Theory and Practice of Science and Technology
2025, VOL. 6, NO. 8, 262-267
DOI: 10.47297/taposatWSP2633-456950.20250608

A Review on the Seismic Performance of Single-Sided Composite Shear Walls

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ABSTRACT

With the rapid development of construction industrialization, prefabricated buildings have attracted widespread attention due to their characteristics of high efficiency and environmental protection. However, traditional fully precast concrete shear walls have problems such as heavy self-weight and complex on-site construction procedures. After China introduced the double-sided composite shear wall structure, with the development of China's integrated technology of external walls, thermal insulation and decoration, researchers proposed a new type of single-sided composite shear wall structure. The single-sided composite shear wall not only simplifies the construction process and improves construction efficiency, but also performs excellently in terms of seismic performance, achieving the effect of "equivalent to cast-in-place". This paper lists the basic characteristics of single-sided composite shear walls, studies the influencing factors of seismic performance based on the theoretical basis of seismic performance, then analyzes the cases of engineering practice, and compares the research progress at home and abroad. Finally, it puts forward the existing problems and future prospects, aiming to promote the research and development of single-sided composite shear walls and provide reference for engineering applications.

KEYWORDS

Single-sided composite shear wall; Seismic performance; Prefabricated structure; Mechanical mechanism

1 Introduction

The precast concrete double - sided composite shear wall (also known as the composite shear wall, Figure 1b) is a semi - assembled composite force - bearing member. It uses two precast concrete wall panels manufactured in the factory as the inner and outer wall panels, connected by steel trusses or other reliable connection methods, installed at the construction site, and concrete is poured in the middle layer [1]. After the double - sided composite shear wall was introduced into China, to meet the application in multi - storey and high - rise buildings in earthquake - resistant fortified areas in China, many domestic universities, scientific research institutions and enterprises have carried out a series of studies on its seismic and mechanical properties.

With the development of China's integrated technology for external walls, thermal insulation, and decoration, the precast concrete outer leaf panel no longer participates in structural force-bearing. It only functions as formwork and an external protective panel for the thermal insulation layer. The load-bearing part of the shear wall is composed of the precast concrete inner leaf panel and the post-cast concrete in the cavity, with only one composite interface. Hence, it is called a single-sided composite shear wall (also referred to as a non-composite shear wall, Figure 1a), serving as a new type of lateral force-resisting component in prefabricated buildings. The precast concrete layer of the single-sided composite shear wall acts as formwork during the construction stage. In the service stage, the outer leaf panel does not participate in structural force calculation, while the inner leaf panel of the wall and the cast-in-place layer participate in structural force calculation as an integrated whole [2].

With the rapid development of construction industrialization, prefabricated buildings have received extensive

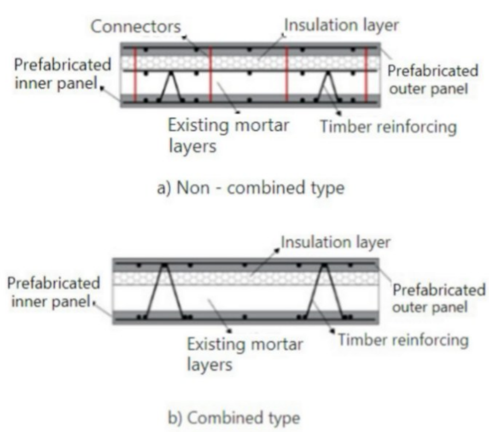

Figure 1 New type of insulation composite shear wall form

attention due to their characteristics of high efficiency and environmental protection. However, traditional fully precast concrete shear walls have problems such as large self-weight and complex on-site construction procedures, while double-sided composite shear walls are difficult to be widely applied due to cumbersome prefabrication and low efficiency. To solve these problems, researchers have proposed a new type of single-sided composite prefabricated shear wall structure. This structure not only simplifies the construction process and improves construction efficiency, but also performs excellently in terms of seismic performance, achieving the effect of "equivalent to cast-in-place". However, current research on composite shear wall structures mainly focuses on the seismic performance of double-sided composite shear walls, and there is relatively little research on the seismic performance of single-sided composite shear walls. This paper lists the basic characteristics of single-sided composite shear walls, studies the influencing factors of seismic performance based on the theoretical basis of seismic performance, then analyzes cases of engineering practice, and compares the research progress at home and abroad. Finally, it puts forward the existing problems and future prospects.

2 Study on influencing factors of seismic performance

2.1 Influence of structural parameters on seismic performance

The core feature that distinguishes this structural system from traditional shear walls lies in its "single-sided prefabrication + cast-in-place" configuration. The thickness of the prefabricated layer is usually controlled within the range of 50-75mm, while the thickness of the cast-in-place layer reaches 100-200mm according to the requirements of seismic grades [3]. The test data from Zhang Yumin's team (2024) shows that this structure reduces the self-weight by approximately 25% compared with fully cast-in-place walls, while maintaining an overall stiffness of more than 85%. From the perspective of mechanical transmission mechanism, the structure forms a triple force transmission system of "prefabricated layer - connector - cast-in-place layer", and it is precisely the structural parameters of the force transmission system that affect the energy dissipation capacity and damage evolution mode of the structure [4].

In terms of the prefabricated layer:

The prefabricated layer is usually provided with concave-convex grooves or shear keys. Xu Zhenhua et al. (2023) confirmed through pull-out tests that when the groove depth reaches 6mm, the interfacial shear strength can be increased by 32% [5]; The external thermal insulation integrated structure proposed by Zhou Linghai (2023) integrates a 50mm thick XPS insulation board on the outer side of the prefabricated layer, achieving a heat transfer coefficient of less than $0.45W/(m^2 \cdot K)$[6]. The axial compression test data from Mao Youtong (2023) indicates that this structure can still keep the insulation layer from falling off under 1.2 times the design load [7].

In terms of connectors:

The connectors adopt stainless steel ties or thermal insulation anchors. Li Jinghui's (2022) research on tie performance shows that stainless steel ties exhibit a typical bilinear constitutive relationship under cyclic loads, with the dispersion coefficient of their yield strength controlled within 8% [8]. Through shear tests on stainless steel ties, Zhang Yumin et al. (2024) found that when using 304 stainless steel ties with a diameter of 8mm, their ultimate shear-bearing capacity can reach 89.6kN, which is 23.5% higher than that of traditional steel bar connectors. Su Yu et al. (2024) revealed that thermal insulation anchors with a diameter of 8mm can reduce the thermal bridge effect by 40%; when the diameter of thermal insulation anchors increases from 6mm to 10mm, the out-of-plane bearing capacity of the wall increases by 19.4%, but the thermal conductivity increases by $0.28W/(m \cdot K)$ accordingly [9]. Comparative tests by Zhang Kai et al. (2025) showed that thermal insulation connectors arranged in a quincunx pattern can increase the ultimate displacement by 12.3% compared with those in a rectangular arrangement, indicating that the spatial distribution pattern of connectors has a regulatory effect on structural ductility [10].

The spacing arrangement of connectors affects the efficiency of shear force transmission. Zhang Kai et al. (2025) confirmed through out-of-plane load tests that when the spacing of connectors is reduced from 400mm to 250mm, the ultimate displacement capacity of the wall increases by 18.7%. However, excessive densification may lead to a decrease in the compactness of concrete pouring.

In terms of the cast-in-place layer:

The design parameters of edge confinement members have a significant impact on seismic performance. Dong Ge et al. (2023) confirmed through pseudo-static tests that when the reinforcement ratio of edge members increases from 2.5% to 4.0%, the cumulative energy dissipation capacity of the specimens increases by 58.6% [11]. However, there remains academic controversy regarding the optimal range of reinforcement ratios. Zhao Duanfeng (2022), in his research on T-shaped composite shear walls, recommended a reinforcement ratio of 6%-8% [12], while Xie Bin (2025) argued that 3.5% -5% is more economically reasonable in the case of post-inserted steel connections. This divergence may stem from the varying demands for confinement effects imposed by different connection forms [13].

The structure of vertical joints is a key factor affecting integrity. A review study by Chong Xun et al. (2022) showed that for specimens with a 30mm-wide post-cast strip and U-shaped reinforcement, their stiffness degradation coefficient was 27% lower than that of specimens with flat joints [14]. The axial compression test data by Zhou Linghai (2023) further verified that when the strength of the grouting material for vertical joints is increased from C40 to C60, the compressive bearing capacity of the wall can be improved by 18.9%, but the enhancement effect is no longer significant when the strength exceeds C70 [15]. These findings provide a quantitative basis for the engineering value selection of structural parameters. However, there are academic differences regarding the treatment methods of vertical joints. Zhao Duanfeng (2022) advocates the use of cast-in-place concealed column connections [12], while Xie Bin (2023) has verified the superiority of post-inserted steel connections, which can increase the energy dissipation capacity at the joints by 22.3% [13].

The reinforcement of the cast-in-place layer adopts a bidirectional distribution form. Dong Ge et al. (2023) confirmed through seismic tests that this configuration can reduce the crack propagation rate by more than 50% [11]. Wang Deru et al. (2021) showed in construction practice that the application of longitudinal rib composite technology increased wall hoisting efficiency by 35% while ensuring the compactness of cast-in-place concrete reached over 98% [16]. It is worth noting that Mao Youtong's (2024) latest research found that when the concrete strength grade of the prefabricated layer exceeds C60, the interface slip increases sharply, suggesting that the strength difference should not exceed 20MPa [17].

In terms of the thickness ratio of composite walls:

Mao Youtong's (2023) seismic tests showed that when the thickness ratio of the prefabricated layer to the cast-in-place layer is 1:1.5, the displacement ductility coefficient of the specimen reaches 5.8, which is better than 4.2 of the equal-thickness design. This difference stems from the fact that changing the thickness ratio effectively adjusts the stiffness distribution, making the formation position of plastic hinges more reasonable [17].Further pull-out tests by Xu Zhenhua's team (2023) revealed that when the anchoring depth of metal connectors increases from 60mm to 90mm, the pull-out bearing capacity increases by 31.7%, but the enhancement effect tends to flatten out when exceeding 100mm, indicating the existence of an optimal anchoring depth threshold [5].

In terms of the interaction between structural parameters:

Engineering practice by Wang Deru et al. (2021) confirmed that the longitudinal rib composite shear wall with comprehensively optimized structural parameters exhibited better damage control ability than traditional designs in actual earthquakes. Li Jinghui (2022) found that when both the connector spacing (250mm) and edge constraints (3.8% reinforcement ratio) are optimized simultaneously, the performance improvement of the specimen can reach 1.7 times that of individual optimization[16]. It can be seen that the collaborative optimization of structural parameters should become a key direction for future research. Especially in the context of intelligent design, establishing a multi-objective optimization model through parameter sensitivity analysis will have important engineering value.

In terms of material durability:

There are still obvious deficiencies in material durability. A review by Chong Xun et al. (2022) pointed out that adding 1.5% steel fiber can increase the shear strength of the composite interface to 3.8MPa, which is 36% higher than that of ordinary concrete14. However, Li Jinghui's (2022) research found that the ties in sandwich insulated walls are prone to brittle fracture under repeated loads, with their fatigue life being only 65% of that of cast-in-place joints, indicating that the durability issue of composite materials still needs to be addressed[18]. Mao Youtong's (2024) long-term performance tests showed that under a chloride ion erosion environment, the bond strength of the composite interface degraded by 28% after 5 years, significantly higher than the 12% degradation of cast-in-place structures [17]. Future research should focus on the engineering applicability of new materials such as nano-modified concrete and FRP connectors, while establishing time-varying seismic analysis models that consider material degradation effects.

2.2 Correlation between loading modes and failure modes

Dong Ge and Gu Qian (2023) found through quasi-static tests that the failure mode of specimens under low-cycle repeated loading exhibits obvious three-stage characteristics: initial cracks appear at 1/3 height from the wall base; the composite interface starts to slip when the displacement angle reaches 1/200; and the displacement ductility coefficient can reach 4.2-5.8 at the final failure[11]. It is noteworthy that this failure mode is essentially different from the diagonal through cracks observed in monotonic loading tests, indicating that the loading history has a decisive impact on the structural damage evolution. Under the mechanism of out-of-plane loading, the test data by Zhang Kai and Cheng Bei (2025) show that reducing the connector spacing from 300mm to 150mm can increase the insulation layer peeling load by 62%, but the ultimate displacement angle of the wall decreases by 18% instead[10]. This indicates that the optimization of structural parameters needs to balance the contradiction between bearing capacity and deformation capacity. The axial compression tests by Zhou Linghai (2023) further reveal that when the axial compression ratio exceeds 0.3, the specimens will transform from flexural failure to shear failure, with the bearing capacity decreasing by 22%-35%, a phenomenon that has not been fully considered in current specifications[15]. Test data show that the critical axial compression ratio for failure mode transformation is positively correlated with concrete strength; the critical value of C40 concrete specimens is approximately 0.05 higher than that of C30 specimens.

Studies on the influence of different loading rates have presented academic controversies. Mao Youtong (2023) pointed out through dynamic loading tests that when the loading rate increases from 0.5mm/s to 5mm/s, the slip amount of the composite interface decreases by 40% [17]. However, the study by Xie Bin (2023) shows that under 1Hz sine wave loading, the fatigue failure of connectors leads to a sudden drop in bearing capacity by 30%[13]. This divergence may stem from differences in the connection structure of specimens: the former uses welded connectors while the latter adopts post-inserted steel connections. The pull-out tests by Xu Zhenhua et al. (2023) provide evidence for this: the strength degradation coefficient of stainless steel tie members under cyclic loading is 0.75, significantly lower than that of carbon steel members (0.85), indicating that material selection has an important impact on dynamic performance [5].

The quantitative evaluation of failure modes requires a collaborative analysis of multiple indicators. The comprehensive damage index proposed by Chong Xun et al. (2022) shows that when the displacement angle reaches 1/100, the damage index of specimens with vertical joints is 15%-20% lower than that of monolithic specimens, which verifies the regulating effect of structural joints on damage distribution [14]. Li Jinghui (2022) established a mathematical model between the strain of tie members and interface slip through tests on sandwich wall panels, with the correlation coefficient R^2 reaching 0.91, providing a theoretical basis for failure early warning [8]. However, it should be noted that most existing studies are based on standard specimens. The engineering practice by Wang Deru et al. (2021) shows that construction deviations exceeding 5mm will lead to a significant deviation between the actual failure mode and laboratory predictions [16].

Future research should focus on the multi-field coupled loading effect. Zhao Duanfeng's (2022) tests on T-shaped walls show that bidirectional seismic action will reduce the bearing capacity by 12%-18% compared with unidirectional loading, and the failure location shifts to the flange [12]. The latest research by Zhang Yumin et al. (2024) attempts to incorporate thermal-mechanical coupling into the analysis framework and found that when the temperature rises to 60℃, the slip load of stainless steel connectors drops by 25%. This coupling effect has not been systematically considered in existing seismic design [4].

2.3 Standard unification and construction quality

Zhao Duanfeng (2022) found through comparative studies that there are obvious divergences among different research institutions regarding the reinforcement configuration requirements for T-shaped cross-section composite shear walls, with the recommended values of the reinforcement ratio of edge members ranging from 8% to 12% [12]. The research on thermal performance by Su Yu et al. (2024) shows that the differences in local regulations on the thickness of external thermal insulation layers lead to a fluctuation range of 0.15 W/(m²·K) in the wall heat transfer coefficient [9]. These phenomena of inconsistent standards not only increase the difficulty of design but also hinder the promotion and application of new connection technologies, which need to be improved and unified.

The engineering practice by Wang Deru et al. (2021) indicates that when the deviation of the pouring thickness of the cast-in-place layer exceeds 5mm, the initial stiffness of the composite wall will decrease by 12%-18% [16]. Li Jinghui (2022) found through tie performance tests that for every 1% increase in the construction moisture content of the sandwich insulation layer, the interface bonding strength decreases by approximately 0.8 MPa[8]. The research by Zhang Kai et al. (2025) shows that when the installation angle deviation of the connector reaches 5°, its shear-bearing capacity will decay by 22.3%, while the current construction specifications have not made clear regulations on this [10]. These indicate that the construction quality control system needs to be improved.

3 Conclusions and prospects

3.1 Research conclusions

Researchers have conducted extensive studies on the seismic performance of single-sided composite shear walls and compared them with cast-in-place concrete shear walls, drawing the following main conclusions:

(1) An integrated external thermal insulation structure has been proposed for the precast layer, and its reliability has been verified.

(2) The connector system adopts stainless steel tie members or thermal insulation anchors, and the arrangement of connectors follows the principle of "moderate densification at the edges".

(3) In terms of the cast-in-place layer, there are still divergences regarding the optimal range of reinforcement ratios for edge constraint members and the treatment methods for vertical joints. The reinforcement of the cast-in-place layer adopts a bidirectional distribution form.

(4) Changing the thickness ratio of the composite wall can effectively adjust the stiffness distribution, making the

formation position of plastic hinges more reasonable, and there exists an optimal anchorage depth threshold.

(5) Single-sided composite shear walls with comprehensively optimized structural parameters exhibit better damage control capability in actual earthquakes than those with traditional designs. The collaborative optimization of structural parameters should become a key direction for future research.

3.2 Research prospects

Future research should focus on "enhancing seismic resilience" as the core, and break through existing technical bottlenecks through material innovation, mechanism deepening, technological upgrading, and standard improvement. This will enable single-sided composite shear walls to not only meet the needs of low-rise and mid-rise buildings but also be reliably applied to high-rise buildings in high seismic fortification zones, truly becoming a core component of prefabricated structures that is "safe, efficient, economical, and applicable".Based on existing research, it is recommended to further carry out the following research work on the seismic performance of single-sided composite shear walls:

(1) Optimize the performance of connectors from the dual dimensions of material innovation and structural design. Development of new connector materials: Explore the composite application of high-performance materials (such as ultra-high-strength steel bars and fiber-reinforced polymer (FRP)) with traditional steel bars. Focus on testing the bond-slip characteristics, ultimate bearing capacity, and ductility of connectors made of different materials under low-cycle repeated loading, and establish the corresponding relationship between "material properties and seismic parameters". Intelligent connector design: Combine BIM and parametric design to preset weak joints, and integrate sensing elements (such as strain gauges and optical fiber sensors) to monitor the stress state of connectors in real time.

(2) Deepen the research on the working mechanism of the composite interface through both experimental and theoretical efforts:

Multi-factor coupling experimental research: Break through the limitations of existing single-variable tests and design a four-factor orthogonal experiment involving "composite interface roughness + steel bar anchorage length + concrete strength + load frequency".

Micro-mechanism analysis: Utilize micro-testing technologies such as scanning electron microscopy (SEM) and X-ray diffraction (XRD) to analyze the microstructures (e. g., porosity, distribution of hydration products) of the concrete interfacial transition zone (ITZ) at the composite interface. Based on this, optimize the surface treatment processes of precast wall panels (such as reserving key grooves and applying interface agents) to enhance the anti-slip capacity of the composite interface.

(3) Construct a simulation system that is closer to reality.

Refined model construction: Develop a "multi-scale coupling model": at the macro level, use the finite element method to simulate the overall force of the wall; at the micro level, establish meso-scale elements for the composite interface and connectors (such as considering the constitutive relationship of concrete crack propagation and steel bar yielding). Meanwhile, introduce machine learning algorithms to optimize model parameters.

Upgrade of dynamic response simulation: In view of the randomness of seismic loads, combine dynamic time-history analysis with probability statistics methods to simulate the dynamic response of single-sided composite shear walls under the action of different seismic waves, predict their residual deformation and repair possibility under extreme earthquakes, and provide a "performance-based" basis for structural seismic design.

(4) Improve the construction quality control system:

Intelligent construction monitoring technology: Implant RFID chips or QR codes during the production of precast wall panels to record information such as material performance and steel bar positioning; during on-site construction, use 3D scanning technology to monitor the installation accuracy of precast panels in real time, and correct deviations in a timely manner through comparison with BIM models. Develop automatic vibration monitoring equipment for composite interface pouring to ensure the compactness of concrete in the cast-in-place layer.

Establish a standardization system: Clarify core parameters such as connector selection (e. g., diameter, spacing), composite interface structure (e. g., roughness requirements), and reinforcement of edge components under different seismic fortification intensities and building heights; unify design methods (e. g., applicable scenarios for elastic analysis and elastoplastic checking calculation). Meanwhile, develop standardized node details (e. g., connection nodes between precast panels and beams/columns) to reduce design redundancy.

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