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Research Prospect on Damage-Controlled Design for Resilient Prefabricated Thermal Insulated Shear Walls

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ABSTRACT: Prefabricated thermal insulated integrated shear walls represent a key technological approach for promoting the green transformation and upgrading of the construction industry. However, the structural integrity of current sandwich-insulated composite shear walls is weakened by the presence of the insulation layer. As a result, these shear walls are predominantly applicable to low- to mid-rise buildings situated in regions with low seismic intensity. Furthermore, seismic damage tends to concentrate at the wall foot, making post - earthquake repair difficult. Shale ceramsite concrete, combining lightweight, high strength and good thermal insulation performance, is an ideal material for achieving insulation - structure integration without a sandwich layer. This paper systematically reviews research findings on the seismic performance of prefabricated shear walls as well as the mechanical and thermal properties of shale ceramsite concrete. By integrating the damage - controllable design concept of shear walls with replaceable foot components, this paper proposes a concept of resilient prefabricated thermal - insulation integrated shear walls based on the synergy of materials and structural details. The findings can provide a theoretical basis and technical direction for the application of prefabricated shear walls in high - intensity seismic zones.

KEYWORDS: Prefabricated shear wall; Shale ceramsite concrete; Insulation - structure integration; Damage - control; Replaceable foot component

I. INTRODUCTION

The research and application of prefabricated thermal-insulation-integrated shear walls represent a crucial implementation path for promoting the green transformation and upgrading of the construction industry. Due to the poor thermal insulation performance of ordinary concrete, the current technology commonly enhances thermal insulation by adding thermal insulation materials to the sandwich layer of composite shear walls. However, the presence of this sandwich layer reduces the structural integrity, restricting its application primarily to low- and medium-rise buildings in low-seismicity regions, while also adversely affecting their seismic performance [1 - 3]. Although appropriately designed prefabricated shear walls can generally achieve the goal of "equivalent to cast-in-place", with failure modes similar to those of cast-in-place concrete shear walls [1, 4], their typical failure manifest as compression buckling of reinforcement and crushing of concrete at the wall foot (as shown in Fig. 1). Nevertheless, post-earthquake damage investigations [5, 6] have shown that such damage is difficult to repair, often requiring complete demolition and reconstruction, which results in substantial economic losses and severe social impacts.

Paper is organized as follows. Section II presents the study on material and component performance of shale ceramsite concrete shear walls. Section III introduces the concept of damage-controllable design based on replaceable base components, Section V presents conclusion.

II. MATERIAL AND COMPONENT PERFORMANCE OF SHALE CERAMSITE CONCRETE SHEAR WALLS

To simultaneously meet thermal insulation requirements and preserve structural integrity, utilizing shale ceramsite concrete for wall construction has proven to be an exceptionally effective approach. Shale ceramsite concrete is characterized by a dry density spanning from 1150 to 1850 kg/m³. This material seamlessly integrates lightweight

properties with high strength [7] and outstanding thermal insulation performance [8], thereby satisfying both load-bearing and energy-saving demands. Seismic performance tests on shale ceramsite concrete shear walls, conducted by Yang et al. [9], demonstrated that this type of shear wall exhibits commendable seismic behavior, with failure modes similar to those observed in ordinary concrete shear walls. Liu et al. [10] constructed prefabricated external walls using ceramsite concrete and performed quasi-static tests on five shear walls with varying window-to-wall ratios. Their findings revealed that the window-to-wall ratio significantly impacts the initial cracking load, initial cracking displacement, and failure mode. Ye et al. [11] carried out axial compression tests and finite element simulations on four lightweight steel-desert sand ceramsite concrete shear walls, analyzing their axial compression performance. Due to the lightweight and high-strength characteristics of ceramsite concrete, its application in prefabricated components can substantially reduce the demands on transportation and lifting equipment in prefabricated construction, making it particularly well-suited for prefabricated structures. Yang et al. [12] conducted shaking table tests to investigate the seismic performance of fully lightweight shale ceramsite concrete prefabricated pipe galleries. They also compared these galleries with those made of ordinary concrete. The results showed that fully lightweight shale ceramsite concrete pipe galleries exhibit excellent deformability and seismic performance.

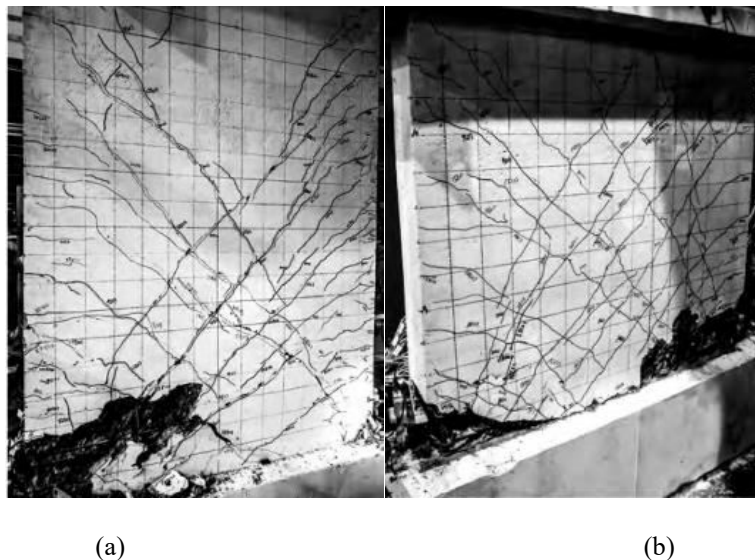


Fig.1. Failure modes of shear walls (a) Cast-in-place concrete shear wall (b) insulated composite shear wall

III. DAMAGE-CONTROLLABLE DESIGN BASED ON REPLACEABLE BASE COMPONENTS

Traditional reinforced concrete shear walls integrate the seismic force-resisting system and functional components into a single entity. These walls rely on self-induced damage to dissipate seismic energy and prevent collapse. However, post-earthquake damage tends to concentrate at the wall foot, making post-earthquake repair difficult. Shear walls with replaceable foot components address this issue by designing the vulnerable foot components as easily detachable and replaceable energy-dissipating elements. This configuration directs seismic energy into this zone, thereby reducing energy dissipation and damage in non-replaceable regions. After earthquake, structural functionality can be rapidly restored by replacing the damaged components [13]. This design concept integrates strategies such as concentrated energy dissipation, vibration reduction, reparability, and replaceability to achieve controllable structural damage. To ensure that seismic energy is primarily concentrated in the replaceable foot components, the load-bearing capacity and stiffness of this region are often reduced. This creates a stiffness contrast with the upper concrete structure, promoting yielding and energy dissipation in the replaceable components first [14]. Shale ceramsite concrete offers a distinct advantage for composite shear walls in prefabricated construction. It integrates thermal insulation and structural functions without requiring a separate insulation layer, thereby preserving structural integrity. The challenge of post-earthquake repair can be addressed by incorporating replaceable energy-dissipating components (dampers) at the wall foot. Accordingly, this paper proposes the steel-ceramsite concrete

composite shear wall with replaceable foot components(as shown in Fig. 2). The design aims to meet multiple objectives, including superior thermal insulation, broad applicability, and ease of post-earthquake repair.

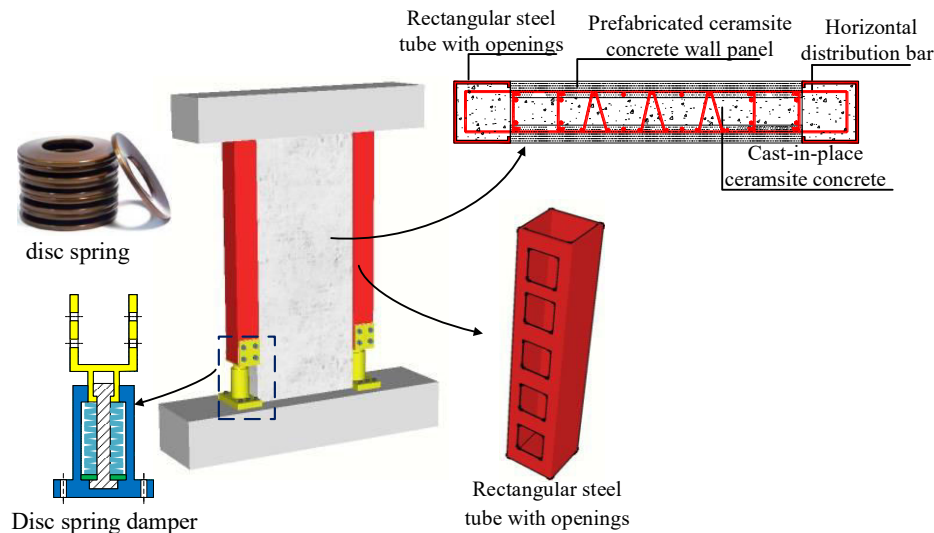


Fig.2. The steel - ceramsite concrete composite shear wall with replaceable foot components

IV. CONCLUSION

(1) Traditional sandwich-insulated composite shear walls have reduced structural integrity due to the presence of the insulation layer, making them primarily suitable for low- to mid-rise buildings in low-intensity seismic zones. Moreover, seismic damage tends to concentrate at the wall foot, and post-earthquake repair is difficult, which limits their application and promotion in high-intensity seismic zones.

(2) Shale ceramsite concrete has a dry density ranging from 1150 to 1850 kg/m³, can achieve a strength grade of LC50, and has a thermal conductivity of 0.16–0.28 W/(m·K), combining lightweight high strength with excellent thermal insulation performance. Using shale ceramsite concrete to fabricate prefabricated shear walls enables the integration of thermal insulation and structural functions without the need for a sandwich insulation layer, thereby preserving structural integrity.

(3) Fabricating composite shear walls using shale ceramsite concrete integrates prefabricated thermal insulation and structural functions without requiring a separate insulation layer, thereby preserving structural integrity. In addition, installing replaceable dampers at the wall base addresses the challenge of post-earthquake repair. The proposed steel-ceramsite concrete composite shear wall with replaceable base components is designed to meet multiple objectives: excellent thermal insulation performance, broad applicability, and ease of post-earthquake repair.

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