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Comparative Study on Existing Seismic Performance Evaluation Methods of Buildings Based on Life Cycle

Liang LI

Zhengzhou University of Aeronautics, Zhengzhou, Henan 450015, China

ABSTRACT. *This paper aims at the main structural forms of multi-storey buildings (frame structure, masonry structure and bottom frame structure) in our country in the whole life cycle, and compares the analysis results of bottom shear method, mode decomposition response spectrum method, time history analysis method and Pushover method by using the general finite element software SAP2000. Then it is converted into the displacement response of the corresponding multi-degree-of-freedom structure, and the total displacement response of the structure is obtained through the mode combination method. By comparing it with the target displacement of the shear wall, it is judged whether the design result meets the performance target requirements. The results show that the four seismic performance evaluation methods have little difference in the analysis results of multi-storey buildings. Among them, Pushover method is a fast, simple and practical evaluation method. Weak links can be found when evaluating the seismic performance of structures under rare earthquakes, which can provide more references for seismic performance evaluation and reinforcement.*

KEYWORDS: *The whole life cycle, Multi-storey buildings, Earthquake resistance, Performance evaluation, Compare*

1. Introduction

China is located in an earthquake-prone area. Successive earthquakes of different sizes have caused a large number of houses to be damaged to different degrees [1]. The buildings are developing in scale and concentration. Suffering from the same earthquake disaster, the degree of casualties and property losses caused by structural damage is even more serious. On the one hand, how to identify and strengthen the well-preserved buildings in earthquake-stricken areas is directly related to the smooth progress of post-disaster recovery and reconstruction. On the other hand, how to carry out seismic appraisal and reinforcement of existing buildings to ensure good seismic performance of buildings is directly related to the safety of people's lives and property [2]. The risk management of the project runs through the whole life cycle, and the three sub-processes of risk analysis are carried out cyclically in each stage of the life cycle of the project. The level of risk varies in different stages and the level of detail of risk analysis varies. Elasto-plastic time-history analysis is

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considered to be a correct and reliable method for solving structural seismic response, which can reflect the damage of structures with time variation [3]. However, there are many problems in the application process, such as the selection of seismic waves, evaluation of calculation results and low calculation efficiency, which make it difficult to popularize and apply in engineering. In this paper, finite element analysis software SAP2000 is used to evaluate the seismic performance of multi-storey structures. Pushover method is compared with bottom shear method, mode decomposition response spectrum method and time-history analysis method. The error between Pushover method and other three seismic performance evaluation methods is analyzed to study whether it is suitable for evaluating the seismic performance of multi-storey structures under frequent and rare earthquakes and the direction for further research.

2. Comparative Study on Seismic Performance Evaluation Methods of Multi-Storey Frame Structures

2.1 Engineering Case Modeling

Since each node in the tree structure of the concept lattice is a concept, how to define the similarity between concepts becomes the key to measure whether the two concepts are similar.

In the application of specific evolutionary analysis methods, conceptual similarity calculation should be done well. At present, the concept similarity calculation is mainly to find out the correlation between the two concept lattices and to adjust the application of the concept lattices. Through the different matching of concept lattices and the change of usage rules, the representative function of concept lattices is strengthened. At the same time, the difference of application environment between the two concept lattices and the application characteristics of concept lattices can be found, which is of great significance to the use of the whole concept lattices. In evolutionary analysis, concept similarity calculation is a basic analysis method, which can effectively analyze fuzzy concept lattice and improve the accuracy of the whole similarity calculation in the specific similarity calculation process. The calculation of concept similarity can summarize the strict application situation and the application degree of concept lattice, which has an important influence on the application of the whole concept lattice. Through the calculation of concept similarity, we can find out the characteristics and application positions of two identical concept lattices, which is of great help to the analysis of software functions.

The spatial finite element model of frame structure is established by SAP2000 software. Beam and column elements are simulated by rod elements, and cast-in-situ concrete slabs are simulated by shell elements. The section properties of slabs, beams and columns are defined according to actual engineering data. The bottom node is a fixed end constraint. An example of a 4-layer structure model is shown in Figure 1.

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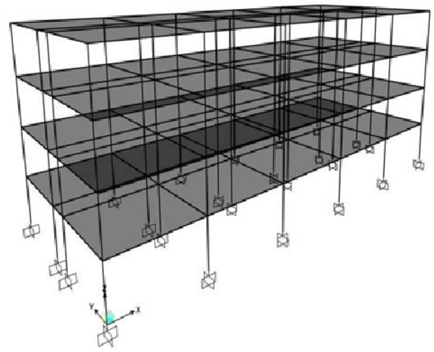

Fig.1 4-Layer Structure Model

Due to the uncertainty of many factors in seismic design, the modified elastic response spectrum method is usually used in the calculation method in seismic design, while the complex nonlinear time-history analysis method is seldom used. In the analysis and calculation of the whole structure, the code adopts the elastic analysis method, while in the section design of the component, the elastic-plastic limit design method is adopted [4]. Different methods are adopted for different building types. Conventional masonry, inner frame, bottom frame, frame, frame-shear structure and industrial factory buildings need samples, i.e. a large number of representative drawings need to be collected for seismic performance evaluation and calculation, so as to form corresponding sample libraries. Comparison of Existing Methods for Evaluating Seismic Performance of Buildings Based on Full Life Cycle Based on the existing methods for evaluating seismic performance of buildings, the full life cycle theory is applied to guide and implement environmental management of public works [5]. On the one hand, it reflects the possible losses of the existing buildings based on the initial design. On the other hand, existing buildings are different from new buildings, which may lead to the lack of some structural information when buildings need seismic appraisal, resulting in structural uncertainty. The contact part between the wall and purlin or the girder of the wall-bearing house bears the whole weight of the roof system, and its seismic performance mainly depends on the strength of the wall and the degree of bonding between the wall and the roof. By distinguishing the uniaxial stress-strain relationship between the two materials, the nonlinear characteristics of the components and the common working characteristics of the materials are shown.

2.2 Seismic Performance Evaluation under Frequent Earthquakes

The bottom shear method, mode decomposition response spectrum method, time history analysis method and Pushover method are used to evaluate the seismic performance of the structure. Due to the structural symmetry and weak lateral stiffness, only the lateral (Y-direction) related data are listed. By comparing the

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analysis results of Pushover method and time history analysis method, the correction coefficient of the maximum lateral displacement of Pushover method is obtained to make up for the deficiency of Pushover analysis method [6]. If the reliability of a structure during a strong earthquake is pinned on the ductile response of the structure, it is of paramount importance to carefully design the reinforcement structure. Through structural measures to ensure no shear failure or anchor failure and instability. Because there is no ready-made simplified evaluation method for public buildings such as old houses and stadiums, the earthquake damage matrix can only be obtained through a large number of statistical analysis based on the existing earthquake damage records for the evaluation of the existing investigated houses [7]. On the one hand, the material characteristic value of the capability model should be the average value of materials obtained from on-site inspection or other information sources divided by the confidence factor value when comparing with the structural requirements for safety determination; On the other hand, when calculating the strength capacity value of the plastic member transmitting the action effect to the brittle member, the material characteristic value should take the material average value multiplied by the confidence factor value. See Table 1 for maximum lateral shift and interlayer displacement angle. For a 2-5 story frame structure, the analysis results of the four evaluation methods are in good agreement. The four seismic performance evaluation methods have the maximum node lateral displacement less than the anti-seismic limit value and the maximum interlayer displacement angle less than 1/550 limit value. Therefore, the structure can resist seismic action well.

Table 1 2-5 Layer Model Analysis Results

Analysis results		Bottom shear method	Reaction spectrum method	Time history analysis	Pushover analysis
2 layer	Side shift (mm)	2.36	2.41	2.47	2.21
	Interlayer displacement angle	1/3615	1/3522	1/3566	1/4160
3 layer	Side shift (mm)	4.21	4.50	4.57	4.55
	Interlayer displacement angle	1/2428	1/2137	1/2085	1/2863
4 layer	Side shift (mm)	5.68	6.04	6.55	5.61
	Interlayer displacement angle	1/2084	1/2056	1/2237	1/2285
5 layer	Side shift (mm)	7.46	7.71	8.10	6.63
	Interlayer displacement angle	1/2039	1/1806	1/1722	1/2011

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2.3 Seismic Performance Evaluation under Rare Earthquake

Pushover method is used to analyze the seismic performance of structures under rare earthquakes. Pushover curve reflects the development process of component failure. This example defines two working conditions, as shown in Table 2.

Table 2 Pushover Condition

Type of working condition	Lateral force distribution form
Gravity+Y acceleration	Uniform
Gravity+Mode 2	Inverted triangle

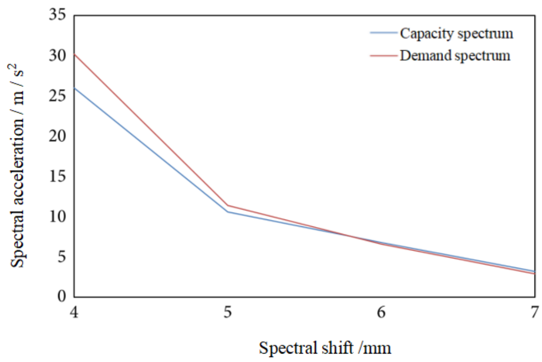

Fig.2 Through Pushover Analysis, the Capacity Spectrum and Demand Spectrum Curves Are Obtained

In structural design, the internal force of the section and the selection of reinforcement bars are usually determined according to the most unfavorable load combination that may occur [8]. The most unfavorable combination may or may not include seismic forces. For some buildings, village-in-city buildings and rural residential buildings, there are neither corresponding drawings nor ready-made simplified evaluation methods. We propose a method of on-site measurement combined with structural theoretical calculation to evaluate the seismic performance. The model must meet the basic provisions of the European code for seismic design on the calculation model and the provisions on accidental torsion effect. In addition, in general, the strength and stiffness of secondary seismic components can be ignored in model analysis. The capacity spectrum and demand spectrum curves are obtained through Pushover analysis, as shown in Figure 2. Because the strength of the raw soil wall is very low, it is easy to produce a large number of cracks, and the general earthquake damage is mostly cracks formed along its joint or the wall inclines and topples. In general, “plastic hinge+elastic rod+plastic hinge” is adopted to model the actual beam member into a beam element composed of plastic hinge

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and elastic rod. moreover, the pushover analysis adopts a constant lateral load distribution mode, and the calculation workload is relatively small, which is a better evaluation method.

3. Comparative Study on Seismic Performance Evaluation Methods of Multi-Storey Masonry Structures

3.1 Engineering Case Modeling

According to the equivalent frame, a simplified model is established, and the solid wall is divided into three parts by aspect ratio calculation. The rigid domain is used to simulate the junction of the skirt beam and the wall limb of the wall with openings. The characteristic values of the rod elements are shown in Table 3. An example of a 4-layer structure model is shown in Figure 3.

Table 3 Eigenvalue of Bar Element

Cross-sectional area of column and chain bar Ac (mm^2)	Cross-sectional area of inclined support Ad (mm^2)	Moment of inertia of column I c(mm^4)
48850	3.06×10^5	6.20×10^{10}

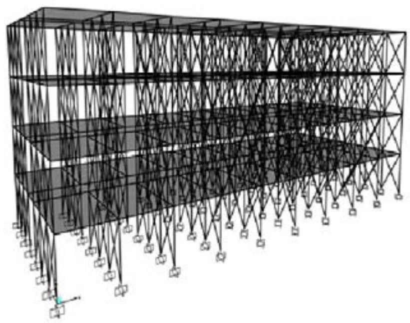

Fig.3 4-Layer Structure Model

The nonlinear seismic demand spectrum can be obtained by two methods: reducing the elastic response spectrum; The inelastic response spectrum was directly obtained through statistical research. Concrete materials used in structural models can be divided into unconstrained concrete and constrained concrete [9]. Unconstrained concrete for the middle of shear wall and slab; Simulation of confined concrete for shear wall ends, beams and columns. The magnitude of the earthquake intensity used in the design is only an artificial assumption and does not reflect the influence of the earthquake recurrence period. Secondly, the moderating effect of different site soil stiffness on earthquake motion and the stiffening problem of site soil under earthquake action have not been completely solved. At present, the classification of site soil types is semi-empirical in nature. When the brick column is not firmly fixed with the beam and purlin, the roof system will impact the brick column and even the wall due to the asynchronous movement of the brick column and the beam during the earthquake, thus aggravating the damage of the brick column [10]. Based on the average shear strength per floor area as the seismic capacity index of masonry buildings, the average shear strength per floor area coefficient method can be used as a simplified method for seismic performance evaluation of multi-storey masonry buildings.

3.2 Seismic Performance Evaluation under Frequent Earthquakes

Four seismic performance evaluation methods are used to evaluate the seismic performance of the structure. Because the structure is symmetrical and the lateral stiffness is weak, only the lateral (Y-direction) related data are listed. See Table 4 for the maximum lateral shift ratio of time history analysis method and Pushover method.

Table 4 Maximum Lateral Shift Ratio of Time History Analysis Method and Pushover Method

layer numbers	2 layer	3 layer	4 layer	5 layer	6 layer	7 layer
Lateral shift ratio	1.16	1.24	1.21	1.34	1.33	1.42

By studying the seismic performance of 2-7 story masonry structure under frequent earthquakes, the analysis results of the four methods are relatively close. However, as the number of floors increases, the error also increases. According to the comparison of the maximum lateral displacement of the structure, the analysis results of the four methods are in good agreement for 2-4 floors masonry structure. In general, the equivalent period of the first few modes of the structure participating in the calculation is greater than 0.1s at the “good use” performance level, and the structure has entered the elastoplastic stage at the “personal safety guarantee” and “collapse prevention” performance levels. The model does not consider the tensile strength of concrete. Secondly, it ignores the strength growth of concrete under the constraint of stirrups and only considers the increase of peak strain. However, compared with other models, the peak strain of confined concrete is still small. Construction quality problems, such as material properties and section geometry changes within a certain range during construction, as well as changes in ductile structural measures during construction, have an important impact on the seismic performance of actual structures. This shows that under rare earthquake, when the number of structural layers is the same, the initial time point of plastic deformation of the wall moves backward with the increase of the ratio of green wall. Therefore, increasing the wall ratio of the raw soil building can delay the occurrence of plastic deformation of the wall under earthquake and improve the ductility of the raw soil building.

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3.3 Seismic Performance Evaluation under Rare Earthquake

Through the analysis of the Pushover method, the capability spectrum and demand spectrum curves are obtained, as shown in Figure 4.

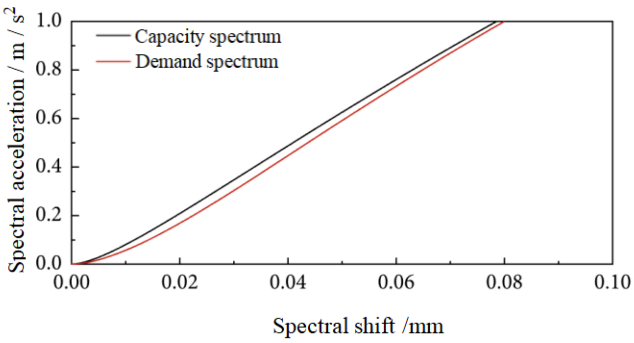

Fig.4 Capability Spectrum and Demand Spectrum Curve

When the model is applied to calculate the constitutive relation of concrete, the following method can be used to calculate the confined core area concrete, while the volume stirrup ratio only needs to be taken as 0 for the unconstrained protective layer concrete, and can also be calculated according to the constitutive relation in the specification. According to the specific situation of the building structure, a certain distribution of horizontal force is exerted on the building, gradually increasing the horizontal force to make each component of the structure enter plasticity in turn. Because the characteristics of the whole structure will change after some components enter plasticity, the magnitude and distribution of horizontal force can be adjusted in turn. The limit of the number of buildable floors of the building conforms to the previously deduced conclusion that two floors can be built in the area with seismic fortification intensity of 7 degrees, while only one floor can be built in the area with seismic fortification intensity of 8 degrees. The seismic performance evaluation results of the corresponding buildings are most similar to the evaluation results of the investigated buildings on the surface, and should be taken as the earthquake damage prediction results of the buildings to be tested. Therefore, the structure has good seismic performance under frequent earthquakes. Pushover method was used to evaluate the seismic performance of the structure under frequent earthquakes, and no plastic hinge was found, which shows that the structure has no weak links under frequent earthquakes. Under the two Pushover conditions, the capacity spectrum and demand spectrum curves of the 2-7-story masonry structure have intersection points, indicating that the structure can resist the set horizontal seismic action and has certain seismic capacity.

4. Conclusion

Compared with the traditional Pushover method, MPA method can consider the influence of higher mode shapes and is suitable for calculating the seismic response of all structures. Four seismic performance evaluation methods are used to evaluate the seismic performance of different structural forms of multi-storey buildings. The results show that the analysis results are relatively close, and the influence of high-order modes of the structure is very small. The application of PERFORM 3D can obtain the main seismic demand parameters (peak absolute acceleration and displacement angle between layers) for structural vulnerability analysis under various seismic intensity levels. It provides PACT with accurate demand vector for performance evaluation using IDA curve data. The accuracy of using elastoplastic analysis method to evaluate the seismic performance of structures is limited by the following factors: simplification of structural calculation model, determination of restoring force model, selection of seismic waves, failure criteria of structures and damage accumulation model of members. Due to human assumptions in actual analysis. Under rare earthquakes, Pushover method can show the distribution of plastic hinges and determine the weak parts of the structure compared with the other three seismic performance evaluation methods, providing more references for the actual engineering seismic performance evaluation and reinforcement.

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