Seismic Response Analysis of Double-tower Structure with Large Chassis Based on Pushover Method

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Abstract: In practical engineering, the use of double-tower structures with large chassis is becoming increasingly widespread due to their novel shapes and diversified functions. However, the previous earthquake damage shows that complex structures are more prone to damage, and their irregularity aggravates the response to earthquake. In this paper, SAP2000 software is used to establish a model for static elastic-plastic (Pushover) analysis of the large chassis double-tower structure, to investigate the location of the performance points and the distribution of plastic hinges under multiple encounters and rare earthquakes. The results show that under the action of earthquake, when the target displacement is reached, no plastic hinges appear in any of members, which meets the design requirements; the plastic hinge first appears in the beam, and then appears in the column, mainly showing the B state plastic hinges, and the structure has good seismic performance, meeting the seismic design requirements of "strong column and weak beam".

Keywords: Large Chassis; Twin-tower Structure; Plastic Hinge; Static Elastic-Plastic Analysis

1. Introduction

At present, the double-tower structure with large chassis is a widely used structural form, but tests and previous earthquake damage investigations have shown that the damage caused by the earthquake is particularly serious, and its irregularity will lead to the destruction or even collapse of the whole structure. Therefore, in-depth understanding and analysis of the characteristics of the seismic response of the large chassis double-tower structure is very important to its safety, economy and rationality [1].

Static elastic-plastic (Pushover) is based on the assumption that the seismic response is only controlled by the first mode and the structural deformation at each step in the response process does not affect the shape vector. The static elastic-plastic analysis was firstly proposed by Freeman in 1975, and it has only aroused the interest of many engineers in the nineties. This analysis method has been incorporated into seismic codes of ATC-40, Japan, and Korea [2, 3]. It is clearly stipulated in the Code for Seismic Design of buildings (GB50011-2010) that static elastic-plastic checking can be used for buildings with irregular and obviously weak parts [4].

This paper first establishes the required model, selects the beam and column and specifies the position of the hinge respectively, defines the load, checks and designs the hinge after linear analysis, determines the problem of over-reinforcement and then carries on the static nonlinear analysis of the model. It evaluates the seismic performance of the structure through the analysis results of the structural performance points and the plastic hinges, determines whether the seismic response characteristics of the structure meet the requirements, and strengthens the weak parts of the structure. To provide reference for future research [5, 6].

2. Modeling and Calculations

2.1 Modeling

Based on the current code for the design of concrete structures in China, the finite element software SAP2000 is utilized for calculations. This paper's model is a concrete frame structure with the seismic fortification intensity of 7 degrees, the basic seismic acceleration of 0.10g, the type III building site, and the site characteristic period of 0.51 s. It is designed for a 50-years lifespan and the safety level of two. The total height of the building is 69.6m, 16 floors, four commercial floors in the podium with a floor height of 4.8m, and the rest of the office building floors with a height of 4.2m each. The stress reinforcement is HRB400, and the hoop reinforcement is HPB335. Beams, columns and podium slabs are all made of C40 concrete, while others are C35 concrete, with the podium slabs being 140mm thick, and the other slabs 130mm thick. The live load of 3.0KN/m2 and the constant load of 4.5 KN/m2 are applied to the floors, along with the uniformly distributed load of 12KN/m added to the beam. The transverse and longitudinal column spacings of the tower are 7m and 6m respectively, primarily using columns with cross-section sizes of 1000mm×1000mm and 900mm×900mm, and beams with cross-section sizes of 600mm×800mm and 600mm×700mm [7]. The model is illustrated in Figure 1.

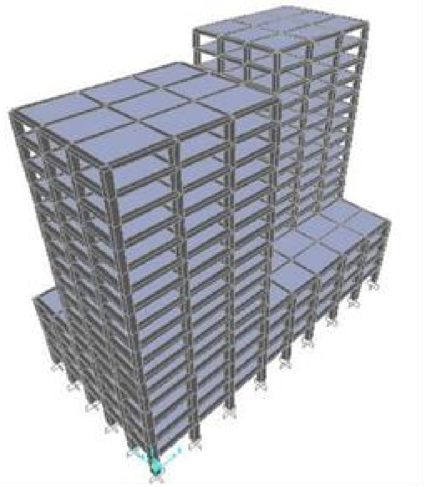

Figure 1. Concrete Frame Structure Model

2.2 Definition of Plastic Hinges

The plastic hinge is an important parameter in static nonlinear analysis. In SAP2000, beams are defined to have bending moment hinge and a shear hinge in the main direction, which is M3 hinge in the program. Columns are defined to have an axial hinge and a moment hinge, associated with the PMM hinge in program, and shear wall generally defines PM and shear related hinge. The plastic hinge is generally located at both ends of the member with large bending moment. This positioning is clear, making it convenient to study the structural characteristics.

The case of the plastic hinge shows that the plastic hinge in the AB section is not deformed, which is a rigid angle, the B point is the critical yield point of the plastic hinge, and the plastic hinge loses its bearing capacity after the C point, which is the ultimate bearing point. Point D is ultimate bearing capacity and point E is complete failure. The capacity levels of the hinge are categorized as IO, LS and CP. IO the direct use state, LS is the life safety state and CP is the collapse prevention state. Whether the bearing capacity and deformation meet the requirements is determined by the number of plastic hinges when the displacement reaches the performance point. In this paper, the plastic hinge is the default hinge. For the frame, the beam uses the M3 hinge, and the column utilizes the P-M2-M3 hinge configuration [8, 9]. The force-displacement curve of the plastic hinge is shown in Figure 2.

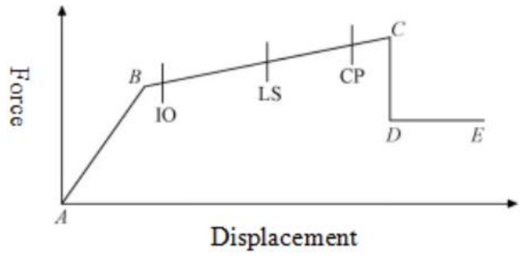

Figure 2. Force-displacement Curve of Plastic Hinge

3. Analysis of Calculation Results

3.1 Analysis of the Performance Points under the Action of Frequent and Rare Earthquakes

In ATC-40, the response spectrum is established first, then the capacity curve is transformed into the capacity spectrum, and then a test performance point is selected to form a bilinear capacity spectrum. Finally, the reduction coefficient is calculated, and the intersection point of the reduction demand spectrum and the capacity spectrum is the performance point in the same coordinate. If the point of intersection is outside the allowable range, it should be reselected for calculation.

The parameter CA of the structure under frequent earthquake is 0.032, and the value of CV is 0.076; in the case of rare earthquake, the value of parameter CA is 0.2 and the value of parameter CV is 0.48. The Pushover analysis of the model shows that the capacity spectrum-demand spectrum curve under frequent earthquakes is shown in Figure 3, and the capacity spectrum-demand spectrum curve under rare earthquakes is shown in Figure 4.

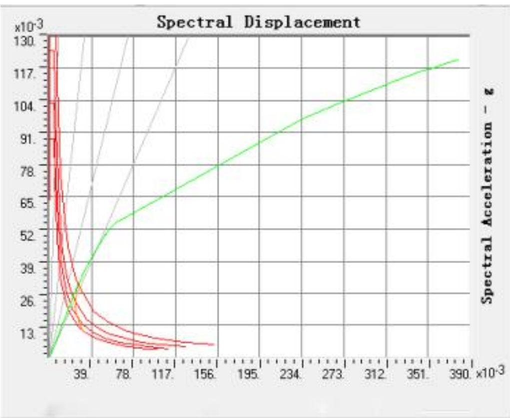

Figure 3. Capacity Spectrum-demand Spectrum Curve under Frequent Earthquake

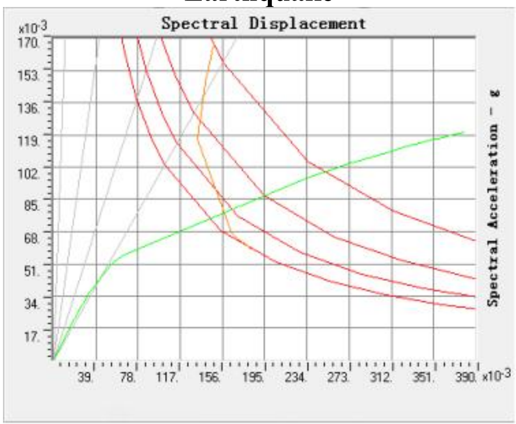

Figure 4. Capacity Spectrum-demand Spectrum Curve under Rare Earthquake

According to the analysis, it can be determined: Under the action of a frequent earthquake, the structural performance point coordinates (Sa=0.0267g, Sd=25.58mm) indicate that the base shear force V is 5437.26kN and the vertex displacement D is 24.77mm; under a rare earthquake, the structural performance point coordinates (Sa=0.0683g, Sd=136.44mm) indicate that the base shear force V is 11817.24kN and the vertex displacement D is 69.48mm. When the corresponding target displacement was reached, no plastic hinges had yet appeared in the bars, satisfying the design requirements [10].

3.2 Distribution of Plastic Hinges

Through the static elastic-plastic analysis of the model, the development of the plastic hinge can be seen from Figure 5-Figure 10: (1) in Figure 5, the plastic hinge first appears in the right beam of the 6th and 7th layers, with the hinges in B state, and the position of the plastic hinge is symmetrical. There is no plastic hinge in other beams and columns. (2) in Figure 6, the plastic hinge is mainly distributed in the right beam of the 6th to the 11th layers, and the tendency is to the left. At this time, no plastic hinges are present in the beams and columns in the skirt, but the hinges remain in the B state. (3) in Figure 7, plastic hinges begin to appear in the large chassis beam, but none are present on the first layer and 14th floor; additionally, no plastic hinges appear in the column, and the hinges are still in B state; (4) in Figure 8, the plastic hinges appear symmetrically in the left column of the fifth floor, with a large number of plastic hinges on the whole structure, including IO state plastic hinges in the beams of the 6th and 9th layers. Other layer plastic hinges are still in B state; (5) in Figure 9, plastic hinges appear in the columns of the first and fifth layers, and more plastic hinges are evident in the beams in the IO state, mainly in the middle layer, with additional plastic hinges emerging at the ends of the beams throughout the structure. (6) in Figure 10, the B state plastic hinge is present on the first layer of the column, and plastic hinges are also found in the columns of the 6th layer and the 12th to 14th layers. The IO state plastic hinge shows an upward trend, yet no IO state plastic hinges are found in the columns. The distribution of plastic hinges is essentially symmetrical, initially appearing in the beam section of the tower, then on the chassis, and ultimately on the first floor. After a large number of plastic hinges appear in the beams, those at the ends of the columns start to appear and develop slowly, aligning with the seismic design principle of “strong columns and weak beams.”

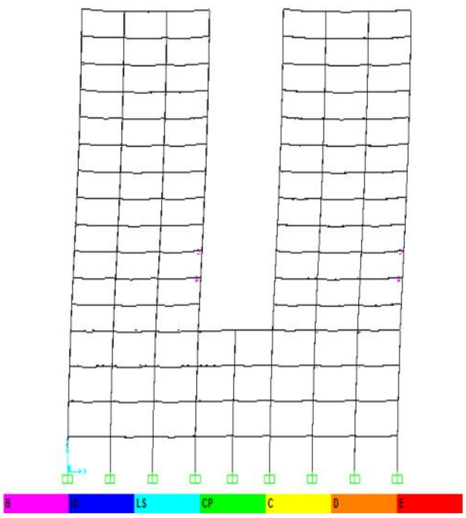

Figure 5. Plastic Hinge Development

Process (a)

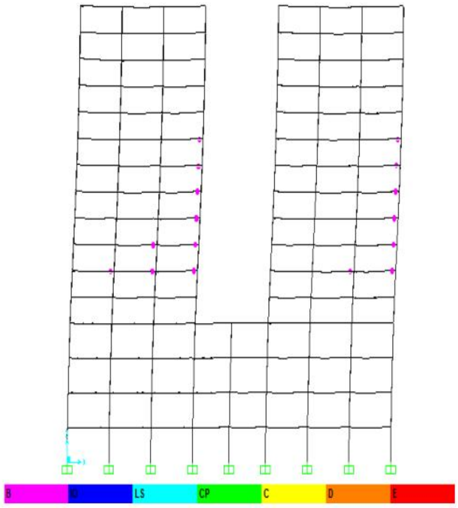

Figure 6. Plastic Hinge Development Process(b)

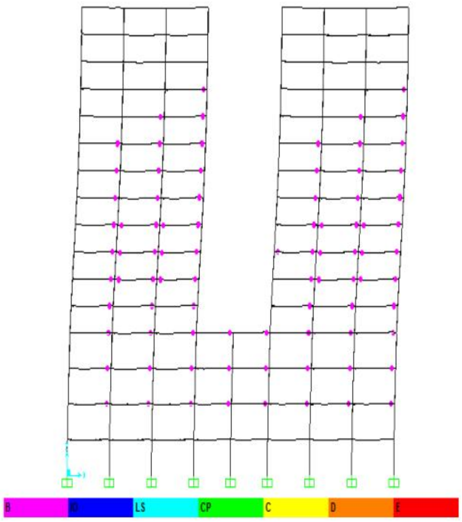

Figure 7. Plastic Hinge Development Process (c)

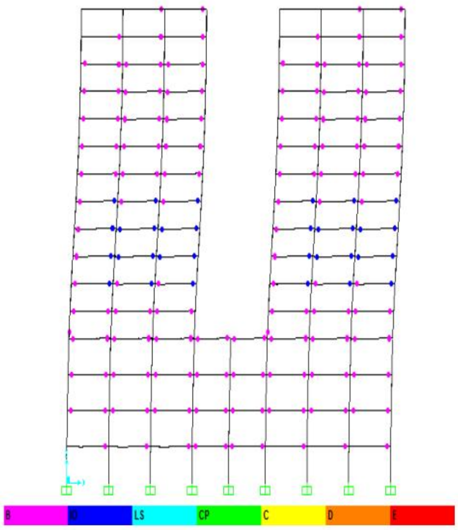

Figure 8. Plastic Hinge Development Process (d)

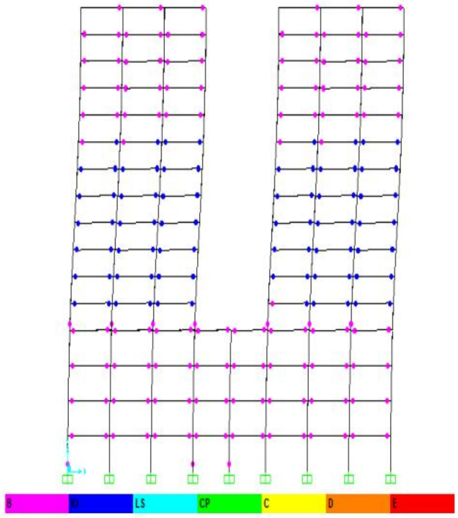

Figure 9. Plastic Hinge Development Process (e)

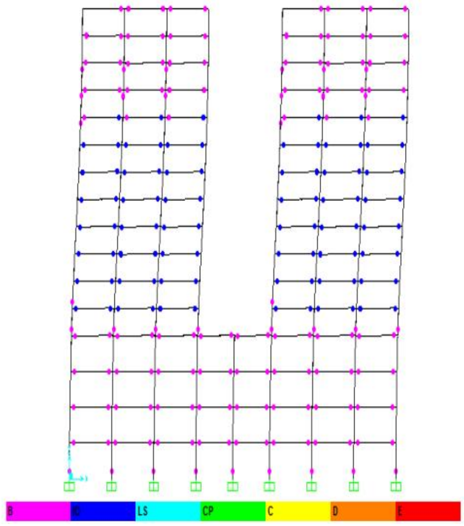

Figure 10. Plastic Hinge Development Process(f)

4. Conclusion

The concrete frame structure is established by using SAP2000 software, and the seismic performance of the double-tower structure with large chassis is analyzed. Initially, the hinges and loads of the structure are specified, followed by an analysis of the performance points and plastic hinge development under frequent and rare earthquakes. The results show that under the action of frequent earthquakes, the base shear force V of the structure is 5437.26kN, and the vertex displacement D is 24.77mm; under rare earthquakes, the base shear force V of the structure is 11817.24kN, the vertex displacement D is 69.48mm, and the plastic hinges of each member do not appear, which meets the design requirements. The development of the plastic hinge reveals that its distribution is primarily in the beams, developing from the middle to both sides. The plastic hinges at the ends of the columns are less frequent in B state and develop slowly. Plastic hinges first appear in the beams and then in the columns; LS and C state plastic hinges do not appear. The seismic performance of the structure is satisfactory, and the development of plastic hinges aligns with the seismic design principle of “strong columns and weak beams”.

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