Research on the Technology of Integrated Thermal Insulation Single-sided Composite Shear Wall

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Abstract. The extended service life of external insulation thin plastering systems is a common source of concerns in China. Although prefabricated concrete sandwich insulation walls are a superior option, they still have drawbacks, including high cost, inefficient production, and inefficient construction and installation. A novel kind of single-sided composite shear wall with integrated thermal insulation is suggested in this context. This paper investigates the structural design and seismic performance of a novel type of composite shear wall at high axial compression ratios and large shear-span ratios. The findings demonstrate that the new type of wall's overall seismic performance is comparable to that of cast-in-place shear walls, and that the specimens' ductility and energy dissipation capacity are essentially the same. It can be used in the integrated shear wall structure system that is assembled. The engineering use of this new type of wall is supported by the ability to build the assembled integral shear wall structure using post-poured concrete and dependable bearing steel bar connection technology.

Keywords: composite shear wall, low-cycle horizontal reciprocating test, prefabricated building

1 Introduction

In China, the external thermal insulation thin plastering system is widely used in residential buildings. With the increase in service life, the system has experienced frequent problems in recent years, mainly reflected in the following aspects: (1) It is prone to hollowing, cracking, leakage, shedding, and causing fire, etc., and there is a large potential risk; (2) It has a great impact on the quality of the residence and even causes loss of life and property; (3) It does not meet the needs of the high-quality development of the construction industry in the new era.

With the rising labor costs in China, the improvement of the processing level of materials and prefabricated components, the improvement of prefabricated construction technology, and the promotion of national policy guidance, prefabricated buildings are showing a trend of rapid development. The prefabricated concrete shear wall structure system is widely used in residential buildings in China. Among them, the

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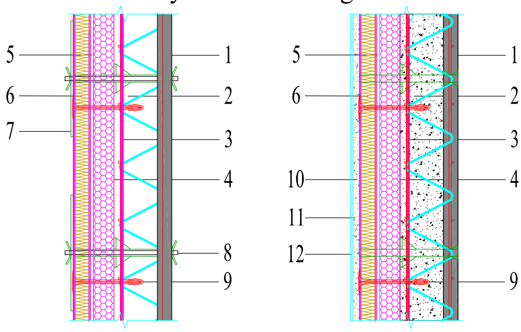
precast concrete sandwich thermal insulation exterior wall is a scheme to solve the problem of exterior thermal insulation. It can make it possible for structures and thermal insulation to coexist for the same amount of time. Low production efficiency, inefficient building and installation, and excessive cost are still issues, though. To save costs and maintain precision in the installation, The use of insulation to the exterior of precast concrete shear walls is becoming more common in the market. The bonding strength of the post-bonding thermal insulation is poor and the bonding effect of the thermal insulation board is impacted because the surface of the precast concrete shear wall is painted with mold release agent during the production process. In the engineering implementation of this system, the phenomena of thermal insulation shedding has happened.

The capacity to accomplish the same life as thermal insulation and structure, along with the benefits of easy construction and great production and installation costs, make a new type of thermal insulation composite shear wall presented in this context. The new composite shear wall is fabricated in the factory, concrete is poured into the cavity of the component at the construction site, and the finishing layers are applied on the outside. Among these, the inner wall plate functions as both an inner template and a component of the shear wall during the building phase, and the insulation board doubles as both the outer template and the outer insulation board. The schematic diagram of the wall before and after assembly is shown in Figure 1.



(a) Before assembly (b) After assembly

1-Inner wall panel 2-Post-poured cavity/post-poured concrete 3-Truss steel bar 4-Graphite polystyrene plate 5-Bonding mortar 6-Reinforced vertical wire rock wool composite board 7-Back board 8-Connector-I 9-Connector-II 10-Rubber powder polystyrene granule 11-Anti-crack mortar 12-Glass fibre mesh cloth

Fig. 1. Schematic diagram of the basic structure of the integrated thermal insulation single-sided composite shear wall

Aiming at the structural mechanical performance of composite walls, scholars from all over the world have carried out extensive research. Scholars from other countries mainly focus on the out-of-plane bending performance [1,2], axial and eccentric compression performance [3,4], the performance of connectors [5] and other aspects of composite walls. Since China experiences frequent earthquakes, research on composite shear walls by Chinese scholars focuses on its seismic performance. More studies have been done on the material's seismic performance for double-sided composite shear walls [6–9]; less research has been done on the material's seismic performance for single-sided composite shear walls, though Ma W., Jiang Q., and others [10–11] have done some pertinent research on the material's seismic performance.

Although China has utilized the composite shear wall structure to some degree, there are still certain issues with the integrated thermal insulation single-sided composite shear wall's engineering application. These issues are primarily related to the two aspects that follow. On the one hand, the composite shear wall structure project has made a moderate breakthrough in the maximum applicable height of the house, and it has reached 80 meters in the high seismic intensity area with an intensity of 8 degrees., and the shear wall members on the bottom floor show the characteristics of a high axial compression ratio; At the same time, with the improvement of living quality demand, it has gradually become a trend to adopt large-size window design in buildings, which increases the shear-to-span ratio of shear walls; Composite shear walls with potential high axial compression ratios and large shear-span ratios have been gradually applied in engineering, but the current related research focuses on the seismic performance of composite shear walls with small axial compression ratios and small shear-span ratios, which cannot meet the needs of engineering. On the other hand, as a new type of wall, the formation of the structural system, structural analysis method, connection design and other aspects of the integrated thermal insulation single-sided composite shear wall still need to be systematically studied. Most of the existing research on structural design focuses on double-sided composite shear walls, but simply referring to their design method cannot be directly applied to the new shear wall project in this study, especially the connection design. In order to better understand this new type of wall's seismic performance at high axial compression ratios and high shear span ratios, the research team carried out an experimental study [12]. In order to assist the implementation of this novel type of wall in high-rise (less than or equal to 80 meters) shear wall structural engineering in locations with high seismic intensity, this study provided a summary of the test and conducted additional research on its structural design.

2 Overview of Experimental Research

Engineering experience indicates that in the high seismic intensity area, shear walls near 80 meters can have an axial compression ratio of 0.3–0.4 and a shear span ratio of 1.8–2.0 if they have big window apertures. The research team designed test specimens as shown in Table 1 and Fig. 2, in order to study the seismic performance of the new type of wall under high axial compression ratios and large shear-span ratios. additionally conducted low-cycle horizontal reciprocating tests to investigate the failure mode and crack distribution of the test specimens. Examine its bearing capacity, energy dissipation capacity, stiffness deterioration, and failure mechanism. Then, compare its results to those of cast-in-place shear wall specimens subjected to the identical testing parameters.

Table 1. Main information of test specimens [12]

Specimen number	Shear span ratio	Axial com-pression ratio	Wall height (mm)	Wall width (mm)	Longitudinal reinforcement ratio of edge members	Stirrup ratio of edge member volume
SW1-1	1.2	0.1	2100	1900	1.16%	1.45%
SW1-2	1.2	0.3	2100	1900	1.16%	1.45%
SW1-3	1.2	0.4	2100	1900	1.5%	1.45%
W1	1.2	0.4	2100	1900	1.5%	1.45%
SW2-1	1.9	0.1	2900	1700	1.16%	1.45%
SW2-2	1.9	0.3	2900	1700	1.16%	1.45%
SW2-3	1.9	0.4	2900	1700	1.5%	1.45%
W2	1.9	0.4	2900	1700	1.5%	1.45%

Note: The thickness of the inner-wall layer, cast-in-place layer, and insulation layer of SW series specimens is 50/150/150mm respectively, and the thickness of the wall of W series specimens is 200mm.

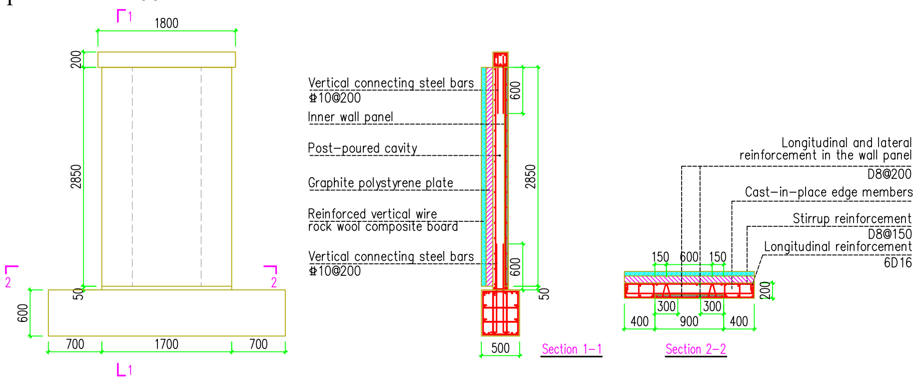
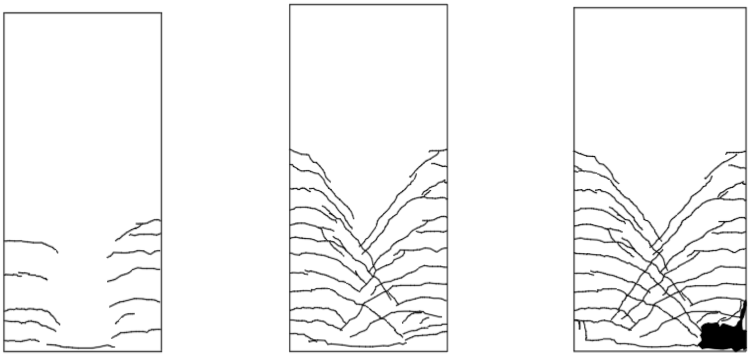


Fig. 2. Schematic diagram of the SW2 series specimens

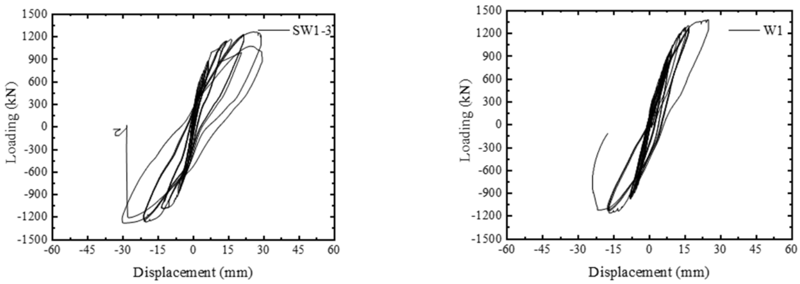
The failure patterns of SW specimens and experimental phenomena are comparable. Horizontal flexural fractures initially form at the shear wall's edge during the loading process, and they progressively spread up the wall's height. The longitudinal tendons of the edge members give, the horizontal flexural cracks become flexural-shear inclined cracks as the loading increases, the cracks are dense at the wall's base, and the flexural-shear inclined cracks on both sides intersect at the center of the shear wall. In addition, a small portion of the concrete at the root of the compression side relaxes, all of the longitudinal tendons of the edge members yield, and long fissures deepen the joint surface between the ground beam and the bottom of the shear wall. As the stress increases, the outermost longitudinal reinforcement of the edge member buckles, the longitudinal reinforcement and stirrups in the bottom area of the edge member become exposed, and the crack development is nearly complete. The bearing capacity also drastically reduces. Fig. 3 depicts the crack formation of specimen SW2-3.



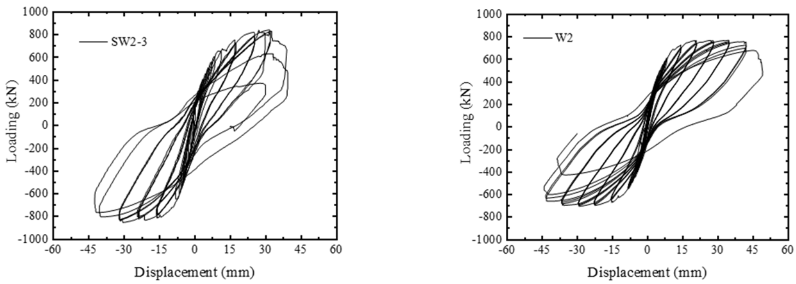
(a)Yield load development (b) Peak crack development (c) Ultimate crack development

Fig. 3. Schematic diagram of SW2-3 crack development of specimen [12]

Cast-in-place concrete shear wall specimens and incorporated thermal insulation single-sided composite shear wall specimens both collapse essentially in the same way. The failure mechanism of specimens progressively shifts from bending-shear failure to bending failure with an increase in shear span ratio. Throughout the whole testing procedure, there is no discernible slip deformation between the prefabricated and cast-in-place layers, and their interplay is satisfactory. Cast-in-place concrete shear wall specimens and incorporated thermal insulation single-sided composite shear wall specimens both collapse essentially in the same way. The failure mechanism of specimens progressively shifts from bending-shear failure to bending failure with an increase in shear span ratio. Throughout the whole testing procedure, there is no discernible slip deformation between the prefabricated and cast-in-place layers, and their interplay is satisfactory.



(a) SW1-3 (b) W1



(c) SW2-3 (d) W2

Fig. 4. Hysteresis curves of typical specimens [12]

Fig. 4 displays the hysteretic curves of representative examples. Further investigation, analysis, and comparison are conducted between the specimen's hysteretic properties, stiffness degradation, displacement ductility, and energy dissipation capacity and the cast-in-place concrete shear wall. The skeleton curves and hysteretic curves of single-sided superimposed shear walls are essentially the same as those of cast-in-place shear walls; the stiffness in the later stage is essentially the same as that of cast-in-place shear walls; the ductility and energy dissipation capacity are essentially the same as those of cast-in-place shear walls; and the stiffness is higher in the early stage and degenerates faster. The big shear span ratio specimen has a lower ultimate bearing capacity under the same axial compression ratio than the small shear span ratio specimen; the stiffness degradation occurs more quickly and the early stiffness is lower, but the ductility is superior and the energy. Even though the high axial compression specimen has a slightly lower ductility and a higher ultimate bearing capacity than the specimen when the shear-span ratio is the same, the inter-storey displacement angle of the shear wall can still meet the design code requirements in the event of a rare earthquake.

3 Structural Design

3.1 Structural System

The integrated thermal insulation single-sided composite shear wall is suitable to be used in the assembled integral shear wall structure system and used as the external wall of the building. The internal wall structure can adopt a cast-in-place shear wall structure, a composite shear wall, or a fully prefabricated shear wall. Composite floors can be used in the floor system. Using industrially produced insulation, single-sided composite shear wall panels, prefabricated interior wall panels, superimposed floor slabs, prefabricated balcony panels, prefabricated stairs, and other components, through post-poured concrete and reliable load-bearing steel bar connection technology, the assembled integral shear wall structure can be formed, which ensures that the structure has the same ductility, bearing capacity, and durability as the cast-in-place concrete structure.

Each applicable internal wall structure system has its own characteristics and scope of application. Starting from the overall benefit, the composite internal wall structure system can be unified with the integrated thermal insulation single-sided composite shear wall in terms of construction method and technology and can play a more effective role. In application, other systems can also be selected according to the characteristics of the project, but the requirements of each system in design, component production, and construction, as well as the coordination between systems, should be fully considered.

3.2 Structural Analysis and Component Design

The experimental results of this study show that the seismic performance of a single-sided composite shear wall with structural insulation integration is similar to that of a cast-in-place shear wall, so when the connecting reinforcement adopts a safe and reliable connection method and the joints between the old and new concrete adopt coarse surfaces and other structural measures that meet the requirements, the same method can be used in the design of the structure analysis as a cast-in-place concrete structure.

The elastic method can be used to analyze the effect of the structural bearing capacity limit state and the serviceability limit state of the new wall in this study. The seismic adjustment coefficient of the bearing capacity of the members and joints, the combination of loads, the limit of the ratio between the maximum displacement and the height of the floor, the limit of the elastic-plastic displacement angle between the floors, the stiffness assumption of the superimposed floor, and the stiffness increase coefficient of the floor beam can be implemented according to the relevant requirements of the cast-in-place shear wall.

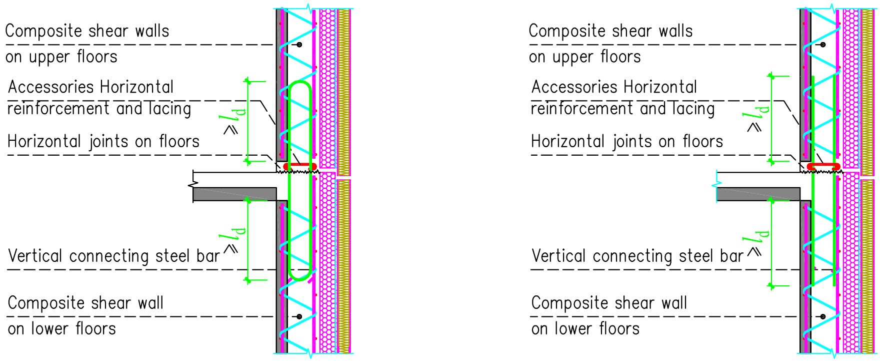
The bearing capacity and section design of a single-sided composite shear wall are calculated using the effective thickness of the entire section, which is determined by adding the thickness of the post-poured concrete to the thickness of the inner wall panel. Since the single-sided composite shear walls' horizontal joints are crucial components that influence the structure's mechanical performance, care should be taken in verifying the bearing capacity of these joints. At the same time, it should be noted that for the design of eccentric tensile single-sided superimposed shear walls, the eccentric tensile wall limbs should be cast-in-place. If single-sided composite shear walls must be used in this condition, it is recommended to supplement the internal force analysis of the structure under the horizontal earthquake action of fortification intensity. The situation of a small eccentric tensile wall should be avoided as much as possible, and the design should be based on elasticity or non-yielding under moderate earthquakes.

3.3 Connection Design

Horizontal Joints

The horizontal joints of the integrated thermal insulation single-sided composite shear wall should be set at the floor position. In order to ensure the dense pouring of post-poured concrete at the horizontal joints, the height of the horizontal joints should not be too small and can be controlled to more than 50mm. At the same time, in order to ensure the plugging quality of the formwork in the construction of post-poured concrete at the horizontal joints of the floor, it is recommended to control the height of the horizontal joint to not more than 70mm.

Vertical connecting steel bars should be set at the horizontal joints of the walls, as shown in Fig. 5. The test results show that the single-sided composite shear wall with 100% overlap and linear overlap length l_d equal to $1.2l_{aE}$ at the bottom joint has a higher bearing capacity, and the design of its bearing capacity can be carried out according to the relevant regulations of the cast-in-place shear wall. Ring-shaped steel bars can also be used for vertical connections. At this time, the force transmission of steel bars not only depends on the lap connection between steel bars but also on the local extrusion effect of ring-shaped anchor heads on concrete, which can also increase the anchoring capacity. According to the research of Wang Jun et al. [13], the straight-line lap length of steel bars l_d can be l_{aE}. On the outside of the vertical connecting steel bar within the height range of the horizontal joint, two additional horizontal steel bars should be set with the length, the diameter of which is not less than the diameter of the horizontal steel bar of the shear wall, and the horizontal lacing bars should be reliably connected with the vertical connecting steel bar.



(a) Ring bar lap (b) Straight bar lap

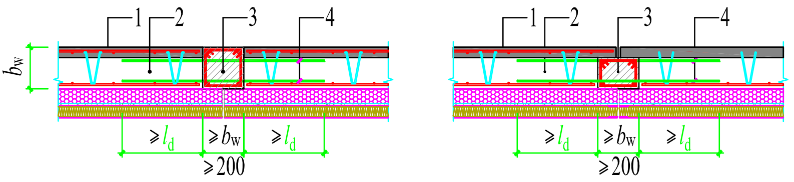
Fig. 5. Vertically connected steel bar overlapping construction at the horizontal joints of the single-sided composite shear wall

Vertical Joints

The vertical joints of single-sided composite shear walls should avoid the maximum and complex areas of stress as much as possible and avoid setting them in the areas where edge members are constructed. When the horizontal connecting steel bar at the vertical joint part adopts a straight steel bar, the straight lapping length l_d of the steel bar should not be less than $1.2l_{aE}$; when the ring-shaped closed steel bar is used, the straight-line lapping length l_d of the steel bar from the bending point of the steel bar should not be less than l_{aE}.

Non-Edge Component Parts.

The vertical joints between adjacent single-sided composite shear walls can be connected in the form of post-poured sections, and the post-poured sections can be fully cast-in-place (Fig. 6-a) or superimposed (Fig. 6-b). No less than four vertical steel bars and horizontal stirrups should be installed in the post-pouring section.

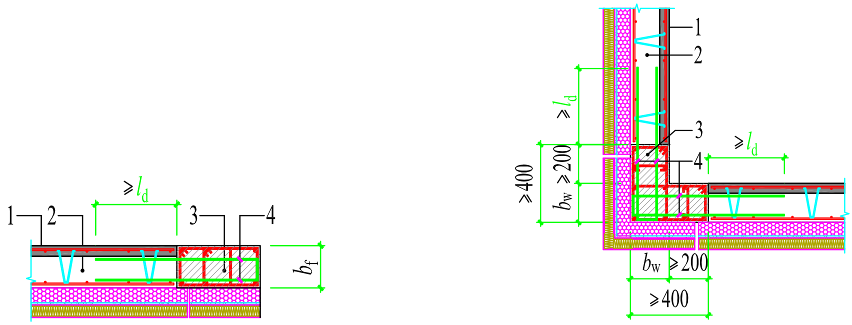


(a) The post-cast section is fully cast in situ (b) The post-cast sections are superimposed 1-Single-sided composite shear wall panel 2-Post-poured cavity 3-Post-cast joint 4-Horizontal connecting bars

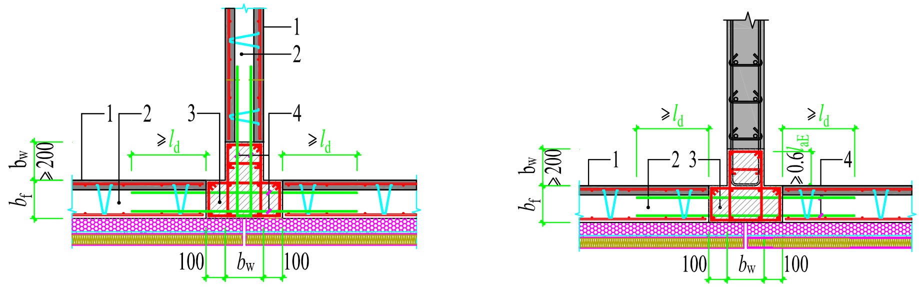
Fig. 6. Schematic diagram of vertical joint connection of the single-sided composite shear wall (non-edge member area)

Edge Component Parts.

For the vertical joints at the corner and the junction of longitudinal and transverse walls of the single-sided composite shear walls, horizontal connecting reinforcing bars should be installed in the cavity of the wall panel to reliably connect with the cast-in-place edge members. Horizontal connecting steel bars should be straight steel bars, or ring-shaped closed steel bars can be used. When the inner wall adopts fully prefabricated shear walls, as shown in Fig. 7-d, the horizontal reinforcement of the wall extending out of the wallboard should be annular reinforcement, and the anchoring lap length between the horizontal reinforcement and the cast-in-place edge members should not be less than $0.6l_{aE}$and the installation distance of the reinforcement should be left.



(a) Straight wall (b) Corner walls



(c) Winged walls-interior walls are composite shear walls (d) Winged walls-interior walls are fully prefabricated shear walls

1-Single-sided composite shear wall panel 2-Cavity post-poured concrete 3-Cast-in-place edge members 4-Horizontal connecting bars

Fig. 7. Schematic diagram of the connection between the shear wall and the edge member of the single-sided composite shear wall

4 Conclusion

With the intent of achieving the integrated thermal insulation single-sided composite shear wall in shear wall structures, this study investigated the wall's structural design approach and conducted experimental research on the wall's seismic performance at high axial compression ratios and large shear span ratios. This provided a foundation for the application of the new wall at these ratios. It aids in the high-quality creation of prefabricated structures and supports the high-rise superimposed shear wall structural engineering used in the high seismic intensity area. The following are the principal findings:

(1) The integrated thermal insulation single-sided composite shear wall's seismic behavior was investigated experimentally. The results indicate that the single-sided composite shear wall specimen's failure mode is essentially the same as the concrete shear wall specimen cast in place, and that the single-sided composite shear wall's hysteretic curve and skeleton curve are essentially the same as those of the cast-in-place shear wall. The early stage of the single-sided composite shear wall has a higher stiffness, which degenerates more quickly. In the later stage, the rigidity is nearly identical to that of cast-in-place shear walls, and overall seismic performance is comparable.

(2) The integrated thermal insulation single-sided composite shear wall is suitable for application in the assembled integral shear wall structure system; the internal wall structure can adopt the cast-in-place shear wall structure or various kinds of assembled integral shear wall structure; and the assembled integral shear wall structure can be formed through post-poured concrete and reliable bearing steel bar connection technology, which ensures that the structure has the same ductility, bearing capacity, and durability as the cast-in-place concrete structure. Each applicable internal wall structure system has its own characteristics and scope of application. In application, the appli-

cable system can be selected according to the characteristics of the project, and the composite shear wall system should be preferred.

(3) Combined with the experimental results, when the connecting reinforcement adopts reliable connection methods and the joints between new and old concrete adopt rough surfaces and other structural measures that meet the requirements, the same method as cast-in-place concrete structures can be used for structural analysis in design.The connection of the integrated thermal insulation with the single-sided composite shear wall is the key to ensuring the integrity and seismic performance of the structure. Linear reinforcement can be used for lap connection, and ring-shaped reinforcement can also be used to improve lap performance and construction convenience.

While some progress has been made in this work regarding the seismic performance and structural design approach of the integrated thermal insulation single-sided composite shear wall, more research is still required in conjunction with engineering applications. To provide more useful information for engineering practice, it is especially required to analyze the seismic performance and design technique of shear walls with superposed edge members and the vertical joints of wall panels located in the area of edge members.

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