Research on Structure-Node Design and Performance of High-Performance Multifunctional Integrated Wall Panel

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Abstract. A high-performance multifunctional integrated composite wall panel system, which was composed of a high-performance thin-walled large cavity shell and multifunctional core, was proposed in consideration of the advantages of ultrahigh-toughness cement-based composite materials, the standard panel surface density was ≤75 kg/m², and the minimum ultimate flexural load was 2,333 N/m², and according to the thermal engineering theory, the heat transfer coefficient of modified polystyrene particles foamed concrete for the multifunctional core was calculated as 0.756 W/(m²‚K), and that of the designed three-layer (standard panel + 35 mm rock wool + gypsum plasterboard) composite structure was 0.481 W/(m²‚K). By combining the characteristics of standard panel, customized exterior wall, sealing, waterproof, and other measures were proposed, and meanwhile, multiple structural combinations were constructed to meet the energy conservation design needs in different climatic regions.

1. Introduction

A prefabricated panel is a building envelope, especially the exterior wall is exposed to the outside, so it is supposed to have waterproof, anti-fouling, durable and good-looking functions. As an envelope member of buildings, the prefabricated panel can be affected by various external actions due to large volume and large exposed area. It may be susceptible to wind load, earthquake, etc. besides stress-carrying during the fabrication, overturning, lifting and other processes. Therefore, it will be significant to study the static mechanical properties of wall panel. A prefabricated external composite sandwich-type panel mainly consists of outer part, sandwich layer, and inner part, which exert the facing, thermal insulation and structural effects, respectively, as shown in Figure 1, and they are connected via dedicated connectors. As the critical component in the prefabricated external composite sandwich-type panel, connector plays a significant role in the coordinated stress-carrying of outer and inner parts of the wall panel, and its mechanical properties will have a direct bearing on the safety, applicability and durability of wall panel [1].
The ultrahigh-toughness cement-based composite material, which has been developed in recent years, is featured by high strength and high durability [2]. Produced through the integrated forming process, the high-performance multifunctional integrated external wall panel integrates the decoration, thermal insulation and waterproof functions. The adulteration of fibers in the external wall panel effectively strengthens its shear performance, fatigue resistance, shock resistance and durability, so the building envelope is of favorable anti-seismic energy dissipation capability [3]. The key technical problems of this new-type wall panel will be analyzed and discussed in this paper.

2. Structural Design Research

2.1 Structural design of standard high-performance multifunctional integrated composite wall panel

The high-performance multifunctional integrated composite wall panel was designed into a combination of 100 mm high-performance thin-walled large cavity shell + multifunctional core (Figure 2), where the former was made of high-toughness cement-based composite material and different thermal insulation materials could be used for the latter according to actual needs [4]. The standard high-performance multifunctional integrated composite wall panel is shown in Figure 3, and its multifunctional core was formed by the modified polystyrene particles foamed concrete. Outside the wall panel was the facing layer, and the pattern could be customized to realize self-decoration.

1- High-performance thin-walled large cavity shell; 2-Functional core

Figure 2: Structure of Standard High-Performance Multifunctional Integrated Composite Wall Panel

Figure 3: Standard High-Performance Multifunctional Integrated Composite Wall Panel
The waterproofing plan, which centered on material waterproofing, supplemented by structural waterproofing, was adopted to realize the waterproof function in the joints between standard panels, a certain groove-tongue slope was set at the joints, too, the middle part of the groove-tongue was plastered with adhesive mortar, and both inner and outer sides of the groove-tongue joints were treated with weather-proof sealant to prevent vapor from entering the panel joints and flowing and permeating in the room as shown in Figure 4.

Figure 4: Waterproofing Plan for Joints Between Standard Panels

2.2 Structural design of customized exterior wall
As for the standard high-performance multifunctional integrated composite wall panel, the customized exterior wall structure, which was formed by splicing standard panels through lightweight section steel and bolts, was proposed in this paper. According to the building energy conservation requirements and application scenarios in different regions, the multifunctional core and exterior wall structure in the standard panel were adjusted in order that they could satisfy the actual needs [5].

In accordance with Design Standard for Energy Efficiency of Public Buildings (GB/T 50189-2019), the customized exterior wall was divided into two types [6] according to the heat transfer coefficient K of exterior wall: K≤1W/(m2·K) (heat transfer coefficient requirement of exterior wall of public buildings in hot-summer and cold-winter regions) and K≤0.5W/(m2·K) (heat transfer coefficient requirement of exterior wall of public buildings in severe cold region). The customized exterior wall structure with heat transfer coefficient of K≤1W/(m2·K) was formed by splicing five standard 100×600×3000 mm panels (100 mm high-performance thin-walled large cavity shell + modified polystyrene particles foamed concrete core) using section steel (Figure 5). According to the thermal engineering theory [7], the heat resistance and heat transfer coefficient of the structure with modified polystyrene particles foamed concrete core were calculated as 1.323 m2·K/W and 0.756W/(m2·K), respectively; the heat transfer coefficient of customized exterior wall was K≤0.5W/(m2·K), standard panels (100 mm high-performance thin-walled large cavity shell + modified polystyrene particles foamed concrete core) were used at the outer side, 35 mm rock wool filled the middle part, gypsum plasterboard was used at the inner side, the rock wool was fixed with steel wire mesh, and the gypsum plasterboard was connected to the section steel via connectors (Figure 6). The heat resistance and heat transfer coefficient of standard panel (100 mm high-performance thin-walled large cavity shell + modified polystyrene particles foamed concrete core) + 35 mm rock wool +gypsum plasterboard composite structure were 2.079 m2·K/W and 0.481W/(m2·K), respectively.
1-Decorative sheet (gypsum plasterboard, etc.)  2-Fixation of steel wire mesh/inorganic grille cloth  
3-Rock wool  4- Erection bolt  5- Standard panel  6-Section steel

Figure 5: Structural Design of Customized Exterior Wall with Heat Transfer Coefficient of K≤1W/(m²·K)

Figure 6: Structural Design of Customized Exterior Wall with Heat Transfer Coefficient of K≤0.5W/(m²·K)

The waterproofing plan, which centered on material waterproofing, supplemented by structural waterproofing, was also adopted to realize the waterproofing function of joints between customized exterior walls. The joints of upper and lower wall panels were blocked with PE strips, and the inner side and outer side of the joints were treated with weather-proof sealant to prevent vapor from entering the panel joints and flowing and permeating into the room.

3. Design Research on Connection Nodes

3.1 Splicing design between standard panels
Customized nuts were embedded above the high-performance thin-walled large cavity shell at inner side of the wall panel (Figure 7). The embedded customized nuts could avoid stress concentration in the trepanning process, reduce the manual operating error and improve the positioning accuracy, and meanwhile, they could be embedded at any part of wall panel [8]. When the standard panels were spliced, two customized M18 nuts were embedded at both end of each standard panel to fix and connect the two ends of section steel as shown in Figure 8.
According to relevant stipulations specified in Technical Standard for Assembled Buildings with Concrete Structure (GB/T 51231-2016), the sealing materials at joints should not be damaged in order to ensure the normal serviceability of external wall panel under an earthquake. The joint width between panels should be large enough in order that the external wall panel would not fall off under a rarely met earthquake. The joint width between panels was taken as 15 mm according to the existing external wall panel system standard. Meanwhile, the elliptical holes were opened on the standard section steel-spliced panel in order to control the joints.

### 3.2 Connection node design for customized exterior wall
The external wall panels were connected to the major structure using the four-point simple support via steel connection components. The horizontal loads borne by the external wall panels mainly included horizontal force caused by center-of-gravity shift, wind load and horizontal seismic force. The nodes were connected using a simple support with uniformly distributed load, and all nodes of external wall panels were widened Z-type connectors. The nodes were connected to connection components via embedded Z-type junction plates. In order to enhance the horizontal drawing resistance and vertical sliding resistance of the Z-type junction plates, they were embedded in the major structure after being welded with steel plates via anchor bars on the section steel. The connection structure of customized exterior wall is shown in Figure 9.
4. Bending Property Test

The deformation failure caused by wind load and seismic load was mainly taken into consideration for the external prefabricated concrete wall panel, so the ultimate load of the standard high-performance multifunctional composite wall panel under the action of out-of-plane load was investigated. The load was uniformly applied in the bending test until the panel experienced a failure or obvious cracks were generated, and load before the fracturing was recorded as the final test result. The bending test of standard panel cured for 28d was conducted for three times using the above loading system, and the test results are seen in Table 1. The ultimate bending load test is displayed in Figure 10.

| Test No. | 1    | 2    | 3    |
|----------|------|------|------|
| Ultimate uniformly distributed bending load (N/m²) | 2389 | 2500 | 2333 |
| Panel self-weight (kg) | 133.4 | 132.8 | 133.9 |
| Surface density (kg/m²) | 74.11 | 73.78 | 74.39 |
As seen in Table 1, the surface density of standard high-performance multifunctional integrated composite wall panel with the multifunctional core made of modified polystyrene particles foamed concrete was smaller than or equal to 75 kg/m², the minimum ultimate bending load was 2,333 N/m², the maximum deflection was about 12 mm, and the bending failure load/panel self-weight multiples>3 times, thus satisfying the standard requirements.

5. Conclusion
(1) A high-performance multifunctional integrated composite wall panel system was developed, this system was relatively independent of the major structure, the members were also independent of the functional configuration, the members were standardized, modularized and prefabricated with flexible and varied structures, multiple combinations could be realized, so the requirements of different energy conservation design standards in different climatic regions could be met.

(2) The structures like connection nodes, splicing and waterproofing structures applicable to this high-performance multifunctional integrated composite wall panel system were developed. According to the thermal engineering theory, the heat transfer coefficient of the structure with the multifunctional core made of modified polystyrene particles foamed concrete was calculated as 0.756 W/(m²·K), and that of the structure composed of standard panel+ 35 mm rock wool + gypsum plasterboard was 0.481 W/(m²·K).

(3) The high-performance multifunctional integrated composite wall panel was of superior overall mechanical properties, with surface density of ≤75 kg/m², minimum ultimate bending load of 2,333 N/m², maximum deflection of about 12 mm, and bending failure load coefficient of >3 times.

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