of the els-centro (EL) wave X direction and Y direction, KOBE wave Y direction and NB wave Y to the four-medium operating conditions were carried out for each of these structures. At the time of analysis, the acceleration peak (PGA) is required for the modification of small and large earthquakes, and the PGA = 510cm/s2.

4.2 Structural self-oscillation period contrast

In this paper, the three kinds of schemes are analyzed in terms of dynamic time analysis, and the three structures have the following table 4. Research showed that the composite shear wall structure has good seismic performance, each order natural vibration period of structure is reduced, the effects on high order natural vibration period of slightly less than low order natural vibration period. Steel reinforced concrete core tube and grille type of concrete-filled steel tube core barrel each order natural frequency of vibration are improved, shows that the structure of two kinds of composite shear wall structure stiffness were increased, the stiffness of grille type concrete-filled steel tube core barrel increase more bright. Compared with steel reinforced concrete core tube, grille type concrete-filled steel tube core barrel to the improvement of structure dynamic rigidity of the torsional rigidity of peace, to the improvement of the translational stiffness is slightly greater than the torsional rigidity.

| Table 4. structural cycle(s) |
|------------------------------|
| Vibration mode | A  | B  | C  |
| 1              | 2.848 | 2.649 | 2.394 | 4 | 0.736 | 0.677 | 0.612 |
| 2              | 2.826 | 2.599 | 2.342 | 5 | 0.676 | 0.628 | 0.578 |
| 3              | 1.598 | 1.452 | 1.309 | 6 | 0.565 | 0.519 | 0.469 |
4.3 The comparative study of the analysis results of the structure time analysis

4.3.1 Interlayer displacement Angle.

![Graphs](image1)

Figure 6. The comparison of the interlayer displacement Angle under the small earthquake

![Graphs](image2)

Figure 7. The comparison of Maximum interlayer displacement Angle of the three structural system

| Maximum interlayer displacement Angle | EL wave on the X direction | EL wave on the Y direction | KOBE wave on the Y direction | NR wave on the Y direction |
|--------------------------------------|---------------------------|---------------------------|-----------------------------|---------------------------|
| A Small earthquake                    | 0.00141                   | 0.00157                   | 0.00128                     | 0.00119                   |
| B Small earthquake                    | 0.00479                   | 0.00651                   | 0.00081                     | 0.00639                   |
| C Small earthquake                    | 0.00129                   | 0.00137                   | 0.00116                     | 0.00109                   |
| A Severe earthquake                   | 9.4%                      | 13.9%                     | 10.5%                       | 9.5%                      |
| B Severe earthquake                   | 0.00336                   | 0.00482                   | 0.00632                     | 0.00451                   |
| C Severe earthquake                   | 42.6%                     | 35.2%                     | 39.8%                       | 41.9%                     |
| A earthquake                          |                           |                           |                             |                           |
| B earthquake                          |                           |                           |                             |                           |
| C earthquake                          |                           |                           |                             |                           |

The figure 6 shows that under the action of minor earthquakes, the four kinds of seismic load conditions, the displacement between layers of grille type concrete-filled steel tube core barrel Angle significantly reduced, and the steel reinforced concrete core tube under the action of minor earthquakes for building between 1-10 of layer displacement Angle slightly enlarged, other layers of interlayer displacement Angle were reduced, the main reason is that under the action of minor earthquakes structure generally remain in elastic stage, the plan B 1-10 layer at the bottom of the wall thickness of the wall thickness of the scheme is A little some, the stiffness of floor will be slightly lower accordingly; And because the scheme C grille type steel concrete composite shear wall components due to three to the compression of concrete, concrete elastic modulus increases, less wall thickness, program C stiffness is increased.

From figure 7, table 5 shows that under the strong earthquakes, the four kinds of seismic load conditions, steel reinforced concrete core tube and grille type concrete-filled steel tube core barrel has obvious decrease interlayer displacement Angle, grille type concrete-filled steel tube core barrel of interlayer displacement Angle and decrease the rate of about 140%, interlayer displacement Angle of steel reinforced concrete core
canister decreases by only about 40%, thus for high-rise steel concrete composite shear wall structure using grating type can not only reduce the thickness of the wall body, get more interior space, and in small earthquakes, strong earthquakes show superior seismic performance and ductility. Grille type steel concrete composite shear wall structure stiffness and bearing capacity of small earthquakes with large, earthquake, can not only keep the larger degradation of bearing capacity and stiffness degradation and have good ductility and energy dissipation capacity, grille type steel concrete composite shear wall seismic performance is good.

4.3.2 Shear force of core cylinder.

![Figure 8. Layer shear of the three structural systems under small earthquakes](image)

(a) EL wave on the X direction (b) EL wave on the Y direction (c) KOBE wave on the Y direction (d) NR wave on the Y direction

As can be seen from figures 8 and 9, the larger the inter-storey shear force of the core tube and the smaller the ratio of horizontal load borne by the frame column indicates the larger the stiffness of the shear wall structure when the earthquake occurs, and the slower the degradation of the shear wall stiffness is, which is beneficial to the seismic resistance of the super-high-rise structure. By the picture above you can see, in under the action of minor earthquakes and strong earthquakes, because of the structural system B and C core barrel interlaminar shear structural system are than A interlayer shear structural system is increased, the strong earthquakes lower shear increases more obvious, that when the earthquake hit structural system B and C shear wall structural system core tube has A larger residual stiffness and strength. When the earthquake hit, found that the structure of the system structural system of the various layers of shear were greater than C B layer shear, show that grille type steel concrete composite shear wall has better seismic performance.

4.3.3 Shear force at the bottom of the structure. Structure at the bottom of the shear force is at the bottom of the shear structure, structure is the underlying structure of each floor shear of the largest position, is also one of the important indexes of structural seismic performance analysis.

Because of structural system and structural system B C structural lateral stiffness degradation is slow, the rarely met earthquake structure underlying the schedule of total shear curve compared with A structural system, shear peak time and the time history curve of shape has certain change, structural system and structural system B models C the bottom of the total shear force most of the time is more than A structural system, structural system B and C structural system stiffness degradation is slow, A concrete shear wall structure system stiffness degradation rapidly. This paper compares the bottom total shear value of three structural systems, the shear force of the underlying framework and the shear strength of the underlying core barrel, as in table 6.

To the table above, numerical analysis, found that structural system B and C due to the shear wall structure system core tube structure lateral stiffness degradation is slow, rarely met earthquake, compared to A structural system, structural system and structural system B C significantly increase the lateral stiffness of structure, four kinds of working conditions, the bottom of the structural system and structural system B C shear peak has increased, among them, the structure C lateral stiffness degradation is more slow, severe earthquake, the structure C lateral stiffness than the lateral stiffness of A structural system has improved significantly.

Structure system adopts the core tube is grille type C steel concrete composite shear wall structure form, has resulted in A frame column structure system C and A frame column structural system must be changed, because the total structure of the bottom shear increases, lead to the increase of shear at the bottom of the concrete filled steel tube column has response, therefore, the core tube is grille type steel concrete composite
shear wall are not suitable for, with reinforced concrete column can be assigned frame column shear increases too much cause destruction concrete frame column in advance; The core barrel is a concrete composite shear wall of grid-type steel plate which must be used with the concrete column of steel pipe, strong and strong, complementary to each other, and work together.

### Table 6. The comparison of the shear peaks at the bottom of the three structural systems

|        | Shear wall | Concrete filled steel tubular column |
|--------|------------|--------------------------------------|
|        | shear force (KN) | difference value | shear force (KN) | difference value |
| A      | ELX        | 16036                  | 14003             | 2387             |
| KOB EY | 23899      | 20985                  | 3098              |
| B      | ELX        | 27563                  | 24323             | 3297             |
| KOB EY | 24025      | 21112                  | 2297              |
| C      | ELX        | 26361                  | 22811             | 3614             |
| KOB EY | 24025      | 21112                  | 2297              |
|        | NRY        | 24025                  | 21112             | 2297              |
|        | ELX        | 26361                  | 22811             | 3614             |
|        | KOB EY     | 26361                  | 22811             | 3614             |
|        | NRY        | 26067                  | 23477             | 2631             |
|        | ELX        | 29715                  | 26607             | 3597             |
|        | KOB EY     | 30099                  | 26707             | 3498             |
| C      | ELX        | 43185                  | 38969             | 4578             |
| KOB EY | 48842      | 45067                  | 42382             | 4902             |
|        | NRY        | 44596                  | 40939             | 4009             |

5. Conclusion

This paper designed the three steel concrete composite shear wall specimen grating type, and the test research under low reversed cyclic loading. In combination with a 30 layer between concrete filled steel tubular frame structure system, establish reinforced concrete core tube, steel reinforced concrete core tube and grille type double steel concrete composite shear wall core tube structure of three kinds of system comparison, carries on the rarely met earthquake under the action of the dynamic elastic-plastic time history analysis of contrast calculation, from the interlayer displacement Angle and layer shear, the bottom shear structure seismic performance analysis contrast, verify the superiority of the new composite shear wall structure seismic performance. The main conclusions are as follows:

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. With the increase of the axial pressure ratio, the load capacity of the concrete composite shear wall of the grille type plate is increased, and the ductility and energy dissipation of the wall is decreasing.

3. 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.

4. For three structural systems under severe earthquake dynamic elastic-plastic time history analysis, in the severe earthquake, the concrete filled steel tubular frame - grille type double steel concrete composite shear wall core tube structure system slow lateral strength degradation and stiffness degradation, structural lateral stiffness increased significantly, interlayer displacement Angle decrease significantly.

5. Because of the steel reinforced concrete core tube and grille type double steel concrete composite shear wall core tube with the increase of lateral stiffness and the severe earthquake action, the interlayer shear, grille type steel concrete composite shear wall increase is more obvious.

6. The lattice structure of the steel concrete composite shear wall lateral stiffness increases, the total structure of the bottom shear increases, lead to the increase of shear at the bottom of the concrete filled steel tube column.
has response, grille type steel concrete composite shear wall must and concrete-filled steel tube column, combination of complementary advantages.

(7)he research shows that the concrete filled steel tubular frame - grille type steel concrete composite shear wall structure system has a good seismic performance, under severe earthquake load, the grid steel concrete composite shear wall still maintains large stiffness and large carrying capacity, can continue to withstand the severe earthquake loads, grille type steel concrete composite shear wall good anti-earthquake ductility, models can guarantee that is worth of popularization and application.

6. References

[1] ZHAO Xin,DING Jiemin,SUN Huahua et al. Structural design of the Shanghai Tower for wind loads [J]. Journal of Building Structures, 2011, 32(7): 1-7. (In Chinese)

[2] Wang Dasui, Zhou Jianlong, Yuan Xingfang. Structural design of Shanghai World Financial Center [J]. Building Structure, 2007, 37(5): 8-12. (In Chinese)

[3] Hossain K M A, Wright H D. Experimental and theoretical behavior of double skin composite walls under in-plane shear [J]. Journal of Constructional Steel Research, 2004, 60(1): 59-83.

[4] Eom T S, Park H G, Lee C H, Kim J H, Chang I H. Behavior of double skin composite wall subjected to in-plane cyclic loading [J]. Journal of Structural Engineering, ASCE, 2009, 135(10): 1239-1249.

[5] DING Jiemin, WU Honglei, ZHAO Xin. Current situation and discussion of structural design for super high-rise buildings above 250m in China [J]. Journal of Building Structure, 2014, (03): 1-7. (In Chinese)

[6] Link R A, Elwi A E. Composite concrete-steel plate walls: analysis and behavior [J]. Journal of Structural Engineering, 1995, 121(2): 60-71.

[7] Driver R G, Kulak G L, Kennedy D Z et al. Cyclic test of four-story steel plate shear wall [J]. Journal of Structural Engineering, ASCE, 1998, 124(2): 112-120.

[8] Elgaaly M, Liu Y. Analysis of thin-steel-plate shear walls [J]. Journal of Structural Engineering, ASCE, 1997, 123(11): 1487-1496.

[9] Cao Wanlin, Wang Yaohong, Dong Hongying, Zhang Jianwei. Shaking table test study on shear walls with concrete-filled steel tube columns and embedded steel-plate [J]. Earthquake Engineering and Engineering Vibration, 2011, 31(20): 75-81. (In Chinese)

[10] LU Xilin, GAN Chunjie, WANG Wei. Study on seismic behavior of steel plate reinforced concrete shear walls [J]. Journal of Building Structures, 2009, 30(5): 89-96. (In Chinese)

[11] Nie Jianguo, Tao Muxuan, Fan Jiansheng, et al. Research advances of composite shear walls with double steel plates and filled concrete [J]. Building Structure, 2011, 41(12): 52-60. (In Chinese)

[12] McKinley B, Boswell L F. Behaviour of double skin composite construction [J]. Journal of Constructional Steel Research, 2002, 58: 1347-1359.

[13] BU Fanmin, JIE Jianguo, FAN Jiansheng. Experimental study on seismic behavior of medium and high shear-span ratio composite shear wall with double steel plates and infill concrete under high axial compression ratio [J]. Journal of Building Structures, 2013, (04): 91-98. (In Chinese)