Elastic time history analysis of a super tall building

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Abstract: In this paper, the principle of elastic time history analysis and the selection of seismic wave in time history analysis are briefly described; the elastic time history analysis of a super high-rise building is carried out by using the SATWE software of PKPM. The analysis results show that the base shear force and other indexes of the structure meet the requirements of the code under the action of 7-degree multiple intensity earthquake, and can meet the seismic design standards of the current seismic code in China.

1. Introduction

The project is a high-rise residential project with a total construction area of about 200000 square meters, consisting of 12 high-rise residential buildings. The number of floors above the ground is 15, and there is no basement. The frame supported shear wall structure is adopted. The first floor is the Metro Depot, the second floor is the frame supported transfer floor, and the upper part is the residence. The seismic fortification intensity of the project is degree 7, the seismic grade of the shear wall at the bottom reinforcement part and frame supported frame is grade 2, and the seismic grade of the upper shear wall is grade 3. Due to the existence of torsion irregularity, concave convex irregularity, floor discontinuity, stiffness mutation, size mutation, component discontinuity, multi tower and other structural overruns in the project, it is necessary to conduct elastic time history analysis for the project to ensure the reliability and seismic performance of the structure.

2. Principle of elastic time history analysis

The time history analysis method is a more effective seismic calculation method based on the response spectrum method. It can accurately understand the internal force and displacement response with time of the structure in the process of earthquake. By using the building as an elastic or elastic-plastic vibration system, directly input the ground seismic acceleration record, directly integrate the motion equation, and then obtain the displacement, velocity and acceleration of each particle in the calculation system. This method can reflect the whole process of the structure under the action of earthquake more accurately and completely.

Time history analysis has been included in the design code in many countries. The technical code for concrete structures of high-rise buildings in China stipulates that: for high-rise buildings with seismic fortification of 7-9 degrees, the elastic time history analysis method shall be used for supplementary calculation under frequent earthquakes in the following situations: (1) class A high-rise buildings; (2) class B and class C high-rise buildings listed in table 3.3.4; (3) high-rise buildings not meeting the requirements of article 4.4.2-4.4.5 of this code; (4) The complex high-rise building structure specified in Chapter 10 of this code; (5) the high-rise building structure with special uneven mass distribution along the vertical direction.

The dynamic equation of the structure is as follows:
$$M\ddot{\delta}(t) + C\dot{\delta}(t) + K\delta(t) = F(t)$$

Where: is the mass matrix, and is the diagonal matrix when the concentrated mass method is adopted, and the mass of each floor shall include the self weight of the structure and the service load of part of the floor; is the damping matrix; is the stiffness matrix, which is constant when the structure is elastic, and is elastic-plastic when the structure is elastic. Take as the variable, as the ground acceleration, as the function of time $t$, and $\ddot{\delta}(t)$, $\dot{\delta}(t)$, and $\delta(t)$ as the acceleration, velocity and displacement response arrays of the structure, respectively, as the function of time $t$. When the ground motion is known, the dynamic equation of the above formula is used to solve $\ddot{\delta}(t)$, $\dot{\delta}(t)$, and $\delta(t)$, and then the response of the structure in the earthquake is obtained, and further check and verify whether the structure designed has weak parts in strength, deformation or ductility. As far as possible to avoid serious damage such as collapse under rare earthquakes, the non-stationary envelope function is taken as the following form in the process of synthetic bedrock ground motion time history:

$$f(t) = \begin{cases} 
(t/T_1)^2 & 0 \leq t < T_1 \\
1 & T_1 \leq t < T_2 \\
e^{-(t-T_2)} & T_2 \leq t < T_3 
\end{cases}$$

3. Selection of seismic wave for time history analysis

In the time history analysis of structures, different seismic waves will have different seismic responses. Therefore, the selection of seismic waves must meet certain conditions, and the spectrum characteristics, effective peak value and duration of seismic acceleration time history curve must conform to the actual situation of specific projects. The seismic response generated by the input seismic acceleration shall also meet the requirements of the code for seismic design of buildings, that is, the bottom shear of the structure obtained by each time history curve shall not be less than 65% of the bottom shear obtained by the mode decomposition response spectrum method, and the average value of the bottom shear calculated by multiple time history curves shall not be less than 80% of the bottom shear obtained by the mode decomposition response spectrum method. Only by selecting the seismic wave that meets these conditions can we simulate the seismic response of the structure under the real earthquake action. Through analysis and comparison, two natural waves and one artificial wave given in the site safety evaluation report are finally selected, and the time acceleration curve of each wave is shown in Figure 1.
Dynamic characteristics analysis of 3-structure

In view of the large number of units in this project, this paper takes 6# as an example for calculation and analysis. The modal analysis of the structure is carried out by using PKPM and ETABS software, and the corresponding dynamic characteristics, such as the natural vibration period, the mode-to-mass ratio and the inherent mode, are obtained. The first three natural vibration periods of the structure and the corresponding modal mode participation mass ratios are shown in Table 1. Since this project is a multi-tower structure, the calculation is divided into three towers, tower 1, tower 2, and tower 3. The calculation results of each tower are given in Table 1, and the corresponding calculation results of the tower are also given in the time history analysis.

It can be judged by the mode participation mass ratio

(1) From the table, it can be seen that the vibration modes meet 90% of the requirements of the participation factor in the specification, which indicates that the number of vibration modes selected can meet the requirements of the calculation accuracy;

(2) The ratio of the first torsion period to the first translation period is 0.846, which is less than the limit of 0.85 required by the specification, indicating that the structure system meets the specification requirements.

Elastic Time-History Analysis of 4 Structures

The prototype structure is analyzed by elastic time history using PKPM software. When calculating and analyzing, the peak acceleration of seismic wave is 35gal, and the seismic action is input from X and Y directions for time history analysis.

Base shear statistics of structures subjected to earthquakes and Figure 5.
From the above calculation results, it can be seen that:

1. The average shear value mentioned above is greater than 80% of the mode decomposition response spectroscopy method, and the bottom shear value under the action of each wave is greater than 65% of the mode decomposition response spectroscopy method, which meets the requirements of Article 5.1.2 of GB50011-2001.

2. From the maximum floor shear curve graph, the CQC method can basically envelope the average interlayer shear curve corresponding to the three selected seismic waves, which meets the requirements.

4. Conclusion
1. Selection of seismic wave is a key problem in time-history analysis of structures. The seismic response produced by different seismic waves varies greatly. The selected seismic wave characteristics should be statistically consistent with the curve of seismic influence coefficient used by the mode decomposition response spectrum method, and the obtained structural base shear force should also meet the requirements of specifications.

2. By analyzing the structure, the seismic response of the three selected seismic waves is compared on average with that of the mode decomposition reaction universal method. The result can meet the requirements of the specification. Therefore, it can be considered that the structure has certain safety and reliability under the action of reaeartquakes.

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