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Seismic retrofitting strategies for historic buildings

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Abstract

As the frequency and intensity of earthquakes increase, the issue of seismic retrofitting of historical buildings has garnered increasing attention. Historical buildings are not only an important component of cultural heritage but also a testament to urban development. However, due to the limitations of their structural design and construction techniques, historical buildings often exhibit high vulnerability when faced with earthquakes. This paper reviews seismic retrofitting strategies for historical buildings and explores methods to enhance their seismic resistance while preserving cultural heritage. By analyzing typical cases both domestically and internationally, the paper proposes retrofitting measures suitable for different types of historical buildings and summarizes the advantages, disadvantages, and future development directions of current retrofitting technologies.

Keywords

Historic buildings, seismic retrofitting, cultural heritage, earthquakes, structural restoration.

1. Introduction

China's modern and contemporary historical buildings embody the historical and cultural heritage and unique urban characteristics of various regions, reflecting a city's distinct cultural heritage and character. These buildings constitute an irreplaceable treasure of architectural culture in China, and enhancing the protection of outstanding modern and contemporary buildings has become a key priority for governments at all levels. Historical buildings are important carriers of human civilization, and their unique artistic and cultural value makes them irreplaceable heritage. However, these buildings often face significant challenges due to their age, material deterioration, and outdated design methods, particularly when it comes to withstanding natural disasters such as earthquakes. Therefore, how to enhance their seismic resistance while preserving their cultural and historical value has become a key focus of current research.

2. Characteristics and Vulnerability Analysis of Historic Buildings and Principles of Reinforcement

Historical buildings typically exhibit the following characteristics: First, material degradation: The materials used in historical buildings are primarily brick, stone, and wood, which have undergone significant deterioration due to long-term exposure to the elements and prolonged use, resulting in a substantial decline in material performance. Second, complex structural systems: Historical buildings often employ complex structural systems, such as beam-column frameworks and cantilevered elements, whose mechanical behavior under seismic loads is difficult to predict. Third, lack of modern design concepts: Most historical buildings were designed and constructed without considering seismic design, making them highly vulnerable during earthquakes.

When conducting seismic retrofitting of historical buildings, the following principles must be followed: After on-site surveying and research, based on the historical and cultural value of the building, its current state of preservation, etc., and in accordance with the historical building protection policy of “effective protection, reasonable utilization, and utilization subordinate to protection,” the following protection principles should be established to achieve the effect of “restoring the old to its original state”: (1) Principle of preserving historical authenticity: This building has distinct characteristics of its era. The building's planning layout, floor plan, facade form, beam-and-column structure, and architectural decorations are all material reflections of the economic, political, and cultural conditions of the time. To protect and preserve this historical information, comprehensive protection must be implemented. (2) Principle of maintaining the integrity of the building's appearance: Retain the original facade style of the building and protect historical and cultural decorations indoors and outdoors to the greatest extent possible, ensuring the building retains its original appearance. (3) Principle of reasonable utilization: While adhering to the first two principles, adjust and enhance the building's functional use to promote mutual benefits between preservation and utilization. (4) Principle of identifiability and reversibility: For repaired or replaced components, strive for overall stylistic unity while ensuring ease of identification in detail, achieving unity in facade and visual effects, and minimizing damage to the original building structure.

3. Methods for seismic reinforcement of historic buildings

There are numerous methods for reinforcing historical concrete structures, primarily categorized into two types: structural system reinforcement and structural component reinforcement. Among these, structural system reinforcement primarily involves techniques such as adding steel supports, damping supports, damping walls, node reinforcement, or enhanced connection measures. Component reinforcement methods also vary widely, with common techniques including steel plate bonding reinforcement, carbon fiber reinforcement, section enlargement reinforcement, steel wrapping reinforcement, steel mesh-polymer mortar overlay reinforcement, and high-performance composite mortar reinforced mesh reinforcement, among others[1].

3.1. External reinforcement method

External reinforcement refers to the addition of support structures to the exterior of a building to enhance its seismic resistance. This method is suitable for historical buildings constructed with masonry or timber structures. Steel frame reinforcement: Adding steel frame structures to the exterior of the building, which are connected to the original structure to enhance overall stiffness and stability. Concrete wrapping: Enveloping the exterior of the building with a layer of concrete to enhance the structural seismic performance. Xu Jidong[2] et al. controlled the structural performance indicators under small and large earthquakes by installing buckling-restrained energy-dissipating supports. The analysis showed that after installing buckling-restrained energy-dissipating supports, the overall performance indicators of the structure could meet the seismic design objectives of “no damage under small earthquakes, repairable under medium earthquakes, and no collapse under large earthquakes.” The amount of reinforcement required for major components was significantly reduced, and the damage and impact on the original structure were minimized. For masonry brick wall structures, Zheng Qizhen[3] et al. conducted quasi-static tests to study the effects of single-sided reinforcement using reinforced mesh polymer mortar and UHPC materials on the failure mode, load-bearing capacity, ductility, stiffness, and energy dissipation capacity of low-strength brick walls. The results indicate that reinforcing low-strength historical brick walls with reinforced polymer mortar and UHPC materials can significantly increase the cracking load of the walls, with improvements of approximately 50% and 100%, respectively. The ultimate load is increased to more than twice the original value, and the energy dissipation capacity is improved by more than twofold. The reinforcement effects are superior to those of ideal specimens in terms of load-bearing capacity, stiffness, ductility, and energy dissipation capacity.

3.2. Internal reinforcement method

Internal reinforcement refers to the process of reinforcing a building from the inside, primarily involving the addition of support structures and the strengthening of joint connections. Adding shear walls: Installing shear walls within the building to enhance its lateral load-bearing capacity. Joint reinforcement: Reinforcing beam-column joints, arch joints, etc., to increase joint connection strength and stability. Existing wooden components should be retained whenever possible. In cases where it does not affect the historical appearance of the building's interior, concrete or reinforced steel structural components may be considered as replacements[4].

3.3. Foundation reinforcement method

Foundation reinforcement methods involve reinforcing or replacing building foundations to improve their overall seismic resistance. Grouting reinforcement: Pouring cement grout or other reinforcement materials around the foundation to enhance its load-bearing capacity. Foundation replacement: Replacing or reinforcing the original foundation without damaging the upper structure of the building.

3.4. Material Repair and Replacement

During the reinforcement process, it is also necessary to repair or replace aged and damaged materials to enhance the overall durability of the structure. Material repair: Modern techniques are employed to repair aged materials, such as brick and stone repair and wood preservation. Material Replacement: When necessary, new materials are used to replace severely damaged sections, such as replacing severely weathered old bricks with new bricks. Yu Hong[5] et al. found that historical buildings with masonry load-bearing wall structures have poor overall wall integrity, low horizontal shear resistance, and weak seismic resistance. Using a reinforced mesh cement mortar surface layer method to reinforce the walls can effectively improve the overall seismic performance of the structure; Reinforcing concrete floor slabs using the steel bonding method can effectively increase the stiffness and load-bearing capacity of the slabs without significantly increasing the structural self-weight. This method has minimal environmental impact at the construction site, and the thickness of the slabs remains largely unchanged after reinforcement; The method of reinforcing wooden purlins using ring-shaped wire wraps combined with tensioned steel rods can effectively suppress the development of cracks in wooden structures, enhance the bending load-bearing capacity and stiffness of the purlins, and is particularly suitable for the reinforcement of wooden bending members.

4. Analysis of typical cases at home and abroad

By analyzing typical cases both domestically and internationally, we can better understand the seismic reinforcement strategies for different types of historical buildings. The ancient city of Pompeii in Italy is a famous historical site, and its brick-and-stone structures exhibited high vulnerability during earthquakes. By combining external and internal reinforcement methods, such as adding steel frames and shear walls, the seismic resistance of Pompeii was significantly enhanced. The Great Wall of China is a UNESCO World Heritage Site, and its brick-and-stone and rammed-earth structures are prone to collapse during earthquakes. Through foundation reinforcement and material restoration methods, such as grouting reinforcement and brick-and-stone repair, the seismic resistance of the Great Wall has been significantly enhanced. Himeji Castle in Japan is a wooden structure with poor seismic resistance. Through node reinforcement and material replacement, such as enhancing the connection strength of beam-column joints and replacing decayed wood, Himeji Castle has maintained good stability during earthquakes.

5. Development trends in seismic reinforcement technology for historic buildings

As China's economic development and social civilization continue to advance, the historical value and cultural significance of historical buildings are increasingly recognized. However, the seismic safety of historical buildings remains a critical concern. While significant progress has been made in seismic retrofitting technology and there is a wealth of engineering experience, further development is needed in terms of materials, methods, and techniques to address these challenges[6]. Currently, seismic retrofitting technology for historical buildings is evolving, and future development trends primarily encompass the following areas: Application of modern technology: By utilizing modern technologies such as 3D scanning and modeling, finite element analysis, etc., it is possible to more accurately assess the structural condition and seismic performance of historical buildings, providing a scientific basis for reinforcement design. Development of new materials: Research and development of high-performance new materials, such as high-strength fiber-reinforced composites and smart materials, can enhance the seismic resistance of buildings without compromising their original appearance. Optimization of reinforcement methods: By optimizing reinforcement methods, such as adopting combined reinforcement techniques that integrate multiple reinforcement measures, the seismic performance of historical buildings can be more effectively enhanced. Establishment of standards and regulations: Developing unified standards and regulations for the seismic reinforcement of historical buildings can guide reinforcement work in actual engineering projects, thereby improving reinforcement effectiveness and engineering quality.

6. Conclusion

Seismic retrofitting of historic buildings is a complex and important task that requires balancing the preservation of their cultural and historical value with enhancing their seismic resistance. By employing appropriate retrofitting methods, such as external reinforcement, internal reinforcement, foundation reinforcement, and material restoration, the seismic performance of historic buildings can be effectively improved. In the future, with the advancement of modern technology and new materials, seismic retrofitting techniques for historic buildings will continue to evolve, providing a robust foundation for the protection and preservation of humanity's cultural heritage.

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