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Research on Seismic Performance and Earthquake Damage Prediction of Buildings Based on Performance Testing

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ABSTRACT. *Research on seismic performance of high-rise buildings, predict structural response under earthquake to reduce casualties and design seismic scheme. According to the seismic performance and seismic damage characteristics of the structure, the main factors influencing the seismic damage results of the structure are given. These main factors include the structure form, site type, construction age, building floor number and building area. Each influencing factor is quantified and given different weights according to its sensitivity, and the fuzzy analogy prediction method is adopted to predict the seismic damage of group houses. The structural finite element analysis software SAP is used to predict, analyze and calculate the earthquake damage of buildings. By calculating the inter-story displacement angle, the seismic performance of some important buildings is evaluated by simplified evaluation method. The results show that the method can meet the requirements of the compilation of comprehensive seismic disaster prevention planning for cities.*

KEYWORDS: *Performance testing, Seismic performance of buildings, Earthquake damage prediction*

1. Introduction

Earthquakes can be described as “the first of all disasters” and the losses caused by them are also “the most of all disasters”. They can cause great damage in a very short period of time and cause huge losses to people's lives and property [1]. Strong earthquakes often occur suddenly and unexpectedly, and the huge destructive power they produce poses a very serious threat to human life safety, economic development and social order [2]. In the life cycle of buildings, natural disasters often cause structural damage and affect their seismic performance. Most of the current methods are to build seismic testing models, such as the seismic testing method for long-span concrete filled steel tubular column structures under random vibration. Therefore, based on the contingency of earthquake action, except for special structures, seismic design must be based on large structural damage to resist earthquake action with little probability of occurrence in the future [3]. However, in recent years, people have gradually realized the destructive effect of vertical earthquake on buildings. Many earthquake damage phenomena show the

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characteristics of vertical earthquake damage, especially under the simultaneous action of horizontal and vertical seismic waves. Therefore, it is necessary to conduct in-depth research on the seismic performance of structures under the coupling action of multi-dimensional earthquakes. Therefore, the earthquake damage prediction of important buildings in the city is the most important thing in the earthquake damage prediction work. In this paper, the method of building structural mechanics model is proposed to predict the earthquake damage of important buildings in order to improve the prediction accuracy.

2. Seismic Performance Analysis of Important Buildings

2.1 Introduction to Methods

For the research on seismic capacity of important buildings, the seismic performance analysis of single building is mostly used for vulnerability evaluation. Firstly, based on field investigation data, SAP software is used to establish a mechanical model, then finite element analysis software is used to calculate according to the mechanical model, and finally parameters such as interlayer displacement angle are obtained. The seismic effect, displacement, velocity and acceleration of the ground under different hours of earthquake are applied to the building structure in the form of external loads, and then the responses of stress, displacement and deformation of different particles of the building structure under different times of earthquake are obtained through gradual integration. After statistics, the maximum stress, deformation distribution and weak parts of the building in the whole process of earthquake are analyzed [4]. Aseismic engineering based on functional design seeks to control the damage level of all seismic wave spectra that buildings experience on site. In order to achieve this goal, all possible spectra corresponding to different levels of ground motion parameters need to be selected according to different return periods. These specific ground motion parameters are called “seismic design level” [5]. For some buildings, the cumulative damage effect of different earthquake sequences should also be taken into account on the damage degree. The seismic capacity of key buildings can be analyzed and evaluated according to the research method of single buildings. In actual projects, time-history analysis method is generally used to check whether the structure has weak parts in bearing capacity and stiffness, so as to avoid serious damage such as structural collapse under large earthquakes.

2.2 Steps of Modeling and Analysis

The analysis of important buildings is mainly carried out by finite element method and SAP finite element analysis software. The destruction of walls is mainly caused by shear force, and the ability of walls to resist shear force basically reflects the seismic capacity of masonry structures. The larger the wall area in a unit area of a house, the stronger the structure's ability to resist earthquakes. The calculation parameters of the structure are extracted according to the data of important building

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completion drawings, such as the plane layout size of each layer of the structure, the beam-column section size, the concrete strength and reinforcement strength of each layer, the site category, etc.

General shear wall damage is the main sign of frame-shear wall structural system damage. The damage degree of frame-shear wall structural system can be judged by calculating the earthquake action shared by shear wall and its horizontal displacement. First, the stiffness characteristic value is calculated [6]:

$$\lambda = H\sqrt{\frac{C}{\beta E_{\omega} I_{\omega}}} \quad (1)$$

Among them, β is the stiffness reduction coefficient of the frame and the shear wall, taking the cast-in-place structure β = 1 and the fabricated structure β = 0. 8 to 0. 9; H is the total height of the structure; EωIω is the total stiffness of the shear wall section, which is the sum of the stiffness of each shear wall; C is the total stiffness of the frame section, which is the sum of the lateral stiffness of each frame column, that is:

$$C = \sum Kc = \alpha i_c \frac{12}{h_2} \quad (2)$$

Where ic is the linear stiffness of the column. After calculating the yield bearing capacity between layers and the seismic shear force (or bending moment) between layers according to the above methods, the yield bearing capacity coefficient can be determined. The yield capacity coefficient of layer i can be determined by the following formula [7].

Frame structure:

$$\xi_y(i) = V_y(i) / V_c(i) \quad (3)$$

Shear wall structure:

$$\xi_M(i) = M_{\omega u}(i) / M_e(i) \quad (4)$$

The weak floor is determined by the minimum ξ value method, and the floor corresponding to the minimum or smaller value of the obtained bearing capacity coefficient is taken as the weak floor, and the elongation of the floor is calculated according to the following formula [8].

$$\mu_{\max} = \frac{1}{\sqrt{\xi_{\min}}} e^{\alpha^{(1-\xi_{\min})}} \quad (5)$$

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Table 1 Relationship between Earthquake Damage Levels of Different Structures and Interlayer Displacement Angle

Structure type	Earthquake damage level				
	Basically intact	Minor damage	Moderate damage	Serious damage	Destruction
Frame structure	θ ≤ 1/400	1/400 ≤ θ 1/250	1/250 ≤ θ 1/125	1/125 ≤ θ 1/50	θ≥1/50
Frame shear structure	θ ≤ 1/500	1/500 ≤ θ 1/300	1/300 ≤ θ 1/150	1/150 ≤ θ 1/100	θ≥1/100

Establishing finite element model of high-rise building structure; Verify the finite element model; Dynamic time-history analysis is carried out on the finite element calculation model. The key to control the safety of the main structure and the vulnerability of non-main structures under different fortification earthquakes is how to select seismic measures and structural parameters and how to control the structural design level [9]. Two-dimensional or three-dimensional finite element models of important building structures are established. The structural seismic capacity analysis model adopts a rod system model with beams, columns and shear wall limbs as the basic elements of analysis. A family of functions is obtained by using the expansion and contraction translation of wavelet functions. The simulated seismic signals are subjected to wavelet transformation. When the family of functions forms a standard orthogonal basis, the seismic signals are reconstructed from the continuous wavelet transformation to realize the noise removal of the seismic signals. The location of the weak layer of the structure is also obtained, which provides direct basis for future seismic reinforcement. See Table 1 for the prediction and discrimination of earthquake damage with interlayer deformation of buildings as the main index calculated by structural finite element analysis.

3. Earthquake Damage Prediction Based on Performance Detection

3.1 Earthquake Damage Prediction Method for Single Building

Earthquake damage prediction refers to the probability or possibility of a certain degree of damage to engineering structures in an area under the action of earthquakes of various intensities that may be encountered. Because of the different structural types of buildings, their seismic performance is very different, and the factors that determine the degree of earthquake damage are also different. The anti-seismic performance of the structure does not necessarily take the target specified in the code, and the feasible anti-seismic fortification target can be selected according to the actual needs, the requirements of the owner, the investment capacity and other factors.

According to “Code for Design of Masonry Structures” and “Code for Seismic Design of Buildings”, masonry structures are checked for strength, i.e. the working

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performance in the elastic stage of structures under frequent earthquakes is calculated. The earthquake damage prediction is calculated under the action of small earthquakes, and the earthquake damage index under frequent earthquakes of various intensities is calculated as follows [10]:

Degrees:

$$D_s = 1.864 - 0.007R_s \quad \mu_{\max} = \frac{1}{\sqrt{\xi_{\min}}} e^{\alpha^{(1-\xi_{\min})}} \tag{6}$$

Degrees:

$$D_s = 1.977 - 0.006R_s \tag{7}$$

Degrees:

$$D_s = 1.975 - 0.005R_s \tag{8}$$

Degrees:

$$D_s = 1.866 - 0.004R_s \tag{9}$$

Press the following formula to correct the earthquake damage index.

$$D_{sm}(I) = D_s(I)\left[1 + \sum C_i\right] \tag{10}$$

Where: ci resistance correction coefficient shall be determined according to Table 2.

Table 2 Correction Coefficient Value of Masonry Structure

Condition	Correction factor	
	Satisfy	Not satisfied
The spacing of the walls meets the requirements of the current seismic design code	0	0.11
Rigid floor, rigid roof	0	0.13
The structure has no obvious quality problem	0	0.26
Plane and elevation are regular	0	0.11
Meet the requirements of "Code for Seismic Design of	-0.31	0

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Industrial and Civil Buildings" (TJ 11-78)		
Meet the requirements of "Code for Seismic Design of Industrial and Civil Buildings" (TJ 11-74)	-0.21	0

Therefore, the seismic capacity of the structure is not the seismic checking result after the design is completed, but is designed according to the selected seismic performance target. The seismic signal after noise removal is taken as a signal sample for detecting the earthquake resistance of concrete structure buildings, and the displacement, velocity, acceleration and restoring force of the earthquake are solved by using the structural motion equation. After the earthquake damage index of each floor is obtained, the earthquake damage grade of each floor of the building can be judged, and the damage degree of the whole structure of the building can be measured by the earthquake damage grade of the floor with the most serious earthquake damage. In the earthquake damage prediction, the shear yield strength coefficient of each layer of the frame is first calculated, the floor corresponding to the minimum value is selected as the weak floor, and the earthquake damage situation of the weak layer is judged as the earthquake damage result of the whole frame structure.

3.2 Earthquake Damage Prediction Algorithm for Group Buildings

In this paper, the method of fuzzy analogy prediction is used to predict the earthquake damage of buildings, and the principle of no analogy for different structural types and different site types is followed. The sensitivity of each factor is characterized by the weight iw i. Reference [10] in this paper determines the weight iwi. Considering that the earthquake damage of buildings in different site categories is not comparable, the weight of site categories is enlarged. Although the seismic design theory based on structural performance still sets the minimum allowable values for some important parameters, such as earthquake action, interlayer displacement, etc., it gives designers more flexibility, and designers can choose design methods and corresponding structural measures that can achieve the seismic performance objectives required by the owner.

The impact factors of the house to be predicted are represented by set A, and the impact factors of sample houses are represented by set B. The site categories are recorded as a1, and b1, the number of building floors is recorded as a2 and b2, and the building area is recorded as a3 and b3. Chronology is a4, and b4.

In this paper, the similarity distance between two sets is defined by the weighted Hamming distance formula in fuzzy mathematics:

$$d(A.B)=\left(\sum_{I=1}^{4} w_i \left|a_{i-b_i}\right|\right)^{1/p} \quad D_{sm}(I)=D_s(I)\left[1+\sum C_i\right] \quad (11)$$

Where a, b; are each element in the set, w; is the weight corresponding to each element, p is a fixed parameter (p> 0, when p = 1, it is the Hamming distance). Similarity calculation formula of two sets:

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$$(A,B)=1-cd_p(A,B) \quad (12)$$

Where c is a constant parameter, it needs to be guaranteed when determining this parameter. 0≤ (A, B) ≤1.

Compared with frame structure, shear wall structure uses reinforced concrete wallboard to replace beams and columns in frame structure, can bear internal forces caused by various loads, and can effectively control horizontal forces of the structure, which is the best seismic performance in current building structures. In this case, using fuzzy analogy method to predict the earthquake damage results of the target buildings will produce great errors. In order to ensure the accuracy of the prediction results, it is necessary to ensure that the similarity of the two buildings cannot be lower than a certain threshold similarity. In the system, the weighted Hamming distance corresponding to this threshold similarity is set as a threshold. After the resistance is determined, the failure state is also determined. For example, the resistance limit value corresponding to slight damage is regarded as a certain value. Empirical analysis is generally a deterministic earthquake damage prediction method.

3.3 Process of Building Earthquake Disaster Prediction System

Enter the building information to be predicted, search the sample database, and if the same sample record is collected, the earthquake damage result of the predicted building is the earthquake damage result of the sample record. If there are no identical records in the sample database, seek the fuzzy distance between the house and each record in the sample database of the same structure type, and judge its earthquake damage result according to the thought of fuzzy analogy. The dynamic time-history analysis method of the structure can calculate the internal force and deformation at each moment of seismic response, and can give the sequence of cracking, yielding and failure of the structure and the collapse failure model, find out the location and floor where plastic deformation is concentrated, so as to identify the weak links and failure conditions of the structure. Cut each half-story of the building into a section, and each column in the section will be connected with a joint with a beam or column. This node can be used to judge the sequence of seismic damage between beams and columns, and the structural motion equation can be used to solve the shear force and ductility ratio when the beams and columns are damaged. Its purpose is to examine the damage of buildings in a city or region under different intensities, including the overall earthquake damage level of buildings, the differences in earthquake damage of different building types and the differences in earthquake damage of different zones, which is the necessary basis for formulating earthquake-resistant and disaster-prevention planning countermeasures.

4. Conclusion

Throughout history, earthquakes have always threatened the safety of human life and property with their uncertainty and great destructiveness. City is the center of economic, political and cultural activities in a region. With the rapid development of Chinese economy and the continuous acceleration of the urbanization process, the social components are more closely linked, and the casualties and economic losses caused by the earthquake will continue to increase. In this paper, a method for earthquake damage prediction of important urban buildings by using SAP structural finite element analysis software is proposed, which is helpful to improve the efficiency of urban comprehensive earthquake-resistant planning, and is suitable for the needs of urban comprehensive earthquake-resistant and disaster-prevention planning in the new era. The existing structural analysis software is applied to model and calculate the earthquake damage prediction of structures, and is compared with the simplified calculation method. It is found that the prediction results of concrete structures are basically consistent, and the prediction results of masonry structures are greatly deviated, mainly because the simplified calculation method ignores the functions of structural columns and ring beams of masonry structures. With the development of our country's economy, brick-concrete structure will become the main form of residential structure. With construction guidance and standardized management, it can meet the requirements of seismic fortification.

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