ISSN: 1813-4890

Survey on seismic performance of reinforced concrete structures based on FEMAP58 theory

Weitao Li, Guowei Ni and Bo Liu *

School of College of Civil and Architectural Engineering,

North China University of-Science and Technology, Tangshan 063210, China.

Abstract

The seismic design based on FEMAP58 theory considers the function loss, recovery time and recovery cost of buildings after earthquakes. Therefore, it has been widely concerned by scholars from various countries. Firstly, the characteristics of RC structures and the problems of traditional performance evaluation methods are briefly introduced. Then, the evaluation process and principle of FEMAP58 theory are introduced, and the application examples and research situations of this theory are sorted out from four aspects: structural components, frame structures, shear wall structures, and frame-shear wall structures. Finally, according to the current problems in the seismic research field and the national conditions of China, the emphasis and direction of research work in the future are pointed out.

Keywords

FEMAP58 theory; Post-earthquake restoration; PEER; Seismic performance evaluation.

1. Introduction

Reinforced concrete structure is a common form of building structure. It is widely used in residential, commercial and industrial buildings, as well as Bridges, water conservancy and hydropower projects. The reinforced concrete structure is composed of concrete and steel bar. In the construction process, the concrete is poured first, and then the steel bar is arranged in the concrete. Finally, the concrete and the steel bar work together to form a composite structure with certain strength and stiffness. The reinforced concrete structure has the characteristics of high strength and stiffness, good plasticity, good constructability and strong durability. Reinforced concrete structure usually includes frame structure, shear wall structure, frame - shear wall structure and other forms. Through reasonable design and construction, the structure can meet different use requirements and seismic requirements. In practical engineering, reinforced concrete structure is widely used because of its high reliability and good economy.

In the seismic design codes of various countries, the traditional fortification level of "Small tremors do not damage, moderate tremors can be repaired, and severe tremors do not collapse" is generally used. This shows the seismic design idea of hierarchical design. For example, China's "Code for Seismic Design of Buildings" GB50011-2010[4] and the United States "International Building Code" IBC[5] are based on this concept. The building structure designed according to the above ideas can well control the overall collapse of the structure and the casualties in the building caused by strong earthquakes. However, with the development of economy, not only the construction cost of modern buildings is getting higher and higher, but also the cost of internal non-structural components, technical equipment and decoration even exceeds the construction cost. According to the current seismic code design of the building structure, obviously to the earthquake disaster caused by the direct or indirect economic loss of some powerless.

In recent years, a number of destructive earthquakes have revealed the shortcomings of conventional seismic design methods. Performance-based earthquake engineering (PBEE) has emerged in our field of vision. In order to solve the problems of traditional seismic design method, such as insufficient consideration of non-structural components and weak components, and failure to take into account the performance indicators concerned by owners and users. In order to deal with these problems, the Pacific Earthquake Engineering Research Center (PEER) established the behavior evaluation method of FEMAP58 based on conditional probability and full probability. This is of great significance for the evaluation of seismic capacity of urban engineering structures.

In this paper, based on the reading of a large number of literatures, the research progress on the seismic behavior of different reinforced concrete structures based on the FEMAP58 theory is introduced. Combined with the characteristics of the building structure in China, the emphasis and direction of the research work in the future are pointed out.

2. FEMA P-58 Performance-based seismic assessment theory for buildings

In 2012, FEMA proposed a new generation of earthquake resistance assessment method FEMA P58. This is an important progress in the theory of seismic toughness evaluation of urban engineering structures. Three types of assessments are proposed, namely, Intensity-based assessments. Scenario-based assessments based on seismic environment and Time-based assessments based on seismic risk. The basic principle of FEMA P-58 is to use Monte Carlo method to calculate the structural loss results after random values of the variables, which is a "realization" process. The use of this method requires that, based on the completion of IDA analysis, the structure is determined to be collapsed or not. The ultimate goal of FEMA P-58 is to fit the relationship function between the performance index of the structure and the transcendental probability of the index.

3. Research Status

3.1. Study on the impact of components

The performance of a building is actually influenced by both structural and non-structural components. And most of the building's functions rely on non-structural systems. Non-structural systems account for more than 80% of the initial investment in a building. Recent earthquakes have shown that traditional earthquake-resistant design concepts allow for a large degree of non-structural damage. However, since non-structural systems account for the majority of building investment and are critical to building operations, non-structural seismic damage can result in significant repair costs and long-term functional damage, resulting in billions of dollars in losses in 2010 alone. Therefore, damage prediction of non-structural systems is very important to accurately assess the functional level and economic loss of buildings. It is necessary to consider the performance of non-structural components in seismic vulnerability analysis and evaluation of buildings. This allows for a better understanding of the expected overall seismic performance of buildings that meet the code.

Dhakal RP et al. [1] conducted extensive tests on non-structural components such as ceiling, facade and drywall, and predicted the damage result, maintenance cost and maintenance time of non-structural components after earthquake based on FEMA P58. Donatello C et al. [2] used FEMA P58 to evaluate a reinforced concrete frame building in Italy with masonry fill and partition walls. O'Reilly GJ et al. [3] quantified the performance of the existing building with reference to the method provided by FEMA P58, taking into account the reinforced concrete frame with masonry fill.Zeng Xiang et al. [6] used the strength-based loss assessment method in FEMA P-58 assessment method to assess the loss of the (MCS) model of three typical campus buildings. The analysis results show that the FEMA P-58 method can reflect the component loss caused by the earthquake. Structural components and displacement sensitive components are the main sources of losses under moderate and large earthquakes.Lu Yan et al. [7] adopted the seismic performance evaluation method of FEMA P-58 building developed based on PBEE method, and analyzed a concrete frame structure hotel located in Los Angeles, California, USA. The repair cost of the partition wall of the structure under different earthquake intensities is obtained.

In the above studies, most scholars have considered the building loss caused by non-structural components and considered the building repair cost, casualties and repair time. Because many non-structural components are acceleration sensitive components, and the traditional seismic regulations rarely consider the impact of the engineering parameter acceleration on non-structural components, it will happen that the same kind of reinforced concrete building will be evaluated by the traditional seismic regulations and the FEMA P-58 method to evaluate the earthquake economic loss, and the assessment results will be greatly different. In modern buildings, with the increase in the cost of non-structural components of the building, strengthening non-structural components and improving their seismic level may be more economically beneficial than improving the overall seismic level of the building. This provides a new seismic design idea for building designers.

3.2. Reinforced concrete frame structure building

Reinforced concrete frame structure building in China's building structure, reinforced concrete frame structure building occupies a very important position. With the rapid development of China's economy and the acceleration of urbanization process, reinforced concrete frame structure building has become one of the main structural forms of most buildings in the city, and has been widely used in various types of buildings. Seismic research of reinforced concrete frame structure has been one of the important research directions in the field of construction engineering. In China, due to the special geographical environment of frequent earthquakes, the seismic performance and safety requirements of reinforced concrete frame structures are very high, so seismic research has been widely concerned and sustained investment.

Yan Deng [8] designed a typical multi-storey frame structure. On this basis, buckling constraint support and isolation support are added to form an isolation frame structure, and the seismic performance of the building is evaluated by FEMA P-58 theory. It is found that the use of BRB-frame structure can effectively reduce the maintenance cost and maintenance time of buildings under earthquake action. The isolation frame structure has excellent safety reserve, and the BRB-frame structure has excellent collapse resistance.

According to the seismic toughness evaluation method of FEMA P-58, Wu Wei [9] studied the ductile seismic performance of key fortification RC frames with different seismic fortification under different earthquake intensities. His research focuses on medical architecture.The results show that the toughness and seismic performance of each frame are different. The higher the fortification intensity is, the greater the earthquake loss is under the action of the corresponding intensity earthquake at all levels.

Xiong Rui [10] used FEMA P-58 evaluation method to evaluate primary and secondary school teaching buildings with multi-layer frames before and after BRB reinforcement. It is found that the overall repair cost of the BRB model is much lower than that of the ordinary frame structure, which is mainly reflected in the repair of structural components. However, for the components that are sensitive to acceleration, the corresponding repair cost proportion increases. The repair time is significantly reduced. The repair time of the displacement sensitive component is greatly reduced, but the repair time of the acceleration sensitive component is slightly increased.

The seismic characteristics evaluation method of FEM P-58 has selected some performance indices, which makes it easy for non-technical personnel to understand; In the evaluation of earthquake damage, the concept of global probability is introduced, and on this basis, the earthquake damage is analyzed. The Monte Carlo method can not only improve the calculation accuracy, but also reduce the uncertainty of the calculation results. The performance class is introduced in the performance evaluation, so that the performance evaluation can be clearly reflected in the various components and non-structural parts of the building.

3.3. Reinforced concrete shear wall structure, frame shear wall structure

Reinforced concrete shear wall structure and frame shear wall structure are common seismic structure forms. The reinforced concrete shear wall structure and the frame shear wall structure have certain similarities in form, and both use the wall to provide seismic support.In the design, the shear wall structure usually adopts the strategy of larger wall size and higher layout density. However, the frame shear wall structure focuses on improving the seismic performance of the whole structure by rational arrangement and strengthening connections. Shear walls are also used in the frame structure to further increase the seismic performance. Such a combination can make full use of the advantages of both and improve the overall seismic ability of the structure.

Dong Yao [11] took RC frame shear structure as the research object. Based on the full probability analysis of FEMAP-58, the strength and time history analysis of RC frame shear structures with different fortification levels is carried out with the goal of direct economic loss, maintenance cycle and casualties. The results show that the greater the local earthquake intensity, the greater the earthquake loss of the structure with the same seismic performance. Under the same earthquake action, the seismic performance decreases with the increase of fortification intensity

Cao Yuan [12] established an earthquake loss assessment method based on component deformation by using the theoretical framework of PBEE with full probability. Combined with the index limits of each performance state of beam, column and shear wall members, this study took the plastic rotation Angle of members as the damage identification parameter and designed the frame-shear wall structure in five fortification intensity areas of 6 degrees, 7 degrees, 7.5 degrees, 8 degrees and 8.5 degrees respectively according to the current Chinese code. It is found that the earthquake loss risk of structures in different fortification intensity areas is not consistent. In the proportion of all types of components lost in the earthquake, the loss of non-structural components accounts for about 70%, which is the main component. In the loss of structural members, the loss of beam members is the dominant factor, accounting for more than 80%. With the increase of fortification intensity, the proportion of losses of beam members decreases, and the proportion of losses of shear wall members increases.

Cui Mingzhe [13] took an existing high-rise shear wall building structure as an example and used FEMA P-58 method to evaluate the seismic performance. A building example is evaluated based on ground motion intensity and time, and the results of repair cost, repair time and casualties are given. The analysis results show that the FEMA P-58 building seismic performance assessment method can quantitatively evaluate the seismic performance of existing high-rise buildings, and give intuitive performance indicators.

If the structures built with design codes of different countries are evaluated and compared, the differences in post-earthquake repair capacity of buildings in different countries will be obtained. Li Mengke [14] and Tian Yuan et al. [15] selected two groups of comparative cases of RC frame-core tube structure in high-intensity areas in China and the United States. They used the FEMA P58 method to evaluate and compare the loss of each structure scheme in the two groups of study cases under the action of three earthquake intensities. The results show that the repairing cost and working days of non-structural components account for most of the total

ISSN: 1813-4890

cost and working days. In addition to structural collapse, vulnerable sets that may cause casualties are mainly ceilings and elevators. Under the same seismic hazard condition, the restoration cost of the Chinese plan is less than that of the American plan under the three earthquake intensities. In the case of frequent earthquakes and fortified earthquakes, the repair work days of the Chinese plan are smaller than those of the American plan, and the repair work days of the Chinese plan are slightly larger under rare earthquakes. Under the condition of the same designed base shear force, the repair cost and repair days of the American scheme are less than those of the Chinese scheme under the three earthquake intensities.

4. Existing problems and prospects

At present, there are several problems in the research of seismic performance of reinforced concrete structures based on FEMAP58 theory.The prediction accuracy of existing evaluation methods stays in the performance group rather than the component group. In other words, the evaluation method is aimed at a class of components rather than a single component. Therefore, although the location, quantity and arrangement of different components will really affect the toughness of the building, it is difficult to reflect them in the evaluation process.

In our country, the research on seismic toughness still needs to be improved. For example, PACT, the most commonly used software at present, contains a relatively comprehensive vulnerability database, but the population model and vulnerability data in the software are all from California, USA, which are quite different from domestic. If it is applied to domestic evaluation, the results have large errors and the evaluation results are relatively general. If you want to obtain the results in line with the data of our country, you can refer to the "evaluation Standard for Seismic Toughness of Buildings". However, since the standard does not contain the vulnerability model of the specific structural framework and non-structural components, it needs to be obtained through additional tests or numerical simulations during the evaluation.

There is no fixed and accepted evaluation method for community and urban buildings. Scholars consider the related impact of restoration between buildings according to different mathematical models. However, with a vast territory of our country, different environments define different architectural forms and architectural systems, and the differences in population distribution, management mode and economic development will all have a serious impact on community and urban architecture. Therefore, on the basis of considering the national conditions of our country, it is of great significance to develop a universal evaluation model of community and city system that can be applied throughout the country.

Acknowledgements

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] DHAKALRP, POURALI A, TASLIGEDIK A S, et al. Seismic performance of non-structural components and contents in buildings: an overview of NZ research. Earthquake Engineering and Engineering Vibration,Vol.15(2016)No.1,p. 1-17.

[2] CARDONED, PERRONEG. Damage and loss assessment of pre-70 RC frame buildings with FEMA P-58[J]. Journal of Earthquake Engineering,Vol. 21(2017)No.1,p. 23-61.

[3] O'REILLYGJ, SULL*IVANTJ. Probabilistic seismic assessment and retrofit considerations for Italian RC frame buildings. Bulletin of Earthquake Engineering, Vol.16 (2018)No.3,p. 1447-1485.

[4] GB 50011-2010 .Code for Seismic Design of Buildings . (Beijing: China State Engineering and Construction Press, 2016.)

[5] ICC-IBC-2006, International Building Code 2006. (US： International Code Council INC, 2006.)

[6] X.Zeng ,S.X. Liu , Z.Xu , et al. Case Analysis of campus buildings based on FEMA-P58 method [J]. Engineering mechanics, Vol.33 (2016)No.S1,p.113-118...

[7] Y.Lu ,Y.M. Zhang, Z.H.Yang . Cost sensitivity analysis of unstructural component repair based on FEMA-P58 method. Proceedings of the 20th National Symposium on Modern Structural Engineering(Tianjin ,2020)Vol.1,p.5.DOI:10.26914/c.cnkihy. 2020. 039030.

[8] D.Yan. Assessment of Seismic and Isolation Performance of Reinforced Concrete Frame Structure Based on FEMA P-58 .(MS., China Institute of Seismic Engineering Mechanics,China, 2020). DOI: 10.27490/d.cnki.ggjgy. 2019.000042.

[9] W.Wu . Study on the seismic toughness of medical buildings with different seismic fortification RC frame structures. (MS., Huazhong University of Science and Technology, China,2022). DOI:10.27157/ d.cnki.ghzku. 2020.000452.

[10] R.Xiong. Evaluation of the seismic toughness of the multi-storey frame middle school teaching buildings reinforced by BRB . (MS., Huazhong University of Science and Technology, China,2022).DOI:10.27157/d.cnki.ghzku. 2020.001028.

[11] Y.Dong. RC frame-shear wall structure seismic toughness rating with consistent collapse risk decision .(MS.,Harbin Institute of Technology, China,2020.)DOI:10.27061/d.cnki.ghgdu. 2019. 001695.

[12] Y.Cao .Study on seismic loss assessment method of RC frame-shear wall structure based on component deformation. (MS.,South China University of Technology, China,2018.)

[13] M.Z.Cui,C.K.Wang ,C.H. Chen, et al. Seismic performance assessment of existing high-rise shear wall structures based on the FEMA P-58 method [J]. Project seismic and reinforcement renovation, Vol.43(2021),,No.05:10-17.DOI:10.16226/j.issn.1002-8412.2021.05.002.

[14] M.K.Li. Seismic design and evaluation of high-rise reinforced concrete frame-core cylinder structure in China and America . (MS., Tsinghua University, China, 2016.)

[15] Y.Tian ,M.K. Li ,L.L. Xie , et al. A new generation of performance design method is adopted to compare the seismic loss of typical high-rise buildings in China and the United States [J]. Building structure,Vol.48(2018),No.04,p.26-33.DOI:10.19701/j.jzjg. 2018. 04.006.