Structural analysis of a Concrete supertall buildings

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Abstract. A high-rise building, with a height of 146 meters, 4 floors underground and 32 floors above the ground, is a Class B limit of the specification, and belongs to an ultra-high over-limit structure. Through the selection of different structural systems, its structural system is determined as the frame core tube structure. This structure uses YJK, SATWE, PKPM-SAUSAGE for structural analysis, uses performance-based methods for seismic design, and the weak parts of the structure are strengthened accordingly. Structural analysis mainly includes elasticity analysis of small earthquakes, elastic time history analysis of small earthquakes, elastic and inflexion analysis of moderate earthquakes, inflexibility analysis of large earthquakes and elastoplastic time history analysis of large earthquakes.

1. Project Overview
The project are 2 office towers in the south area, which are D tower and E tower. This article analyzes the design of the D tower office building. The E tower office building has four underground floors and 50 floors above the ground, with a total height of 162 meters, a structural height of 146 meters. The architectural renderings are shown in Figure 1 and Structural calculation model are shown in Figure 2.

The service life of the project is 50 years, the safety level of the building structure is Grade 2, and the design level of the foundation is Grade A. According to the "Code for Seismic Design of Buildings" (GB50011-2010) (2016 edition)¹, the design earthquakes in the project area are grouped into the third group, the site category is type III, and the earthquake resistance rating is 6 degrees 0.05g. And the relevant documents of Shandong Province require unified design according to 7 degrees 0.10g, the corresponding characteristic period is 0.65s. The seismic fortification of the connection between the ground floor and the podium is classified as the key fortification class (type B), and the upper office area is for general fortification (type C).
2. Structural design

2.1. Structural system selection and scheme comparison
The structure belongs to reinforced concrete high-rise buildings belongs to the standard B-level\(^1\) Frame-core tube structure system is selected.

Core tube part: The core tube is located in the center of the tower, for grade B high-rise buildings, it is necessary to adopt more measures to ensure structural safety, while reducing the self-weight of the structure, reducing the earthquake action and reducing the foundation reaction force. Therefore, the layout of outer wall and inner wall of core tube is symmetrical.

Peripheral frame columns: The rectangular reinforced concrete column is adopted to give full play to the function of the surrounding frame and achieve the seismi performance goal of the double-lateral force resistant structure system on the premise of satisfying the function of the building.

2.2. Basic load values
In order to consider the structure main body and the reserved load in the future, the dead load value is 4.0 kN/m\(^2\), and the live load value is 3.5 kN/m\(^2\). The remaining live loads are taken according to the load specification\(^2\). Live load in the public area is 2.5 kN/m\(^2\), live load in the staircase is 3.5 kN/m\(^2\), live load in the refuge floor is 4.0 kN/m\(^2\), and live load in the elevator engine room is 7.0 kN/m\(^2\).

2.3. Sections and materials of main structural members
As the structure height increases, the concrete strength grade of columns and shear walls gradually decreases from C60 to C40 from bottom to top, and the thickness of the outer wall of the core tube shear wall changes from 900mm to 300mm from bottom to top, and the diameter of the concrete columns changes from 1500mmX1500mm to 900mmX900mm from bottom to top. typical beam cross section is 400mm X850mm. The concrete strength and section dimensions of the members are shown in the Table 1 below.
Table 1. Component concrete strength grades and section sizes.

|                | Concrete strength grade | Outer frame column section size | Core tube wall thickness |
|----------------|------------------------|---------------------------------|--------------------------|
| E tower        |                        |                                 |                          |
| Core tube wall, Frame column | -4 to 8 floors C60 | 1500x1500                       | X900, Y900               |
|                | 9 to 12 floors C60     | 1500x1500                       | X700, Y700               |
|                | 13 to 17 floors C55    | 1300x1300                       | X600, Y600               |
|                | 18 to 20 floors C55    | 1100x1100                       | X500, Y500               |
|                | 21 to 26 floors C50    | 1100x1100                       | X500, Y500               |
|                | 27 to 32 floors C40    | 900x900                         | X300, Y300               |
| Beam, Plate    |                        |                                 |                          |

3. Structural performance-based design
According to the "Technical Regulations for Concrete Structures of High-rise Buildings" (JGJ 3-2010) [3] [4], this project belongs to the B-level limit. According to the degree of over-limit, the seismic performance target of the structure is set to C.

4. Calculation and analysis

4.1. Calculation and analysis of frequent earthquakes
In the design process, according to the above different performance objectives, the elastic analysis of small earthquakes, elastic time history analysis of small earthquakes, elastic and non yielding analysis of medium earthquakes, elastic-plastic time history analysis of large earthquakes are carried out. This project's elasticity analysis in the event of frequent earthquakes uses YJK as the main design calculation software for the structure and SATWE to check and compare the main indicators. The torsional coupling effect, accidental eccentricity and two-way seismic effect are considered in the analysis of frequent earthquakes[5].

Through the comparison of the main indexes of the two software calculation results, it can be seen that the results of the two software are similar, which shows that the mechanical model is correct. According to the results of main calculation software yjk, the first period is translation period, and the third period is torsion period. The stiffness difference between the two directions of the structure is small, and the ratio of the first torsion cycle to the first translation cycle of the structure is less than 0.85, which meets the requirements of the code. The maximum inter story displacement angle of the structure is 1 / 992 in X direction and 1 / 1081 in Y direction, both of which are less than the specification limit of 1 / 800. In the case of accidental eccentricity, yjk results show that the maximum floor displacement to average displacement ratio (the ratio of the maximum floor displacement to average floor displacement) is 1.13, which meets the requirement that the code should not be greater than 1.4.

Table 2. Comparison of main calculation results.

|                | YJK       | PKPM      |
|----------------|-----------|-----------|
| Mode of vibration(s) |          |           |
| T1             | 3.9221 (X)| 4.0034 (X)|
| T2             | 3.7881 (Y)| 3.8296 (Y)|
| T3             | 3.2185 (T)| 3.2900 (T)|
| T3/T1          | 0.821     | 0.822     |
| Maximum displacement of vertex (mm) |      |           |
| X direction wind | 55.873    | 67.35     |
| Y direction wind | 46.26     | 53.87     |
| X-direction earthquake | 123.72    | 125.52    |
| Y-direction earthquake | 114.83    | 115.39    |
| Maximum inter story displacement angle |         |           |
| X-direction earthquake | 1/992 (n=31) | 1/986(n=31)|
| Y-direction earthquake | 1/1081 (n=30)| 1/1083(n=31)|
4.2. Calculation and analysis of frequent earthquakes
Horizontal two-way seismic action is considered in the project, in which the ratio of peak acceleration of main direction and secondary direction seismic wave is 1:0.85. In order to check the calculation results of CQC method, yjk software is used to select 2 artificial seismic waves and 5 natural seismic waves for small earthquake elastic time history analysis of the structure. The elastic time history analysis results are compared with the calculation results of mode response decomposition spectrum method, and the comparison results are shown in the figure 3 and figure 4 below. According to the figure, the base shear under the action of seismic wave is less than the floor base shear value of CQC method, and the inter floor displacement angle under the action of seismic wave is less than CQC calculation result. There is no abrupt change in the inter floor displacement angle curve, and the lateral stiffness of the structure changes uniformly along the height without obvious abrupt change. Therefore, CQC method can be used to design the structure.

| Ratio of maximum displacement to average displacement | X-direction earthquake | Y-direction earthquake |
|-------------------------------------------------------|------------------------|------------------------|
|                                                       | 1.13                   | 1.13                   |
|                                                       | 1.13                   | 1.14                   |

Figure 3. X-direction Earthquake floor shear.  Figure 4. Y-direction Earthquake floor shear.

4.3. Analysis on eccentric tension of shear wall
In order to investigate the tension of the flange wall limbs under a moderate earthquake, the tensile force of the shear wall of the whole building is analyzed. The results are shown in Figure 5. From the calculation results in the figure, it can be seen that some wall limbs have tensile stress, and most of the floors have no pull gravity greater than ftk2, and there is a case of large partial tension at the end wall of some floors. Based on the situation of the tension of the wall limbs, the section steel is installed at the corner of the shear wall to resist the tensile force under the earthquake.
Based on the analysis of the shear wall tension of the whole building, it can be seen from the calculation results in the table that the tensile force of all floors is greater than 2ftk, so there is no need to configure section steel.

5. Conclusions

Measures taken in this structural design for overruns:
1. Improve the role of the frame part as the second line of defense, and appropriately increase the reinforcement of the frame column;
2. At the bottom reinforcement part, when the shear wall axial compression ratio is greater than 0.10, restraint edge members are set. In other parts, restraint edge members are set when the axial pressure ratio of the shear wall is greater than 0.25;
3. Optimize the section of the component as much as possible to reduce the weight of the structure;

In summary, the structural indicators meet the requirements of the relevant national standards and the special review points for seismic fortification, and the structure can achieve the expected seismic performance target requirements. Through the introduction of this article, it can provide reliable guidance for similar projects.

References
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