Research progress on seismic resilience evaluation and evaluation methods in building structures

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Abstract. With the demand for resilient city construction, research on structural seismic resilience has practical significance. By discussing the research progress of seismic resilience evaluation and seismic resilience evaluation methods, we aim to promote innovation and development in structural seismic resistance and disaster prevention and reduction work. In the form of earthquake resistance and disaster reduction, structural designers should consider the seismic toughness index of the structure to improve its toughness performance. It has certain reference value for the reinforcement and renovation of new and existing buildings.

Keywords: structural seismic resilience; Resilience assessment methods; Resilience evaluation methods; Seismic resilience index

1 Introduction

Earthquake disasters often cause significant losses to people's lives and property safety. Earthquake disasters have suddenness, unpredictability, high frequency, and produce serious secondary disasters. In recent years, seismic resilience structures have become a higher pursuit goal in the field of engineering structures, which requires structures to have the ability to avoid serious damage during earthquakes and quickly recover their functions after earthquakes[**Error! Reference source not found.**].

Earthquake disasters occur frequently. Only in 2020, there were 20 earthquakes with magnitude above 5.0 in Chinese Mainland (including 17 earthquakes with magnitude of 5.0~5.9 and 3 earthquakes with magnitude of 6.0~6.9). On May 18, 2020, the Qiaojia 5.0 magnitude earthquake in Yunnan caused 4 deaths, more than 1100 houses were damaged to varying degrees, and 11000 people were affected, resulting in a direct economic loss of 101 million yuan; On July 23, 2020, the Nima earthquakeMs6.6 in Xizang caused damage to more than 50 old houses due to its epicenter in the sparsely populated areas above sea level. Due to the revision of seismic design and the development of seismic reduction technology, casualties are reduced during earthquakes. According to the statistical data released by the China Earthquake Administration, there have been 14 major earthquake disasters worldwide, resulting in 196 deaths. Therefore, it is necessary to conduct seismic resilience research on urban and building

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structures, evaluate and evaluate seismic resilience methods, in order to ensure structural safety and reduce disaster losses.

2 Requirements for seismic resilience

Scholars believe that to effectively reduce earthquake disasters, not only do we need our buildings and civil infrastructure to have appropriate earthquake resistance, but we also need our cities to have the ability to comprehensively respond to earthquake damage, especially to ensure that the functions of cities should not be interrupted. Therefore, a completely new concept of urban seismic design has been proposed: to design and construct our cities into. A city with seismic resilience is the ultimate goal of urban seismic design, which is a resilient city. Subsequent scholars have also studied the seismic toughness performance of different structures.

Different countries adopt different research and evaluation methods for evaluating the seismic resilience and performance of structures. The Chilean seismic design code only specifies a range of design life safety performance levels. In Chile, through observation and statistical analysis of strong earthquakes, seismic resilience of buildings is a goal of building structures. In terms of seismic design regulations for low rise reinforced concrete (RC) frames, Arroyo, et al. [2] compared ASCE 7 in the United States, NSR-10 in Colombia, and NEC-2015 in Ecuador. Through a case study of designing a four story building, the results showed that NEC-2015 design was controlled by strong column and weak beam requirements, while displacement limitation and strength control were control factors in NSR-10 and ASCE 7 design. The seismic performance evaluation shows that the performance of the three buildings is sufficient, and the columns in NEC-2015 buildings show slightly better performance. Okada T [3] reviewed the major earthquake disasters that occurred in Japan, and elaborated on the development and current situation of seismic evaluation and seismic retrofitting of existing buildings for low and mid story reinforced concrete buildings. Taking reinforced concrete frame structures as an example, Yu KM [4] introduced the types of losses caused by earthquakes and the types of damage to engineering structures. He analyzed the types and applications of seismic reduction technologies, and used passive control methods as an example to verify the effectiveness of seismic reduction technologies. Therefore, it is of great practical significance to study the resilience and seismic resistance of new and existing structures.

In addition to investigating and analyzing the causes of earthquake damage and taking disaster prevention and control measures, performance evaluation is also required for building structures. An important indicator of building performance evaluation is the varying degrees of damage that occurs when structural and non-structural components deform beyond their load-bearing capacity during earthquakes.

3 Research on the application of seismic resilience evaluation methods

Research on seismic resilience, accompanied by the proposal and development of seismic performance evaluation methods[5].According to the quantitative indicators of seismic resilience, domestic and foreign scholars have studied the evaluation methods of seismic resilience.

Pan, et al. [6] elaborated on the origin and development of resilience in the field of building seismic resistance, and combined with multiple institutional organizations in countries such as China, the United States, and the United Kingdom, summarized four evaluation methods for seismic resilience: FEMA P58 evaluation method, REDi evaluation system, USRC evaluation system, and evaluation method based on the "Building Seismic Resilience Evaluation Standard" (GB/T 38591-2020), The analysis shows that the impact of components on resilience assessment will directly affect the evaluation results of individual buildings, and the seismic resilience of individual buildings is the research basis for the seismic resilience of community cities.

Hosseinzadeh , et al. [7] developed a two-dimensional modeling method using OpenSees software to study the seismic vulnerability and toughness of reinforced masonry flange walls.

Wang , et al. [8] proposed a seismic resilience assessment method for buildings based on goal-capability gap analysis, considering the different functional losses and recovery time goals that buildings should achieve after earthquakes at different levels. He proposed a quantitative evaluation method for post functional losses and recovery time that can be quickly applied in the planning field. The resilience level of buildings is determined by the difference between the functional loss value, recovery time value, and target value.

Huang [9] proposed a resilience based seismic design method suitable for reinforced concrete structures, established resilience design goals for structures under different levels of seismic action, and conducted inverse calculations from the overall resilience design goals to component performance requirements. The resilience based seismic design process was established, taking into account the recoverability of structural functions. Taking the resilient seismic design of a five story reinforced concrete isolation frame structure as an example, the structure designed using the proposed method can meet the limit requirements of various engineering requirements and meet the expected toughness goals.

Li [10] proposed a structural seismic resilience evaluation index based on performance loss and recovery, and established a structural seismic resilience evaluation method that considers the importance of components, laying the foundation for the seismic resilience evaluation of frame core tube structures.

Deng , et al. [11] evaluated the seismic toughness of corroded reinforced concrete frame structures based on a time-varying corrosion damage model using fiber beam elements, taking into account most potential corrosion damage modes of reinforced concrete. Using OpenSees program to establish a framework structure model and conduct nonlinear static analysis, the results show that when the degree of corrosion is small, the seismic toughness of the structure decreases with the increase of the degree of corrosion. However, when the degree of corrosion exceeds 10%, the impact of corrosion on the seismic toughness of the structure is relatively small. This result is consistent with the basic periodic variation law of corroded reinforced concrete frame structures; As the intensity of earthquakes increases, the decrease in structural toughness will also be affected by corrosion.

Guan , et al. [12] and Du, et al. [13] evaluated the seismic, seismic reduction, and isolation performance of a 6-story selfcentering bending frame and RC frame structure using the FEMA P58 evaluation method. Energy dissipation and seismic isolation structures are one of the common ways to improve the seismic resilience of buildings. They not only have a positive effect on the structural response during earthquakes, but also on the post earthquake repair of buildings, which is reflected in improving the structural resilience and providing reference for subsequent engineering applications. Hu ,et al[14] proposed a method to quantify the resilience of structures under mainshocks and multiple aftershocks.Using finite element model validation, the deviation in elastic evaluation is relatively small.

Aroquipa , et al. [15] proposed a simplified method for evaluating the seismic capacity of buildings through probabilistic risk assessment, taking into account labor population, maintenance time, and direct and indirect losses. Two study cases were presented for the calculation of the simplified resilience index at damage definition and loss estimation stages applied to school reinforced concrete moment-resisting frames buildings with a 3-,6- and 9- story height.

Li, et al. [16] compared three seismic design methods: specification based seismic design, performance-based seismic design, and resilience based seismic design, and explained the limitations of traditional design methods and the advantages of resilience based seismic design methods. And it also introduces the framework system (Resilience based Earthquake Design Initiative for the Next Generation of Building, abbreviated as REDi^{TM}) developed by O'Connor, et al. [17], which is beneficial for further research and promotion of resilience based seismic design methods. A case study was conducted on the Fremont Building 181 in San Francisco, USA. Yu, et al. [18] evaluated the recovery time of a hospital in a certain city based on the REDI repair strategy, reflecting the resilience of the structure. The research institutions and evaluation methods are listed in Table 1.

Table 1. Research institutions and evaluation methods

Research institutions	evaluation methods	Indicators and grades of seismic resilience
Federal Emergency Management Agency, FEMA P-58	Seismic performance assessment of buildings	Indicators of inter story displacement angle and floor acceleration of the structure; The three performance levels of repair cost, repair time, and personnel injury are intact, minor damage, and moderate damage

Aoyana Engineering Consulting Compa-ny	Resilience-based earthquake de-sign(REDi^{TM}) rating system	Organizational resilience, building resilience, environmental resili-ence, and loss assessment, with four evaluation dimensions; 65 indicators, including platinum, gold, and silver, with 3 levels
US Resilience Council (USRC)	USRC evaluation sys-tem	The three dimensions of safety, damage, and recovery are plati-num, gold, silver, copper, and member levels, with five levels
Ministry of housing and urban rural development of the people's republic of China	Evaluation Standards for Seismic Resilience of Buildings (GB/T 38591-2020)	Building repair costs; Construc-tion repair time; Personnel casu-alties are classified into three levels, from low to high: one star, two stars, and three stars

4 Conclusion

Due to the significant loss of life and property caused by earthquake disasters, it is necessary to improve the seismic resilience of the structure and re-duce its damage. New and existing buildings require resilience evaluation, and different structures adopt different seismic resilience evaluation methods, providing new ideas for seeking structural seismic resilience goals. The proposal of China's "Evaluation Standards for Seismic Resilience of Buildings" (GB/T 38591-2020) emphasizes the impact of structural and non-structural component damage on the seismic resilience of buildings, filling the gaps of other toughness evaluation methods. Quantifying the damage indicators of structures, such as damage recovery indicators and recovery curve integration indicators, is crucial in the study of seismic resilience. Constructing a comprehensive method for evaluating structural seismic resilience and evaluating structural performance has positive significance.

The building structure considers the seismic resilience throughout the entire process of earthquake disasters, that is, before, during, and after the disaster, selecting appropriate locations for the building structure before the disaster, and adopting new technologies such as shock absorption and isolation for the structure; Control during disasters, allowing shock absorption devices and isolation bearings to function effectively; After the disaster, conduct research and structural safety assessment, summarize and learn from experience, and feedback the problems discovered after the disaster to the pre disaster design, forming a virtuous cycle. A comprehensive resilience index for post disaster structures is formed by combining repair costs, repair time, and personnel casualties, aiming to construct a full life resilience assessment model.

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