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Fragility Analysis of the RC Framework

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Abstract

The safety and reliability of RC framework under earthquake are related to the personal safety and property safety of residents. In order to improve the seismic performance of the RC framework, evaluate and predict its recovery ability after an earthquake, make the seismic performance and vulnerability analysis more accurate and efficient, reduce the corresponding vulnerability, and reduce the economic loss, this paper summarizes the current status of the vulnerability analysis of the RC framework, summarizes the vulnerability analysis of the RC framework under different methods, summarizes the advantages and disadvantages of each method, and provides a reference for the reasonable design of the RC framework in the future.

Keywords

RC frame, Seismic performance, Vulnerability.

1. INTRODUCTION

Under the social background of the rapid development of modern construction in China, industrial buildings and civil buildings have begun to strengthen the use of reinforced concrete frame structures, making it one of the most commonly used structural forms in building construction. The components of the reinforced concrete frame structure are mainly beams and columns, the structure is simple and clear, the force is clear, the strength and ductility are high, and the seismic resistance is very good. In the earthquake-prone areas of China, the reinforced concrete frame structure has become the key structure of the building. As we all know, an earthquake is a natural disaster with strong suddenness, huge destructive power, and a serious threat to the safety of human life and property. On the one hand, before the earthquake occurs, the seismic risk of the building is predicted, the weak link is found, and then the seismic reinforcement measures are taken; on the other hand, once an earthquake occurs in a certain area, the damage to the building and the economic loss caused by the earthquake can also be quickly and effectively assessed with scientific significance. Seismic structure vulnerability analysis is the basis of earthquake damage and loss estimation, and is also the basic component of earthquake damage prediction, which occupies an important position in earthquake damage and loss prediction. Therefore, it is of great significance to carry out in-depth research on structural fragility analysis for earthquake damage and loss prediction and mitigation of earthquake disasters.

2. THE CONCEPT AND DEFINITION OF VULNERABILITY

2.1. The concept of vulnerability

Fragility was first applied in the military field to describe the ability of a ship hull or aircraft to withstand a collision with an object [1] In the past, due to the limitation of people's cognitive level of structural vulnerability, the judgment of structural fragility in engineering practice often relied on the experience of engineers to judge and check. Scholars at home and abroad have different understandings of vulnerability. Beeby [2] According to the theory of energy absorption, the concept of allowable damage energy per unit volume is proposed, and the ultimate allowable damage energy per unit volume is obtained by testing the specified components, so as to ensure that the structure meets the requirements of fragility when it is damaged due to accidental load. Lu [3] Based on the structural form, the concept of fragility is proposed, and the weak parts in the structure are analyzed by considering the possible failure of the structure and studying the combination of structural components. Lind [4] According to the definition of allowable damage probability and vulnerability, allowable damage is defined as the ratio of the failure probability of the damaged system to the failure probability of the undamaged system, while fragility is defined as the reciprocal of the allowable damage. Ziha [5] Based on the concept of uncertainty measure, it is pointed out that the probability distribution of failure modes and effective modes that meet the requirements of system fragility should be as uniform as possible, and the theory of event system fragility based on uncertainty information entropy is proposed. Lv Dagang [6] Structural fragility is defined as damage or damage to a building as a result of an earthquake.

2.2. Definition of vulnerability

Structural seismic vulnerability [7] It means that the structure has reached a specific loss under the action of different ground motion intensities The probability of an injury state, which is not affected by any factors, is an intrinsic property of the structure, as shown in Eq. (1). $F(x)=P(LS_i|IM=x)=P(D\geq D_i|IM=x)$ (1) where: LS_i is a certain limit state of the structure; IM stands for ground motion intensity parameters, such as PGA, etc.; DM represents the damage index of the structure, such as the maximum interstory displacement angle θ_{max} Wait; D is the performance index of the structure; D_i It is the performance index of the quantified structure; F(x) is called the seismic vulnerability function. Structural seismic vulnerability is usually represented by multiple continuous curves, which are called vulnerability curves, which can better express the probability of the structure reaching a specific damage state in each limit state.

3. CURRENT STATUS AND METHODS OF FRAGILITY RESEARCH

3.1. Empirical approach based on available data

Scawthorn [7] For the first time, an empirical method based on measured seismic damage data was proposed to use empirical relationships by experienced engineers to quickly assess seismic vulnerability. The empirical method is one of the simplest methods for constructing the fragility function, which does not need to simulate the seismic damage data, nor does it need to be cumbersome calculation, but only requires experts to subjectively carry out the vulnerability analysis through the measured data of the seismic damage data in the studied area, combined with their own experience, and can also refer to the experience of historical assessment for the fragility analysis of similar building structures, so it also has continuity. Fatma [8] Based on the experience of seismic feedback in 1999 and 2003, the weighting coefficients of each parameter were determined by using the Vulnerability Index (VI) method. On this basis, the concept of damage probability matrix (DPM) was proposed, and the average damage level was defined by it, and the semi-empirical fragility curve was obtained. The empirical analysis method based on seismic damage investigation can directly reflect the damage caused by the earthquake to the building, and can also truly reflect the actual seismic performance of the structure, but there are certain limitations in the practical application, which are manifested in: (1) due to the different intensity and site conditions, it is difficult to collect data on house damage, so the sample size is usually limited, and (2) in remote areas, due to the different human factors and customs during the actual construction of the house, the collected data on the destruction of the house is often

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not representative. The results obtained are not representative of the seismic performance of a house designed according to existing specifications. (3) In the process of collecting seismic damage data, human factors have a great influence. (4) Only the structural forms and regions with abundant seismic damage data are suitable for this method, but this situation is relatively rare.

3.2. Theoretical calculation methods of numerical simulation

Due to the shortcomings of empirical analysis methods based on seismic damage investigation and the continuous improvement of the accuracy and accuracy of seismic damage prediction in construction projects, the importance of theoretical calculation methods based on numerical simulation is becoming more and more prominent. The development process of the fragility analysis method based on numerical simulation, also known as the analytical method, is essentially synchronized with the development of seismic response analysis, that is, from the elastic spectrum method to the nonlinear static method, to the nonlinear time history analysis method, the most commonly used incremental dynamic analysis (IDA) and the generalized cloud map-stripe method of IDA.

The Incremental Dynamic Analysis (IDA) method is a dynamic parameter analysis method based on nonlinear time history analysis, which can be used to comprehensively evaluate the performance of structures under seismic loads. The basic principle is that the same ground motion is continuously amplitude modulated through a certain amplitude modulation ratio, and the dynamic time history analysis is carried out on the structure respectively, so as to obtain the structural response of the structure under the action of the same ground motion with different amplitudes. The increasing ground motion intensity is connected with the corresponding seismic response to form an IDA curve under the action of single ground motion recording, and the dynamic performance of the structure under the action of ground motion is studied by using the IDA curve, and the seismic performance is analyzed. is an improvement of the NLTHA method. The steps are as follows: (1) select the ground motion record to determine the ground motion intensity parameter (IM), ;(2) determine the amplitude modulation principle and amplitude modulation coefficient, and continuously adjust the ground motion intensity through the amplitude modulation coefficient to obtain a series of ground motion records of different intensities; (3) select the corresponding parameters LS (such as interstory displacement angle, etc.) to depict the structure;(4) conduct time history analysis for the ground motion obtained after amplitude modulation, and use the formula to perform probability statistical analysis on the nonlinear time history analysis results, so that the transcendence of the structure or component under a certain IM can be obtained $P_f\,[D \geq LS_i\,|IM] = n_i/N$, i=1,2,3,4, etc. Among them, LS_i it is the ith type of damage state (i takes 1 to indicate slight damage; 2 indicates moderate damage; 3 represents severe damage; 4 represents complete failure); N is the total number of seismic waves; n_i and is the number of seismic waves when the seismic response exceeds a certain damage limit state. (5) Draw the coordinate system with IM as the horizontal axis and P_f the vertical axis, that is, the vulnerability curve.

Wang Ziying and others [8] Based on the seismic fragility analysis of the RC frame structure under the IDA method, PKPM was used to design the structure of a 10-storey three-span RC frame structure. The seismic fortification intensity of the building is 8 degrees (0.2gThe design seismic group is the second group, the site category is Class II., the frame seismic grade is Class I, and the site characteristic period is 0.4s.

The height of the 1st to 3rd floors of the structure is 3.9m, the height of the 4th floor and above is 3.3, the total height is 34.8m, the number of spans is 8×3, and the structural dimensions are 38.4ｍ×14.4ｍ. The 1st to 3rd floors are made of C40 concrete, the 4th floor and above are made of C35 concrete, the beams and columns are reinforced by HRB400, and the floor thickness is 100mm. Based on the incremental dynamic analysis (IDA) method, the seismic

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fragility analysis of the structure was carried out, and the failure probability formula and seismic fragility curve of the frame structure under different ground motion intensities were obtained, and its seismic performance was evaluated. Road rustling, etc [9] Based on the seismic fragility analysis of reinforced seismic damage RC frame structures based on the IDA method, three RC frame structures with 3, 6 and 9 floors were designed, and the height of the first floor was 4.2m, the standard floor height is 3.6m, the structural plane size is 28.8m× 14.7m, the concrete strength grade is C30, the beam,Strength grade of column longitudinal reinforcement and stirrup reinforcementHRB400, the design and use functions are office. The seismic fortification intensity is VII, the design basic seismic acceleration is 0.1g, and the design seismic grouping is Group I, Class II site. The seismic fragility analysis of the seismic damage RC frame structure reinforced by carbon fiber and bonded steel reinforcement methods shows that with the increase of height and PGA, the overall convergence of the IDA curve clusters of carbon fiber and bonded steel reinforced structures after seismic damage of layers 3, 6 and 9 is better. In general, the reinforcement of bonded steel can improve the convergence of the structure to the randomness of ground motion, but with the increase of the height of the structure, the gain effect of the random convergence of ground motion gradually weakens, and the reinforcement method has an obvious effect on the reinforcement of low-level frame structures with seismic damage at a height of 3 floors. Carbon fiber reinforcement has a stronger ability to control the interstory displacement angle of the structure than that of bonded steel reinforcement, and can improve its resistance to rare earthquakes to a greater extent for the seismic damage of the middle frame structure with a height of 6 floors. For the seismic damage high-rise frame structure suitable for 9 storeys height, any one of the two reinforcement methods can be selected according to the actual situation, and the better reinforcement effect can be obtained. Wu Shan et al [10] Seismic optimization design method of RC frame structure for uniform damage. The uniform damage design method of RC frame structure is proposed, with the equal or similar damage index of each floor as the optimization goal, and the reinforcement rate of each frame column as the optimization variable, and the intelligent algorithm and finite element platform collaborative calculation technology are used to realize the uniform damage optimization design of RC frame structure, and the elastoplastic time history analysis and IDA method are used to verify and analyze the optimization effect. The results show that the optimal reinforcement ratio distribution of the frame column is not exactly the same under different seismic waves, and the optimal reinforcement ratio distribution of the frame column does not show obvious statistical rules, but the mean value of the optimization results under different seismic waves can be used as the frame column reinforcement scheme to improve the seismic capacity of the structure, and the optimization method is reasonable and effective.

The cloud map method is a structural demand analysis method that does not require the amplitude modulation of ground motion intensity, while the stripe method and the IDA method are two structural demand analysis methods based on the amplitude modulation of ground motion intensity. Yu Xiaohui and others [11] A probabilistic seismic demand analysis of the cloud map-stripe method is proposed, which eliminates the limitation that the historical cloud map method cannot handle a large number of nonlinear time history analysis results by introducing the method of processing data in empirical seismic vulnerability analysis.

3.3. Mixed Method

The hybrid method is based on the empirical method of seismic damage investigation and the theoretical calculation method based on numerical simulation. If there is a lack of corresponding seismic damage data in a certain area or a certain structural form, the hybrid method is very suitable. The combination of a part of the seismic damage data and the established analytical model can not only offset the subjectivity of the seismic damage investigation method, but also make up for the shortcomings of the analytical method for the

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lack of actual seismic damage data. Yang Shuo [12] In the study of building structure fragility analysis by using the hybrid method, the IDA method is used to obtain the correspondence between the PGA and the interstory displacement angle (failure probability), the seismic vulnerability curve and matrix of each single building, and then the seismic damage survey data is statistically analyzed, the vulnerability matrix is obtained and the average seismic damage index is calculated, and finally the proportion coefficient between the analytical method and the seismic damage investigation method is calculated. The previous mixed methods were mostly based on the two methods of separate calculations, but rarely looked for the relationship between the two, Yang Shuo used three methods to find the proportional coefficient connection between the two, and finally obtained better results. Combined with the principle of the Kappos structure hybrid method, the ref [11The mixed analysis steps of RC frame structure in China are given: (1) the RC frame structure is classified from different layers and heights; (2) The representative buildings were selected for theoretical analysis, and the relationship curve between seismic intensity parameters and damage index was obtained. (3) The classification of RC frame structures is counted, the fragility matrix of each type of structure is obtained, and the average seismic damage index is calculated, and finally the relationship curve between the seismic intensity parameters and the damage index is adjusted by the scale coefficient to obtain the adjusted relationship, and then the mixed fragility analysis is carried out by using the theoretical method.

4. PROBLEMS EXISTING IN THE CURRENT RESEARCH OF THE RC FRAMEWORK

Each of the three methods has its own advantages and disadvantages, but the advantage of the empirical method is that it is simple and easy to implement, it can show the actual seismic damage, and it can show the actual vulnerability of the structure. The disadvantages are the reliance on expert experience, the high degree of subjectivity, the difficulty of obtaining data, the regional and structural specificity, and the subjectivity of observations. The advantages of numerical simulation method are high reliability, most uncertainties can be considered, strong objectivity, but disadvantages are large amount of calculation, and large dispersion in the demand model. The advantages of the hybrid method are that it contains seismic damage data, the amount of calculation is small, the disadvantages are time-consuming and expensive, the appropriate analysis method needs to be selected, and the definition of the damage state is subjective. The seismic data of the existing RC framework is missing, and the seismic data in some remote areas cannot be collected, and the data after the earthquake are difficult to collect, and the experimental methods need to be improved. The theoretical calculation method based on numerical simulation has been continuously improved, but the fragility curve, surface and index obtained by this method cannot fully reflect the real seismic damage state of the structure. Therefore, how to combine the empirical analysis method based on seismic damage investigation and compare and regress the two, try to offset the subjectivity of the seismic damage investigation method and the objective uncertainty of the numerical simulation method, improve the vulnerability analysis expression, and make the seismic vulnerability analysis more realistically describe the damage state of the building. There is less fragility analysis for RC frame structures in high-rise and super-high-rise buildings. Due to the scarcity of seismic damage data of high-rise buildings, it is difficult to use numerical simulation or experimental methods to analyze the vulnerability, and the fragility research methods of a class of structures are given by using numerical simulation or experimental methods to establish only a few models, which have great uncertainty in the selection of structures and components, and the selection of ground motion parameters. However, it takes a lot of time to establish multiple numerical models and the cost of establishing multiple real models by experimental methods, so how to solve the problem of uncertainty in the vulnerability analysis of R C frame structures

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of high-rise and super high-rise buildingsis also the focus of future research. The study of seismic vulnerability is mostly based on a single ground motion input, but the actual earthquake is the input of numerous main and aftershocks. However, due to the lack of ground motion input in the analysis, the input method and number of aftershocks in the ground motion input will be another research direction of seismic vulnerability. At present, the commonly used incremental dynamic analysis method has too much computational cost, and how to reduce the computational amount without affecting the calculation accuracy is also the focus of research. The field of earthquake engineering is the study of "resilient urban and rural", that is, the construction of resilient cities, on the one hand, the formation of resilient structures and components, and on the other hand, the construction of resilient communities and urban-rural areas. Both need to be based on seismic fragility analysis, so the fragility study of recoverable structures and components will also be the focus of future research.

5. SUMMARY

The most common of the three main methods for the fragility analysis of the frame is the calculation method of numerical simulation, but with the progress of science and technology and the accumulation of seismic damage values, the hybrid method will be the mainstream method in the future, and it will also be the focus of future research, and the fragility analysis of the frame is the most accurate, so as to reduce the safety of life and property caused by earthquakes and aftershocks.

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