Research on Application of Steel and Concrete Mixed Structure in High-rise Buildings

Guofang Li*

Zhongyedi construction group(sanhe) architecture design consult co., ltd., hebei, China

*Corresponding author: 1290476940@qq.com

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Abstract: Steel-concrete hybrid structure has some advantages of steel structure and reinforced concrete structure. It is a high-rise building form that conforms to China's national conditions and has good comprehensive economic indicators. The Hudong Shipyard Technology Center Building is a typical high-rise steel-concrete hybrid structure. This article briefly introduces the structural design of this project, including structural layout, structural analysis and calculation, as well as the main calculation results, and mainly introduces the typical node structure, including column foot structure, beam-column connection, beam-wall connection and beam connection, etc. At the same time, the paper briefly introduced the application of steel-concrete hybrid structure in high-rise buildings.

1. Introduction

With the rapid development of my country's economic construction, the number of high-rise buildings in the city has increased, and their height has continued to rise, from the initial 100-meter high-rise building to the current 400-500 meters. Traditional reinforced concrete structures have shown their drawbacks with the increase in the number of building floors and the increase in load. For example, the cross-section size of the components is too large, occupying more usable area, which affects the full performance of the building function; the structure is too heavy., Resulting in an increase in the seismic force absorbed by the structure and an increase in the difficulty of foundation design. To solve these problems, steel structures and steel-concrete hybrid structures have been rapidly developed in super high-rise buildings, especially in recent years, steel-concrete hybrid structures have been widely used. This structure has the characteristics of light weight and fast construction speed of all-steel structure. At the same time, it is better than all-steel structure in terms of cost [1]. It has the advantages of steel structure and concrete structure, and is an optimized structure type. Steel-concrete hybrid structure is becoming the dominant structure type in high-rise construction in my country. This article briefly introduces the structural design of a typical mixed structure building built in Shanghai and the shaking table test based on the model of this building for engineers' reference.

2. Steel-concrete hybrid structure type

2.1 Steel reinforced concrete structure

Steel reinforced concrete structure is a structure in which steel bars are arranged around steel and concrete is poured. Steel concrete beams, steel concrete columns, steel concrete shear walls and cylinders are commonly used in high-rise buildings. The frame of steel reinforced concrete beam generally adopts solid web rolled I-shaped steel or tailor-welded steel plates into an I-shaped section. The steel core column embedded in the steel concrete column has rolled H-shaped steel or H-shaped section welded by steel plate, square steel tube, round steel tube, and is tailor-welded by an I-shaped

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steel or narrow flange H-shaped steel and a split T-shaped steel There are several types such as T-shaped cross section with flange.

2.2 Steel tube concrete structure

The concrete-filled steel tube structure is a structure in which concrete is filled inside the steel tube, and steel tubes are generally no longer equipped with steel bars. The concrete in the steel pipe is effectively restrained by the steel pipe, which can significantly improve its compressive strength and ultimate compressive strain, while the concrete can enhance the stability of the steel pipe, so that the strength of the steel can be fully exerted. Therefore, the concrete-filled steel tube column is an ideal form of compression member and has good seismic performance [2].

2.3 Steel-concrete composite beam and slab

The steel-concrete composite beam slab utilizes the tensile force on the cross-section of steel and the pressure of concrete to make full use of the tensile strength of steel and the compressive strength of concrete. The steel beam in the composite beam slab can bear the construction load, while the profiled steel plate can be directly used as the template for the floor concrete, speeding up the construction progress and reducing the weight of the floor, so it is more used in the structure of high-rise buildings. The plan of a typical high-rise steel-concrete mixed structure is shown in Figure 1.

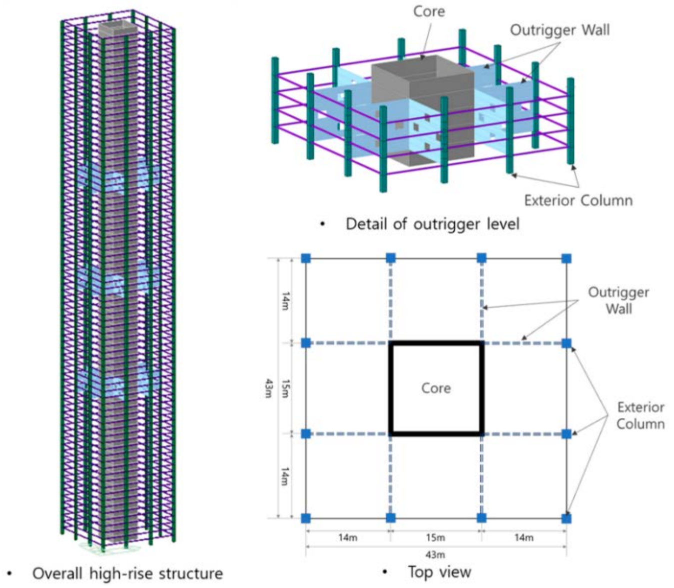

Fig 1. Typical high-rise steel-concrete mixed structure plane

The steel-concrete hybrid structure system combines the advantages of steel structure and concrete structure. Compared with the all-steel structure, the steel consumption can be reduced by 40% to 55%, and the construction speed is equivalent, which can reduce the workload of on-site welding and reduce the cost of fire protection; compared with the concrete structure, it can reduce the weight of the structure and increase the building Use area to shorten construction period. Therefore, it is a better super high-rise building structure in line with my country's national conditions.

3. Characteristics of steel-concrete hybrid structure system

3.1 Structural composition

3.1.1 Framework-Core System

This structural system is generally composed of a reinforced concrete core tube and an outer ring steel frame. The core tube is mainly a square, rectangular or polygonal tube surrounded by reinforced concrete walls, and a certain number of vertical and horizontal reinforced concrete partition walls are set inside. A certain number of section steel frameworks are generally set in the core tube wall to improve the ductility of the structure [3]. The steel frame of the outer ring is formed by rigidly connecting steel columns (steel concrete columns or concrete-filled steel tube columns) and steel beams. The plane shape and column spacing are determined according to the layout requirements of the building. When the height of the building is high, according to the results of internal force analysis, in the top layer of the structure and the middle floors of every several floors, a number of longitudinal and transverse rigid arms (extending arms to the frame) and matching them are set up from the core tube. The outer ring strip steel to the frame.

3.1.2 Tube-in-tube system

This kind of structural system is generally composed of a reinforced concrete core tube (steel-reinforced concrete core tube) and an outer ring steel frame tube, which is suitable for super high-rise buildings with many floors. The outer ring steel frame tube is rigidly connected by dense columns and deep beams. The column distance is generally less than 4 meters. The section height of the steel beam is also large to minimize the shear lag effect and make the outer frame tube form a Effective three-dimensional components give full play to their overall anti-bending effect and reduce the lateral displacement of the entire structure. The structure of the core tube and whether it is provided with an outrigger feeder frame and an outer ring belt-shaped feeder frame are basically the same as the above-mentioned frame-core tube system.

3.2 Structural performance of steel-concrete hybrid structure

3.2.1 Force characteristics

In the steel-concrete hybrid structure, the reinforced concrete core tube with high lateral stiffness is used to bear most of the horizontal load; the outer ring steel frame with high material strength is used to bear most of the vertical load; The span steel beam serves as the load-bearing member of the floor between the inner core tube and the outer frame. In this way, different types of structural members can play their own characteristics. In the frame-core tube system, the lateral rigidity of the reinforced concrete core tube is much greater than that of the outer ring steel frame, and almost bears all the horizontal loads acting on the structure. The outer ring steel frame mainly bears the vertical load and shares a small part of the load [4]. Horizontal load. When analyzing the period and mode shape of the steel frame-concrete hybrid structure, a linear model can be used for the flexible connection; a nonlinear model is used in the limit analysis stage of the frame structure, and the parameters are determined by experiments. Judging from a large number of domestic and foreign documents, the second-order effect (P-Delta effect) should be considered for the steel frame part of the steel frame-concrete hybrid structure. Figure 2 shows the calculation model of the lateral stiffness of the steel-concrete frame. After considering node flexibility, P-Delta effect, etc., it is deduced that the lateral stiffness of the j-th layer of the steel frame is:

$$C_{Fj} = h_{cj} \sum_{j=1}^{m} \frac{12 i_{cj}}{h_{cj}^2} \beta_{ij} - \frac{p_{ij}}{h_{cj}} \tag{1}$$

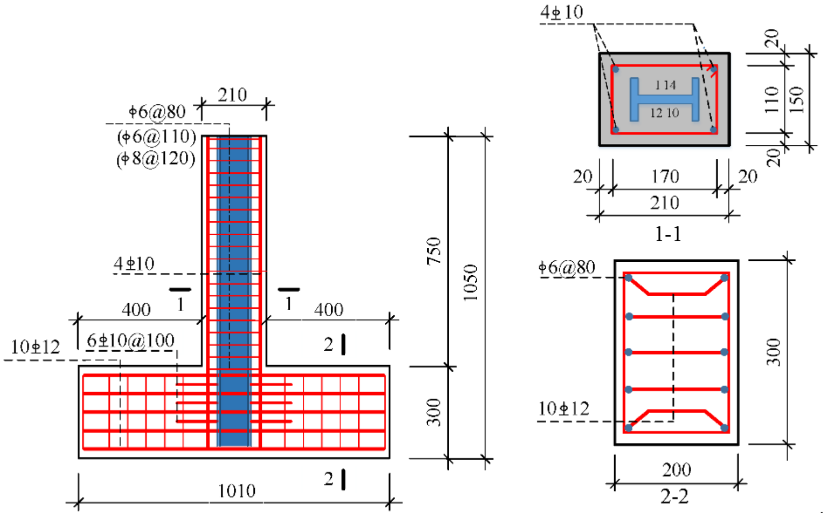

Fig 2. Calculation model of lateral stiffness of steel-concrete frame

Among them: $\frac{12i_{cj}}{h_{cj}^2}$ represents the lateral stiffness of the i-th column in the j-th floor, $\frac{p_{ij}}{h_{cj}}$ represents the reduction in the lateral stiffness of the column due to the $P-\Delta$ effect, and β_{ij} represents the correction factor considering the beam-column effect, flexible connection and $P-\Delta$ effect.

$$\begin{aligned} \beta_{ij} &= f\left(p,\varphi_k,K_{cl},R_{klin}\right) = 0.5\varphi_2\beta_1\beta_2^{-1} \\ \beta_1 &= \left(6\varphi_3 - 3\varphi_4\right)\sum_{i=1}^{2} K_{cl} + 18\prod_{i=1}^{2} K_{cl} \\ \beta_2 &= \left(4\varphi_3^2 - \varphi_4^2\right)6\varphi_3\sum_{i=1}^{2} K_{cl} + 9\prod_{i=1}^{2} K_{cl} \end{aligned} \quad (2)$$

$\varphi_k\left(k=2,3,4\right)$ stands for the stability function, $K_{cl} = r_l \circ K_{cl}\left(l=1,2\right)$ stands for the ratio of the sum of the stiffnesses of the adjacent beams at nodes 1, 2 to the sum of the column stiffnesses, and $r_l = \frac{1}{1+3\alpha_l}\left(l=1,2\right), \alpha_l = \frac{2ib_{ij}}{R_{kl}}$ stands for the connection stiffness coefficient (l=1,2), h_{cj} which stands for the j layer Floor height, i_{cj} represents the stiffness of the i column of the j floor, and R_{kl} represents the spring stiffness at the beam end 1 or 2.

3.2.2 Wind resistance

For an all-steel structure, due to the small lateral stiffness of the structure, the cross-wind vibration acceleration of the structure may exceed the allowable value, which will cause discomfort to the people in the building, and additional vibration reduction measures need to be taken. If the steel-concrete hybrid structure is adopted, the reinforced concrete core tube has great lateral rigidity, so that the structure has strong wind resistance, and its vibration acceleration in the downwind and crosswind directions is easier to control within the allowable value range.

3.3 Case analysis

In order to study the mechanical performance of the steel-concrete hybrid structure under the action of an earthquake, combined with an example of a high-rise residential building, three main structure design schemes were adopted, namely: reinforced concrete slab structure, pure steel structure, and steel-concrete hybrid structure. The layout of the three structural schemes is the same, and only the structure adopted is different. Through calculation, the maximum inter-story displacement curve and the maximum floor displacement curve under the same earthquake action are obtained for comparative analysis [5].

3.3.1 Design scheme

The design object is the main structure of the above ground part of a 13-story residential building, with a total height of 33m and a floor height of 3m; the building area is about 6828m^2; two symmetrical units, one ladder and two households; seismic fortification intensity is 6 degrees, category B building standard.

(1) Plate structure scheme. It adopts reinforced concrete frame and hollow block wall. Part of the shear wall is set to improve the lateral rigidity; the core tube area (elevator room) adopts a shear wall structure. Among them, concrete grade: beam and column are C30, shear wall is C20; section size: beam is 150mm×150mm, column is 200mm×200mm; wall thickness: inner and outer infill walls are 180mm, 240mm, shear wall It is 160mm.

(2) Steel structure plan. The main structure adopts a steel frame and is filled with masonry walls. The core tube area also uses a steel frame, and additional steel supports are provided to increase the lateral rigidity. Among them, the steel material is Q235B; the frame beams are H250×180×8×10, H300×150×8×10, H250×100×8×10, and the frame columns are H250×250×10×14, H400×400 ×18×18; wall thickness: the inner and outer infill walls are 180mm and 240mm respectively [6].

(3) Mixed structure scheme. The steel-concrete hybrid structure adopts a steel frame + a reinforced concrete core tube, which gives full play to the advantages of large rigidity of the concrete structure, small lateral displacement and good seismic performance of the steel structure. The specific structure layout is shown in Figure 3 (limited to space, only one unit of symmetrical structure is listed). Among them, the nature of the material and the size of the main body are the same as the above two solutions.

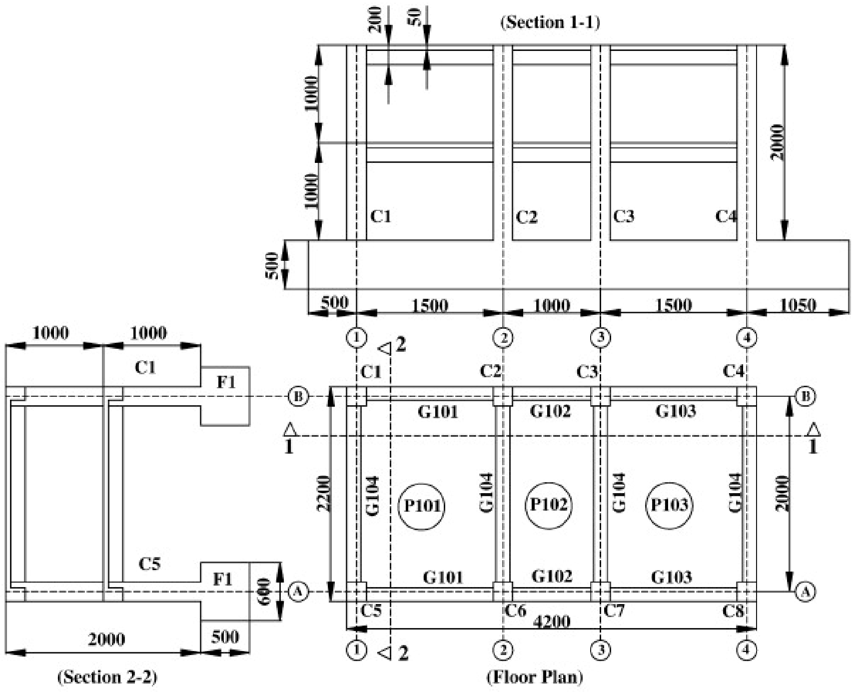

Fig 3. Mixed structure floor plan

(4) Column foot. In this design, the column foot is designed according to the hinged joint, and the exposed column foot is adopted. First, determine the area of the column base plate according to the compressive strength of the foundation concrete and the axial force the column bears, and then determine the maximum bending moment of the base plate according to the form of the column foot and the area of the base plate, so as to determine the required thickness. The horizontal reaction force of the column base plate should be transmitted by the friction between the base plate and the foundation concrete, and the friction coefficient can be 0.4. When the horizontal reaction force exceeds the frictional force, it can be reinforced by welding shear keys under the bottom of the bottom plate or the column foot with reinforced concrete. In this design, the horizontal reaction force of the column foot is very small, and the horizontal reaction force can be transmitted by the friction

between the base plate and the foundation concrete [7]. In the design of the column foot, it should be noted that the calculation of the axial force of the column needs to consider the reduction of live load. When the compression stress of the bottom plate appears negative, the anchor bolt must bear the tensile force. In this design, there is no tensile stress on the bottom plate, so the anchor bolt can be determined by the structure. In order to achieve the purpose of articulation, two anchor bolts are installed on the centroid line of the column bottom plate and connected with the foundation.

(5) Welding cross-section and splicing of columns. In this design, the beam and column sections are welded sections. For box-shaped columns, the corner assembly welds can be partially penetrated V-shaped or U-shaped welds. The thickness of the weld is 1/2 of the plate thickness, but within the range of 600mm on the upper and lower sides of the node and the frame beam. And within 100mm of the upper and lower sides of the site joints, grooved full penetration welds are required. The splicing of the H-shaped column at the construction site adopts the form of full penetration welding of the flange and the high-strength bolt connection of the web. The construction site splicing of the box-shaped column adopts full penetration bevel welding. Clapboard [8]. The diaphragm of the lower column should be flush with the mouth of the column with a thickness of 12mm, and the edge should be planned to have a good contact surface with the welding pad of the upper column. The diaphragm of the upper column is 10mm thick.

(6) The connection of beams and columns. The connection of frame beams and columns should adopt column through type. When the beam and column are rigidly connected, the frame beam and column flange are connected by full penetration welds, and the beam web and column should be connected by high-strength bolts [9].

3.3.2 Result analysis

Through the calculation of the PKPM software, the calculation result is shown in Figure 4 when the seismic wave action direction angle is 0°.

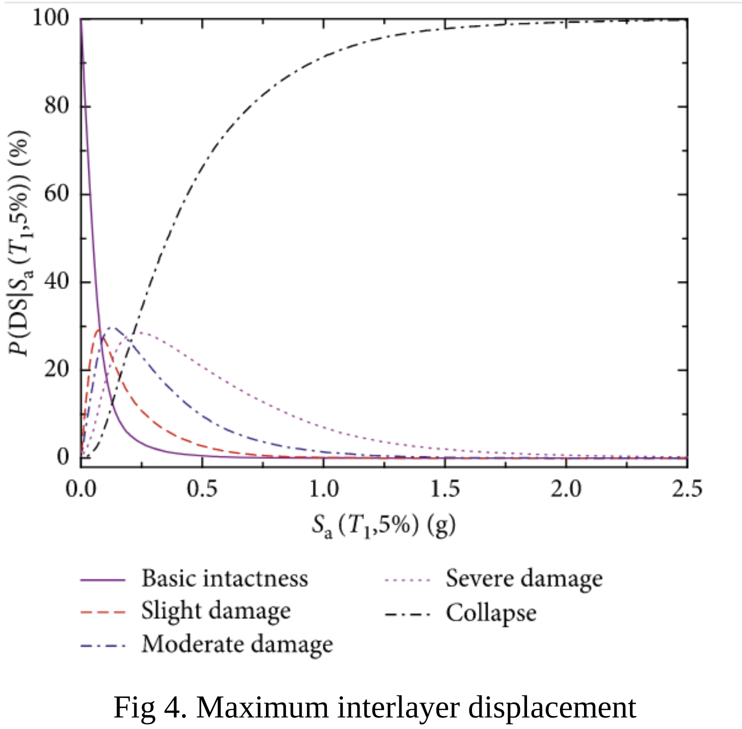

Fig 4. Maximum interlayer displacement

The "Code for Seismic Design of Building Structures" stipulates that the limit of the angle of displacement between floors of high-rise concrete structures is 1/1000, and that of steel structures is 1/300; the ratio of maximum floor displacement to storey height of concrete structures is 1/800, and steel structures are 1/550. It can be seen from Figure 4 that under the same seismic load, the interstory displacement angles of the three structures in the X and Y directions all meet the specifications; among them, the interstory displacement angle of the concrete structure in the X and Y directions is the smallest, and the mixed structure is in the middle. The pure steel structure is the largest, indicating that the stiffness of the hybrid structure is greater than that of the pure steel structure, but less than the concrete structure.

4. Conclusion

Steel-concrete hybrid structures are mostly used in B-level high-rise buildings (or over-limit high-rise buildings), generally core tube systems, tube-in-tube systems or other systems with strong lateral resistance. This structure combines the advantages of steel structure and reinforced concrete structure, with high bearing capacity, good ductility, and strong wind and earthquake resistance. In the past 10 years, the steel-concrete hybrid structure has been widely used in my country, which has good economic benefits and broad development space.

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