Study on Static Elastoplastic Analysis of a High-Rise Frame-Shear Wall Structure

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Abstract. Static elastoplastic analysis is widely used to evaluate the seismic performance of structures. The project example in this paper is the high-rise frame-shear wall structure of the second phase (Yongsheng homeland) of the Baisha resettlement area in Zhengdong New Area. The three-dimensional integral model is used to calculate the force of the building under earthquake using the static elasto-plastic analysis method. Analysis was conducted to obtain the stress conditions of high-rise buildings against plastic deformation, and the sequence of the plastic hinges, and the unfavorable floors of the high-rise structure were identified, which provided guidance for the design of such structures.

1. Introduction

There are two methods used to analyze the impact of seismic action on high-rise frame-shear wall buildings: static elastoplastic analysis and dynamic elastoplastic analysis [1]. The static elastoplastic analysis method can realize the accuracy of strain verification required for design engineering and find out the corner and position of the shaped strand, as well as the weak part of the structure with less time and lower cost, therefore it has good practicability in engineering [2]. The dynamic elastoplastic analysis method calculates the internal force and deformation of the structure at various moments in the whole process of seismic response, and thus discriminating the yield mechanism and weak link of the structure. It is an ideal method for structural nonlinear seismic response analysis. Due to the randomness and structural complexity after the earthquake, the key technologies involved in this method have not been effectively solved.

The research object is the high-rise frame-shear wall construction project entity located in Yongsheng Community of the second phase of Baisha Resettlement Zone in Zhengdong New District. The static elastoplastic method under earthquake is used to calculate and analyze the simulated model, and the results are evaluated. The yield mechanism of the high-rise structure under the impact of earthquake and the order of each plastic hinge appears are analyzed to find out the unfavorable link of the structure [3].

2. Static Elastoplastic Analysis

The static elastoplastic analysis is based on the method of gradually increasing the seismic force (the horizontal force) on the structure, and gradually loading the structure to the ultimate force form to analyze the nonlinear performance of the structure and determine whether the strain and stress of the
building meet the demand. This method is essentially an elastoplastic analysis method combined with the response spectrum [1].

2.1. Hypothesis Conditions of Static Elastoplastic Analysis
(1) In the response of the structure to the earthquake, the displacement shape vector remains unchanged, independent of the lateral shift;
(2) Only the first formation controls the earthquake response of the structure.

2.2. Procedures of Static Elastoplastic Analysis
In this paper, the elastoplastic analysis is carried out by loading the lateral force in inverted triangle mode. During the structural loading process, the distribution of lateral force along the height is proportional to the floor quality and height and the structural deformation is distributed in inverted triangle along the height direction.

(1) Establish a structural analysis model and determine various mechanical parameters;
(2) Calculate the internal force of the building structure [4];
(3) Apply a load in the horizontal direction, and when the internal force generated by the representative value of the gravity load is superimposed with the internal force generated by the horizontal load, the component is brought into a yielding state;
(4) Replace the component that has entered the yielding state, and apply a certain amount of force in the horizontal direction to make the new structure enter the yielding state;
(5) The plastic hinge selects the bending moment and the shearing plastic hinge, and the position is set at the maximum force in the structural elastic phase;
(6) Continue step 3 and 4 until the strain value of the component reaches a high plastic hinge or high structural strain and form a new structure [5];
(7) Draw the relationship curve between the base shear force and the displacement of the structural control points in different loading stages.

3. Project Overview
The high-rise frame-shear wall structure of Yongsheng Community A area has a main building of 22 floors, of 79.70m high, including four-story podium. The main structure adopts the cast-in-place reinforced concrete frame-shear wall structure as the lateral resistant system, the main beam plate and the secondary beam plate are the floor and roof of the cast-in-place reinforced concrete, and the plane structure of the structural standard layer is shown in figure 1. The site category is Class II, the design earthquake group is the first group, and the structural seismic fortification intensity is 8th magnitude.

![Figure 1. Structural layout of standard layer.](image-url)
According to the "Technical Regulations for Concrete Structures of High-rise Buildings" [6], when the seismic fortification intensity is 9th magnitude, the maximum aspect ratio for reinforced concrete high-rise buildings in the form of frame-shear wall structures is 4:1. The high-rise main building has an aspect ratio of 3.9:1, which meets the requirements of technical regulations.

4. Analysis of High-Rise Frame-Shear Wall Structure Static Elastoplasticity
This paper uses PUSH in EPDA/PUSH software to calculate and analyze the static elastoplasticity of the structure.

4.1. Component Model
The one-dimensional components such as beams, columns and supports are simulated by fiber bundle model in the software. The fiber bundle model has good adaptability and is not under the constraint of section form and material [7]. A unit of elastoplastic wall is used to stimulate the frame-shear wall structure and by calculating and analyzing the unit, the elastic-plastic behavior of the frame-shear wall structure can be displayed.

4.2. Material Model
Performance indicators in the material model are taken at standard values. The full stress tangent formula is used to express the normal stress of concrete and steel, as shown in figure 2. Let the intercept of the member be , the tangent modulus be , the formula for calculating the normal stress would be:

\[ \sigma = E_e \cdot \varepsilon + R_e \]  \hspace{1cm} (1)

4.2.1. Concrete Constitutive Model
The SAENZ curve is used to simulate the constitutive relationship of various materials of concrete, and the effect of the falling section is considered, as shown in figure 3, where:

\[ \sigma = \frac{E_e \varepsilon}{1 + \left( R + R_e - 2 \left( \frac{\varepsilon}{\varepsilon_0} \right) - \left( 2R - 1 \right) \left( \frac{\varepsilon}{\varepsilon_0} \right)^2 + R \left( \frac{\varepsilon}{\varepsilon_0} \right)^3 \right)} \]  \hspace{1cm} (2)

\[ R = \frac{R_e (R_e - 1) \left( \frac{\varepsilon}{\varepsilon_0} - 1 \right) \frac{1}{R_e}}{R_e - 1} \]  \hspace{1cm} (3)

\[ R_e = \frac{E_e}{E_o} \]  \hspace{1cm} (4)

\[ R_{\sigma} = \frac{\sigma_0}{\sigma_v} \]  \hspace{1cm} (5)
\[ R = \frac{\varepsilon_1}{\varepsilon_0} \]  

(6)

Figure 3. Concrete constitutive model.

4.2.2. Constitutive model of steel bar.

The ideal elastoplastic model is adopted to simulate the constitutive relationship of the steel material, as shown in Figure 4. A slight slope is given to the plastic flow section in order to ensure the computational efficiency in actual engineering calculations.

Figure 4. Steel constitutive model.

The overall structural model is established based on the above-mentioned component model, material model, and design requirements proposed.

5. Calculation Results and Analysis of Structural Models

The pushover analysis is adopted to analyze the building structure using inverted triangle for horizontal load, the ratio of the total weight to the base shear force is 1:1, the simulated seismic force is applied in the X and Y directions of the building respectively [8]. Through PUSH calculation, the relationship between demand spectrum and capacity spectrum, the plastic hinge distribution, the building displacement and the building displacement angle in X, Y direction can be obtained.

The relationship between the demand spectrum and capacity spectrum in X and Y direction illustrates the relationship between the design response spectrum, the horizontal pushover force and the maximum interlayer displacement angle. In Figure 5, the ordinate is the seismic influence coefficient and the maximum interlayer displacement angle of the structure, and the abscissa is the basic natural vibration period of the structure. The seismic demand spectrum curve under the 8th magnitude seismic fortification intersects with the capability curve (i.e., the period-acceleration curve)
[9]. Above the intersection point, the ordinate represents the displacement angle between the plastic layers of the building under the horizontal load, it intersect with the period-maximum interlayer displacement angle curves at 1/177 (Y direction) and 1/113 (X direction), respectively.

Region: Nationwide, rare occurrence earthquake; type of site: Class 2; Design of earthquake group: group 2; seismic fortification intensity: magnitude 8 Max value of seismic influence coefficient: 0.900; characteristic cycle: 0.4s; elastic state damping ratio: 0.05; coordinate of the intersection of power curve and demand curve: 2.951, 0.157; demand story drift: 1/113.

**Figure 5.** Relationship between demand spectrum and power spectrum in X direction.

Region: Nationwide, rare occurrence earthquake; type of site: Class 2; Design of earthquake group: group 1; seismic fortification intensity: magnitude 8 Max value of seismic influence coefficient: 0.900; characteristic cycle: 0.4s; elastic state damping ratio: 0.05; coordinate of the intersection of power curve and demand curve: 2.612, 0.162; demand story drift: 1/177.

**Figure 6.** Relationship between demand spectrum and power spectrum in Y direction.
The anti-collapse performance point of the structure is the intersection of the seismic demand spectrum curve and the capability curve under the 8th magnitude seismic fortification. The distribution of plastic hinge of the performance points in the X and Y directions is shown in Figures 7a and 7b. The floor displacement and floor displacement angle in the X and Y directions are shown in Figure 8-11. It can be seen from the calculation results that when the pushover performance point is reached, the elastoplastic displacement angle of the layer meets the standard of below 1/100. It is also concluded that the 12th layer in the X-direction and the 16th layer in the Y-direction are the most unfavorable layers of the force strain, as shown in Figures 7a and 7b. It can be seen from the plastic hinges of the 12th layer and the 16th layer that the plastic hinges mainly appear at unfavorable positions such as the beam, the frame column and the root of the bottom column. In the beam hinge, the protective layer of the joints of the beam are generally peeled off, and curved cracks can be found in the plastic hinge area, but there is no permanent deformation in the area and it still has a reliable bearing capacity; at the column hinge, bending cracks generally occur, along with a small amount of shear cracks, but the protective layer of the column is basically intact, and the frame column maintains a good bearing capacity. The above analysis shows that the building has reliable carrying capacity, good seismic performance and emergency capacity.
6. Conclusion
In this paper, the seismic performance of the high-rise frame-shear wall structure model of Yongsheng Community A area is analyzed by static elastoplastic pushover analysis method. The conclusions are as follows:

(1) The high-rise structure can withstand 8th magnitude earthquake which meets the national seismic standard.

(2) It is found in the simulation calculation analysis that the inter-layer displacement angle is 1/113, which meets the requirements of Article 4.7.5 of the current specification of China's high-rise building
concrete structure (JGJ3-2010). (The inter-layer elastoplastic displacement angle of the shear wall structure under strong earthquakes should be less than 1/100).

3) Static elastoplastic pushover analysis is an important part of the seismic design of high-rise frame-shear wall structures. It has strong practicability and should be widely applied in engineering design.

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