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Research status of steel tubular rubber concrete column

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Abstract: Rubber itself has excellent wear resistance and high elasticity, which can be utilized to replace aggregates in concrete. The purpose of this paper is to provide a comprehensive review of the current research status on steel tube rubber concrete columns, including their axial compression and seismic resistance, based on the studies conducted by domestic and international researchers. Valuable suggestions are proposed for the future application of steel tube rubber concrete columns in practical engineering. Furthermore, potential research directions are highlighted.

1. Introduction

Currently, steel tube concrete has been widely used in high-rise buildings[1]. This is because the steel tube concrete structure can fully utilize the advantages of both steel and concrete materials. However, ordinary steel tube concrete is no longer sufficient to meet the requirements of high-rise building development. To adapt concrete to higher construction standards, it is necessary to alter the dynamic characteristics of concrete and optimize the concrete material. Therefore, it is essential to develop high-performance steel tube concrete structures that can be applied in real-life scenarios.

For high-rise buildings, special considerations need to be made in terms of seismic design. These considerations include foundation selection, reducing seismic energy input, and mitigating seismic response. However, the first two methods have certain limitations in their application. Therefore, altering the dynamic characteristics of materials and employing rubber isolation and energy dissipation supports are regarded as promising measures to mitigate structural seismic response. By incorporating rubber and other admixtures into concrete, the damping capacity of the building structure can be effectively enhanced, achieving comparable vibration reduction effects as traditional damping devices without their usage. Rubberized concrete exhibits excellent resistance to impact and fracture, thereby alleviating the effects of seismic forces and reducing seismic shear in high-rise buildings.

Steel-reinforced concrete refers to structural components formed by filling concrete into steel pipes, which can collectively withstand external loads. Depending on the cross-sectional shape, steel-reinforced concrete can be classified into circular, square, rectangular, and polygonal forms. Steel-reinforced concrete has evolved and developed based on the combination of reinforced concrete, spiral reinforcement concrete, and steel pipe structures. It utilizes the interaction between steel pipes and concrete during the load-bearing process. The confinement effect of steel pipes on concrete subjects the concrete to complex stress states, thereby enhancing its strength and greatly improving its plasticity and toughness. At the same time, the presence of concrete can prevent or delay local buckling of steel pipes, ensuring the full utilization of their material properties. The advantages of steel-reinforced concrete composite structures are mainly manifested in their high load-bearing capacity, good plasticity and toughness, favorable cost-effectiveness, convenient construction, and good fire resistance.

2. Research and development status at home and abroad

2.1. Research status of axial compression of steel tube rubber concrete column at home and abroad

Hu Peng and his team[2] have explored the application of rubberized concrete in high-rise building seismic design. They partially replaced cement and sand in steel tube concrete with lithium slag and waste rubber. Eight circular steel tube concrete columns were prepared and subjected to axial compression tests to study their failure modes and basic mechanical properties. The research findings show that although the addition of rubber reduces the strength of the specimens, it simultaneously enhances their energy dissipation capacity and ductility. Furthermore, the addition of lithium slag improves the strength of the specimens. Within the specified replacement rate range, the highest compressive strength of the steel tube concrete columns is achieved at a replacement rate of 20%.

Ahmad et al[3]. conducted a study on the influence of rubber replacement for cement on the axial compressive performance of steel-reinforced concrete columns. They prepared concrete mixtures with replacement rates of 0%, 15%, 25%, and 35%, and fabricated 16 circular steel-reinforced concrete columns. The experimental results demonstrated that increasing the rubber replacement for cement reduced the compressive strength and density of the concrete. The axial compressive load-bearing capacity of the steel-reinforced concrete columns also decreased with the increasing amount of rubber content in the concrete.

Xu Peizhen et al[4]. conducted axial compression tests on 12 circular steel tube rubber concrete (RCFT) short columns to investigate the influence of rubber content on the mechanical properties of circular steel tube concrete columns. The results indicate that the failure mode of circular steel tube rubber concrete short columns is characterized by local buckling or folding of the steel tube at one or multiple locations. During the loading process, the circular steel tube rubber concrete short columns exhibit good deformation capacity and sustained load-carrying capacity. Moreover, the axial compressive load-carrying capacity of circular steel tube rubber concrete short columns decreases with an increase in rubber content.

Gu Liansheng et al[5]. designed ten rectangular cross-section steel tube rubber concrete specimens to investigate the application of rubber concrete in seismic design of high-rise buildings. The study examined three factors: rubber replacement ratio, temperature, and time. The entire process of axial compression tests was observed, and the failure mode was analyzed to obtain the load-displacement curve. The experimental results showed that the rectangular steel tube rubber concrete columns experienced elastic, plastic, and failure stages during the loading process after exposure to high temperatures. The failure mode of the specimens was characterized by non-parallel oblique circular shear failure. With an increase in the rubber replacement ratio, the ultimate bearing capacity of the specimens gradually decreased. As the temperature increased, the ultimate bearing capacity initially decreased slightly, then increased, and finally decreased gradually. The overall trend of the curve was a decrease.

2.2. Research status of seismic performance of rubber concrete column of steel pipe at home and abroad

Xing Huansen[6] conducted a study in which he designed and fabricated eight circular steel tube rubber concrete columns. Through low-cycle repeated tests, he investigated the influence of rubber content, axial load ratio, steel content, and slenderness ratio on the seismic performance of the specimens. The results of the study indicate that these specimens exhibit a higher energy dissipation capacity, and the degradation of their bearing capacity and stiffness shows a relatively stable process. With an increase in rubber content, the ultimate bearing capacity of the specimens decreases to some extent.

Duarte et al[7]. conducted an in-depth investigation on the hysteresis behavior of short steel tube rubber concrete under cyclic loading, considering parameters such as cross-sectional shape, steel tube type, rubber particle content, and axial plastic load. The study focused on cyclic strength, failure modes, hysteresis curves, skeleton curves, and ductility. The experimental results indicate that a rubber content of 5% leads to a 5% decrease in the column strength of the specimens, but it significantly increases the ductility by up to 52%. Such results are particularly suitable for application in earthquake-prone areas.

Zhang Na[8] designed and fabricated four steel tube rubber concrete columns with control parameters including rubber content and axial compression ratio. The rubber content ranged from 0% to 30% with intervals of 10%, while the axial compression ratio varied from 0 to 0.5 with intervals of 0.2. The time-domain waveforms of the steel tube rubber concrete columns were obtained through free vibration testing. Time-domain analysis was employed to analyze the frequency and damping ratio of the columns. The results indicated that the damping ratio increased at the highest rate when the rubber content reached 20%. Applying axial compression altered the cantilever state of the steel tube rubber concrete columns, which significantly affected the frequency and mode shapes of the structure. However, the damping ratio still exhibited an increasing trend with the increase of rubber content. SNAP software was used to perform elastic-plastic time-history analysis on a steel tube rubber concrete frame structure designed based on the hybrid yielding mechanism. The effects of different rubber content on interstory drift, damping energy dissipation, shear force, and deformation energy of the frame columns were studied. The results demonstrated that increasing the yield column's damping ratio had a significant effect on reducing interstory drift and increasing the damping energy dissipation of the frame structure, thus effectively enhancing the seismic safety of the structure.

3. Conclusions

According to numerous domestic and international studies, rubberized concrete has been widely applied in the seismic design of high-rise buildings. However, the hydrophobic nature of rubber results in its limited involvement in the hydration reaction when mixed with cement mortar, leading to a weaker bond interface between rubber powder and cement mortar. Consequently, the mechanical properties of concrete, including compressive strength, are significantly affected. However, the addition of an appropriate amount of polypropylene fibers can enhance the compressive strength and improve the ductility and crack resistance of rubberized concrete. Furthermore, the combination of polypropylene fibers and rubber with steel pipe concrete columns has been studied to investigate their seismic performance and compressive capacity, providing a new approach for the future application of steel pipe rubberized concrete columns in practical engineering.

As a professional in the field, I would like to discuss the future research directions for steel tube rubber concrete columns.

Steel tube rubber concrete columns are structural materials known for their high seismic performance and durability. However, there are still several areas of research that need further exploration and improvement.

Firstly, research can focus on optimizing the performance of concrete and rubber materials. Although some studies have investigated the influence of different proportions of concrete and rubber on column performance, further research is needed to determine the optimal concrete-rubber mix ratio. Additionally, the combination of different types of concrete and rubber materials can be studied to achieve higher compressive strength, ductility, and durability.

Secondly, research can delve into the role of steel tubes in the columns. Steel tubes enhance the strength and stiffness of steel tube rubber concrete columns. Therefore, the influence of different diameters and wall thicknesses of steel tubes on column performance can be investigated to determine the optimal steel tube parameters. Moreover, the bond behavior between steel tubes and concrete can be studied to enhance the overall performance of the columns.

Furthermore, the performance of steel tube rubber concrete columns under different loads and environmental conditions can be examined. For instance, studying the seismic performance of columns under fire, high temperature, and moisture conditions can provide valuable insights for a wider range of applications and design guidelines.

In conclusion, steel tube rubber concrete columns are promising structural materials. Future research can concentrate on optimizing the performance of concrete and rubber materials, understanding the role of steel tubes, improving connection methods and node design, and investigating the performance of columns under various load and environmental conditions. These efforts will further enhance the seismic performance and durability of steel tube rubber concrete columns.

In addition, there has been an increasing emphasis on the research of new materials combined with steel tube concrete structures. Since the founding of the country more than 70 years ago, significant progress has been made in the production and configuration of concrete in China, and the strength has also improved significantly compared to the past. However, overall, these improvements have had minimal impact on the overall performance of buildings. In order to promote the sustainable development of China's housing construction industry and highlight the important role of the construction industry in the national economy and people's lives, we should adhere to the scientific development concept and advocate for scientific green and sustainable development. Therefore, we should consider reducing the cement consumption in concrete and explore the rational use of industrial waste and household garbage. In addition to improving the basic performance of building structures, we should also follow the principles of green development and promote the development of building structures based on the conservation of natural resources.

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