Elastoplastic analysis of Kunshan Xintiandi super high-rise office building under earthquake

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Abstract. Kunshan Xintiandi Super Tall Building is 142 meters high, with 3 floors underground and 31 floors above ground. Its structural system is composed of concrete-filled steel tube frame and core tube. The elastoplastic time-history analysis of the building was carried out by using PKPM-SAWS to analyze the overall index of the whole structure under large earthquake, and the mechanical performance of the key components under large earthquake was analyzed, and the loss mechanism of the key components under large earthquake was obtained, so as to ensure the mechanical performance target of the super high-rise building under large earthquake are not bad.

1. Project Overview
The project is located in Kunshan City, Jiangsu Province. The proposed site is located on Qianjin West Road to the north, Louchuang Road to the south and Sichang Road to the east. Zu Chong Road to the west. The project includes one office tower, four residential towers and one commercial tower. Each monomer shares a large basement chassis, a total of three basement floors. This design is No.5 office building and corresponding basement). This office building has 3 floors underground and 31 floors above ground, a total of 149 meters, a structural height of 142 meters, and a construction area of 58,000 m². The plan dimensions of the main building and the podium are 39.2mx48.4m. The architectural renderings are shown in Figure 1

The design service life of the project is 50 years. The safety grade of the building structure is 2, the fire protection grade of the building structure is 1, and the design grade of the foundation foundation is A. According to the Code for Seismic Design of Buildings (GB50011-2010) (2016 Edition) [1], the seismic group of the area where the project is located, the site category is Class IV, the seismic grade is 7 degrees 0.10g, and the corresponding characteristic period is 0.65s.
2. Structural design

2.1. Overview of structural system
The height of the above-ground structure of the project is 149.7m (31 floors). The main structure adopts the concrete-filled steel tube frame and core tube structure system. As the main lateral force resistance system, shear wall not only provides the ability to resist wind load and horizontal earthquake action, but also bears the additional torsion effect caused by the incoincidence of center of mass and center of stiffness. The outer frame mainly bears the vertical load, and also bears the role of the second seismic defense line. In order to ensure that the structure has good lateral stiffness and strong torsion resistance, the arrangement of shear wall and the stiffness of core tube are adjusted, and the stiffness of the side frame far away from the core tube is appropriately strengthened.

Due to the high storey height, combined with the requirements of seismic structure, the thickness of the shear wall in the bottom strengthening area is taken as 600 mm and the section size is gradually reduced upward until 400. The seismic bearing capacity and structural ductility of the shear wall can be improved by increasing the hoop ratio of the constrained edge members. The outer frame columns are concrete-filled steel tube columns, and the section is gradually reduced from 1200X1200 upward to 900X900.

3. Structural performance-based design
This project is a combination overrun, meet the technical specification for concrete structures of tall building (JGJ3-2010) [2] 7 degrees, composite structure height limit of 160 meters, but because of high altitude, appropriate to the performance-based design of structures, according to the height, set structure seismic performance goals for D. [3] in order to meet the requirements of the structure of the flame to fail, The elastoplastic analysis should be carried out for this kind of super-high and over-limit building to distinguish the overall damage of the structural system under large earthquakes Calculation and analysis.
4. Elastoplastic time-history analysis of rare earthquakes

4.1. Computational analysis and constitutive model under frequent earthquakes

In order to achieve the seismic performance goal of "not falling down under large earthquakes", the elastoplastic time-history analysis of the structure was carried out by using PKPM-SAUSAege software. In SAUSAGe calculation, the stress-strain relationship under tension and compression provided in Appendix C of Code for Design of Concrete Structures (GB 50010 -- 2010) \cite{4} was used as the skeleton curve of concrete hysteresis curve, and the damage coefficient was added to form a complete concrete hysteresis curve under tension and compression. The dynamic hardening model of steel adopts bilinear follow-up hardening model. In the cycle process, there is no stiffness degradation, but Bauschinger effect is considered. The strength/yield ratio of steel is 1.25, and the ultimate plastic strain corresponding to the ultimate stress is 0.25. Sausage software uses nonlinear fiber elements to integrate one-dimensional elements along the cross-section and length directions. Two-dimensional shell-plate elements are integrated along the thickness and in the plane by nonlinear fiber stratification elements.

4.2. Overall calculation results

For the elastoplastic time-history analysis of large earthquakes, the parameters provided by the seismic wave system software include two groups of actual strong earthquake records and one group of artificial simulated seismic waves. Time history curves of selected seismic waves for each group are shown in the figure below. The peak acceleration of rare earthquakes is 100 cm/s², the peak ratio of seismic waves in the primary and secondary directions is 1:0.85, and the duration of seismic waves is 40s.

The maximum inter-storey displacement Angle and vertex displacement of the structure under each group of seismic waves are shown in Table 1, and the displacement curve and inter-storey displacement Angle curve of the structure are shown in Figure 2, 3. As can be seen from the table, the maximum inter-storey displacement Angle of #5 in the X direction is 1/238, and the maximum inter-storey displacement Angle of the structure in the Y direction is 1/241. Both inter-storey displacement angles meet the limit requirement of the seismic performance target of 1/100.

### Table 1 The maximum displacement Angle between structures corresponding to each group of seismic waves

| direction | The seismic wave group | Interlayer displacement Angle | Maximum vertex displacement (m) | Maximum displacement Angle |
|-----------|------------------------|-------------------------------|---------------------------------|----------------------------|
| X         | RH2TG065               | 1/279                         | 0.375                           | 1/238                      |
|           | TH070TG065             | 1/348                         | 0.270                           |                            |
|           | TH002TG065             | 1/238                         | 0.460                           |                            |
| Y         | RH2TG065               | 1/241                         | 0.378                           | 1/241                      |
|           | TH070TG065             | 1/310                         | 0.282                           |                            |
|           | TH002TG065             | 1/278                         | 0.384                           |                            |

4.3. Seismic performance analysis of components

The seismic wave RH2TG065 with the largest seismic response was selected to analyze the seismic performance of the components.

The calculation results of artificial seismic wave RH2TG065

(1) Seismic performance analysis of shear wall
Fig. 2-3 presents the compression damage distribution diagram of the shear wall and the plastic strain distribution diagram of the shear wall reinforcement. It can be seen from the figure that, due to the reasonable opening of the shear wall to form the connecting beam, the energy dissipation effect of the connecting beam is obvious under a large earthquake, thus protecting the load-bearing wall limbs, and most of the shear wall limbs outside the core tube are not damaged. Only the local shear wall at the bottom appears compression damage at the edge members of the corner position, but the maximum damage factor is less than 0.2, the damage width is less than 25%, and the 300mm thick shear wall at the internal connection of the core tube appears local damage. Considering all, most of the shear walls are slightly damaged or not damaged, which meets the preset performance objectives.
2) Seismic performance analysis of frame column

Fig. 4 and Fig. 5 show the compression damage distribution diagram of frame column and plastic strain distribution diagram of steel bar. It can be seen from the figure that the frame column, upper frame column and roof layer concrete of the podium appear compression damage, the maximum compression damage factor is 0.13, and the plastic strain of steel bar appears (maximum 0.00069), showing mild damage. Most of the frame columns have no damage or slight damage, the overall structure can still ensure the seismic bearing capacity, the frame under the action of a large earthquake bearing capacity still has a certain amount of surplus, to meet the requirements of two seismic defense line.
5. Conclusion
According to the above calculation results, the following conclusions can be drawn:

1. Under the action of artificial wave RH2TG065, natural wave TH070TG065 and natural wave TH002TG065, the maximum inter-storey displacement angle of the structure in the X direction is 1/238, and the maximum inter-storey displacement angle of the structure in the Y direction is 1/241. The inter-storey displacement angle meets the limit requirement of the seismic performance target of 1/100.

2. Core concrete shear wall and coupling beam
   State of compression
   Under the rare earthquake action of concrete core tube, the joint beam first appears plastic hinge, and the development of plastic hinge is more obvious in the lower 2/3 area of building height. The large strain area of the concrete core tube is mainly concentrated in the bottom corner part and the shrinkage part of the core tube, but the strain is not high enough and no damage occurs. In the whole earthquake course, the compressive strain of the steel bar in the core tube is small and it is still in the elastic state.

   B) Tension state
   Because of the strong action of the whole structure frame, the concrete and steel bars of shear wall have no tensile strain during the whole time course of rare earthquake action.

   C) Shear state
   The maximum shear strain of the shear wall is small in the course of rare earthquake action, and the cantilever wall section only has a local high shear stress area at the position of the 42-story core tube retraction, while the main wall is basically in an elastic state under shear.

References
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