Seismic Material Selection and Optimization of Prefabricated Concrete Structures in 8th Seismic Intensity Zone Based on Energy Dissipation Mechanism

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Abstract: This paper explores the selection and optimization of seismic-resistant materials for prefabricated concrete structures in Seismic Zone 8, focusing on energy dissipation mechanisms. Based on an analysis of the fundamental characteristics of prefabricated structures, the study discusses the impact of seismic requirements and energy dissipation mechanisms on the seismic performance of structures. The paper emphasizes the performance of commonly used seismic-resistant materials and their influence on energy dissipation capacity, proposing strategies for optimization. The research indicates that appropriate selection of seismic-resistant materials and the optimization of energy dissipation designs can significantly enhance the seismic performance of prefabricated concrete structures subjected to high-intensity seismic forces.
Keywords: prefabricated concrete structures; energy dissipation mechanisms; seismic-resistant materials; Seismic Zone 8

1. Introduction

Seismic Zone 8 is a region in China characterized by intense seismic activity, placing heightened demands on the seismic design of prefabricated concrete structures. Traditional seismic design approaches have typically emphasized increasing the rigidity and strength of structures; however, under seismic loading, the ability of a structure to dissipate energy is equally critical. The energy dissipation mechanism, by absorbing seismic energy, reduces vibrational responses and mitigates the risk of structural damage. This paper integrates energy dissipation mechanisms to examine the selection and optimization methods for seismic-resistant materials suitable for prefabricated concrete structures, aiming to provide effective seismic solutions for buildings in Seismic Zone 8.

2. Seismic Performance Analysis of Prefabricated Concrete Structures

2.1 Basic Characteristics of Prefabricated Concrete Structures

Prefabricated concrete structures, through the integration of modular pre-fabrication and rapid on-site assembly, substantially enhance both construction efficiency and precision. The seismic performance advantages of these systems are primarily attributed to the optimized design of their connecting joints, where high-strength reinforcement or prestressed techniques are employed to augment both rigidity and strength. Nevertheless, these connection points can potentially emerge as weak links, serving as conduits for seismic waves. Therefore, it becomes imperative to refine their design to bolster the overall seismic resilience of the structure.

2.2 Seismic Requirements and Design Standards for Seismic Zone 8

In Seismic Zone 8, the seismic design requirements stipulate that buildings must exhibit superior seismic performance[1]. According to the "Code for Seismic Design of Buildings, " the seismic intensity level for any structure should not fall below a level 8 designation. In the design process, particular emphasis must be placed on the structural parameters of seismic strength, rigidity, and ductility. The selection of appropriate materials and components is vital to ensure that prefabricated concrete structures can effectively absorb seismic energy and maintain stability under the duress of strong seismic events.

2.3 The Impact of Energy Dissipation Mechanisms on Seismic Performance

The role of energy dissipation mechanisms in seismic design cannot be overstated. The incorporation of energy-dissipating materials, such as viscoelastic dampers, significantly enhances the ductility of the structure and mitigates post-seismic damage. By optimizing the energy dissipation pathways, seismic energy is transformed into heat, reducing vibration transmission, which, in turn, strengthens the structure's self-healing capability. This strategic energy dissipation not only fortifies the seismic performance of the building but also contributes to its overall safety.

3. Selection and Optimization of Seismic-Resistant Materials

3.1 Comparative Analysis of Common Seismic-Resistant Materials

In seismic design, the choice of materials is of paramount importance for determining the performance of a structure. Common seismic-resistant materials include high-strength concrete, reinforcing steel, prestressed reinforcement, and viscoelastic materials. High-strength concrete, while ensuring structural strength, significantly enhances the seismic performance of a structure; however, it is prone to cracking and is vulnerable to repeated seismic loading. Reinforcing steel and prestressed reinforcement, with their superior ductility and toughness, contribute to the overall stiffness and seismic resilience of the structure, providing robust tensile resistance under seismic forces. Nonetheless, the corrosion resistance of steel is limited, and its service life is finite. On the other hand, viscoelastic materials primarily function as energy-dissipating elements, absorbing seismic energy through internal friction and deformation, thereby markedly reducing post-earthquake damage.

3.2 Application of Energy-Dissipating Materials in Prefabricated Concrete Structures

In prefabricated concrete structures, the role of energy-dissipating materials is paramount, particularly in enhancing seismic resilience and delaying catastrophic failure. Rubber dampers, which absorb seismic energy through plastic deformation, are frequently employed at connection nodes and supporting systems, effectively reducing vibration responses. Viscoelastic materials are strategically placed at the junctions of walls or beam-column connections, where they mitigate seismic wave effects through friction and shear deformation. This approach proves especially effective under high-intensity seismic events. In high-rise prefabricated buildings, the integration of viscoelastic isolation layers, along with rubber bearings, provides a robust system that isolates seismic waves, thus reducing horizontal displacement and structural damage[2].

3.3 Research and Implementation of Material Optimization Schemes

The optimization of seismic performance in prefabricated concrete structures is intricately linked to the careful selection and pairing of materials. By adjusting the ratio of high-strength concrete to prestressed steel reinforcement, structural stiffness and strength can be significantly improved. The incorporation of energy-dissipating elements, such as viscoelastic dampers or rubber bearings, must be judiciously executed to ensure optimal energy absorption, thereby reducing vibration responses. To enhance the long-term stability of the structure, it is critical to select corrosion-resistant steels or surface-treated concrete materials, which mitigate the risk of fatigue-induced failure. Through computer-aided design and simulation, tailored optimization schemes can be developed based on seismic intensity, ensuring the structural safety and reparability under extreme vibrational conditions.

4. Seismic Optimization Design Based on Energy Dissipation Mechanisms

4.1 Theoretical Foundation of Energy Dissipation Mechanisms

The energy dissipation mechanism refers to the process by which a structure, through energy-dissipating components, converts seismic energy into heat, thereby mitigating the effects of vibrations. Common energy-dissipating elements include viscous dampers, rubber bearings, and plastic hinges. In the design process, careful consideration must be given to the material's energy dissipation capacity, deformation ability, and durability. This ensures that the structure is capable of effectively absorbing and dispersing energy across various seismic intensities, thus preventing localized damage that might compromise its overall stability.

4.2 Impact of Seismic Material Selection on Structural Energy Dissipation Capacity

The selection of seismic materials plays a pivotal role in determining a structure's energy dissipation capacity[3]. For instance, rubber dampers absorb seismic energy through elastic deformation and friction, while viscoelastic materials combine elastic and viscous properties to continuously absorb energy. Moreover, the combination of prestressed concrete with high-strength steel reinforcement enhances both the stiffness and energy-dissipating capacity of the structure, ultimately improving its overall seismic performance. This integration of materials ensures the structural resilience under varying seismic conditions.

4.3 Optimization Design Strategies and Development of Computational Models

Seismic optimization design is realized through the use of refined computational models. Material selection must be strategically aligned with high-strength concrete, viscoelastic materials, and other energy-dissipating elements. Finite element analysis (FEA) is employed to evaluate seismic behavior, enabling reverse design to optimize the energy dissipation paths. Additionally, the design process should emphasize the durability of materials and incorporate nonlinear dynamic analysis to guarantee the structure's long-term performance during seismic events. This approach ensures not only immediate resilience but also sustainable functionality in the face of future seismic threats.

5. Conclusions

This paper analyzes the seismic performance and material optimization of prefabricated concrete structures, emphasizing how energy dissipation mechanisms enhance seismic resilience. Integrating high-strength concrete, prestressed steel, and viscoelastic materials significantly improves structural seismic capacity. In Seismic Zone 8, such optimization notably boosts seismic resistance and safety, offering valuable insights for future architectural design.

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