Experimental Study on Flexural Property of Precast Cavity Concrete Sandwich Wall Panels

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Abstract. The sandwich wall panel studied in this article is prepared by setting a cavity between the outer cavity wall body and thermal insulation layer, which is connected by FRP rod connectors. Through the out-of-plane flexural test, the crack development rule is recorded, and the load deformation rule is recorded under serviceability limit state and limit state of bearing capacity. The analysis results can provide reference for the design of precast sandwich wall panels with cavities.

1. Preface:
As people's requirements for energy conservation and environmental protection and building quality increase, prefabricated structures have become an important form of building design. Precast concrete sandwich panels have greatly improved the thermal insulation effect of the structure and the utilization rate of materials [1], and they have become the main trend for the development of external wall panels in prefabricated structures. However, in severe cold areas, the difference between indoor and outdoor temperature in winter is larger, and the condensation inside the wall will make the thermal insulation layer wet, which will have great effect on its insulation performance and durability. Chu Hongliang et al. [2] confirmed that in all types of precast concrete sandwich wall panels in the cold areas, condensation occurred in the outer cavity wall body; Guo Xingguo et al. [3] calculated that the maximum condensation rate occurred at the boundary of the wet areas on the low temperature side. Outer walls with cavities have been used in coastland of Europe as early as in the 19th century. They are mainly used in masonry structures, which can effectively prevent rainwater from entering into the wall, with good thermal and sound insulation effects. For precast concrete sandwich walls, Li Shuhong and Li Jiuhong et al. [4,5,6] carried out the wet heat calculation analysis on the wall panels with cavities, and proved that the anti-condensation effect of setting a cavity between the outer cavity wall body and thermal insulation layer is better than that of the vapor barrier.

The sandwich wall panel studied in the article is to set a cavity between the outer cavity wall body and thermal insulation layer, which is connected by FRP rod connectors. Through the out-of-plane flexural test, the effects of cavity thickness on the rigidity, flexural capacity, degree of rigidity combination and degree of combination of bearing capacity of the wall panels were investigated. The analysis results can provide a reference for the design of precast sandwich wall panels with cavities.

2. Out-of-plane flexural test

2.1. Test Overview
A total of 3 sandwich wall panels are produced in the test. The member numbers are QB-1 to QB-3. C30 concrete is adopted. Both the inner and outer cavity wall panels are equipped with $\times 5@100$ cold-rolled ribbed reinforcing mesh. XPS thermal insulation layer is adopted. A cavity is set between the cavity wall body and thermal insulation layer, and the layers of the wall are connected by FRP tie pieces. The detailed dimensions of the test pieces are shown in Table 1. A 100 mm wide rib on both sides of the support of the inner cavity wall panels to form the cavity.

| Table 1 Quantity and size of test pieces |
|-----------------------------------------|
| L (mm) | B1 (mm) | B2 (mm) | h1 (mm) | h2 (mm) | h3 (mm) | h4 (mm) |
| QB-1   | 1400    | 1400    | 1200    | 60      | 80      | 20      |
| QB-2   | 1400    | 1400    | 1200    | 60      | 80      | 40      | 50      |
| QB-3   |         |         |         |         |         | 60      |

2.2. Material properties and production of test pieces

The measured cubic compressive strength of the test wall on Day 28 is 31.9 MPa. The reinforcement model of the wall is selected as HRB400. According to the requirements of "Metallic Materials - Tensile Testing Part 1: Method of Test at Room Temperature" (GB/T 228.1—2010), the tensile test is carried out on the reinforcement samples, and the average value of the yield strength $f_y$ of the reinforcement is 325 MPa and the average value of the limit strength $f_u$ is 650 MPa. The thermal insulation layer adopts XPS board with an average compressive strength of 250 Kpa. The connectors are FRP connectors. According to the distance between the inner and outer cavity wall panels, the tie pieces of models BX40-80/160, BX40-100/180 and BX40-120/200 of Shenyang Baolide are selected respectively. There are not any corresponding tie pieces for QB-4. It is self-made using two tie pieces of BX40-100/180 with glass fiber cloth and epoxy resin. The flexural modulus is greater than 30 GPa, the tensile strength is greater than 700 MPa, the bending strength is greater than 800 MPa, and the shear strength between pavement layers is greater than 40 MPa.

Firstly the pouring of the inner cavity wall panels is completed, and then the thermal insulation layer is paved to place the tie pieces. After the concrete strength of the inner cavity wall panels reaches 75%, they are turned over and poured on the fresh cast outer cavity wall panel. The air layer is made by using the difference between the rib height and the thickness of the outer cavity wall panels. Cubic compressive strength test blocks are left at the same time during the concrete pouring.

2.3. Measuring point arrangement and loading scheme

The loading is completed in the structural laboratory of Changchun Institute of Technology. According to the actual force conditions of the member, the test pieces adopt simply support at both ends. The recorded data in the test mainly is mainly force, displacement and strain. Reinforcement and concrete strain are measured with strain gauges. 10 strain gauges are pasted inside and outside the inner cavity wall body, outside of the outer cavity wall body and within 1/4 of the wall. Three strain gauges are respectively pasted along X and Y directions of the internal reinforcement of the inner cavity wall body. During test, a total of 6 displacement gauges are respectively set on mid-span and support of the inner and outer cavity wall bodies (see Figure 1).

It is piled loaded at 16 points on the outer cavity wall panel. The actual loading range is 1.4mX1.2m, 5 levels of loading (as shown in Figure 1), 160 kg (1.568 kN) of each level, and lasing 15 min of each loading.
3. Experimental phenomena and results
According to "Load Code" 2012, the standard serviceability load value of the building envelope at a height of 100m is 1.49KN/m², which is converted to 2.5kN based on the area of the test piece, between the loads of the first and second level of the pile-loading test. During pile-loading test, no visible cracks appear in the member, and the concrete on the tensile side does not reach the limit tensile strain. The deflection meets the requirements of the codes of our country.

The failure modes of the three tests are roughly the same. Take QB-3 as an example to explain the failure process and failure mode. When the load is loaded from 0 to 60% of the limit bearing capacity, the first cracks appear in the middle and lower part of the outer leaf wall panel. When the load is 88% of the ultimate bearing capacity, the first cracks appear in the underside of mid-span of the inner cavity wall panel. At the same time, tensile cracks appear on the underside of 1/3 span of the outer cavity wall panel. When loading to 93% of the limit bearing capacity, the punching failure of the connector of the support accessories appears (see Figure 2a), which also appears in the simulation wind load test of the sandwich wall panels. If loading is continued, cracks develop rapidly, and the inner cavity wall panel is one-way slab damaged by bending, showing that a series of parallel tensile cracks appear in the mid-span (see Figure 2b), and the reinforcement in the wall panel does not reach the yield stress. Due to the location of connectors, the outer cavity wall panel forms a two-way slab flexural failure mode between the connectors, but the overall deformation is still a one-way bending deflection (see Figure 2c).

4. Analysis of experimental results
After more than 40 years of continuous evolution, the technology for producing sandwich wall panels has gradually matured, forming 3 types of non-combined, partially combined, and combined sandwich wall panels [7]. Precast sandwich panels based on truss reinforced connectors and non-metallic...
plate-type connectors can achieve the combined effect of inner and outer cavity wall concrete slabs [8.9]. The point-type connector can make the inner and outer cavity wall panels develop the partially combined and non-combined forms.

4.1. Load-strain analysis
From the load-strain relationship of mid-span cross-section, the compression zone is concentrated on the outer cavity wall panel, and the neutral axis is near the surface of the inner cavity wall panel. As the load increases, the stress in the tensile zone increases significantly, and the stress in the compressive zone increases slowly. Under the initial load of level 1, the cross-section strain basically meets the plane cross-section assumption, and it can be considered that the inner and outer cavity wall panels are completely combined. However, when the load is increased to above level 2 till cracks development, the outer cavity wall panel is still mainly under compressive strain, the inner cavity wall panel appears both compressive and tensile strain, and the neutral axis appears inside the inner cavity wall panel (see Figure 3). Some combined wall panels have obvious characteristics.

![Fig. 3 P-ε curve of measurement points of each layer of mid-span of QB-3](image)

4.2. Calculation and analysis of degree of wall panel combination
There are two methods for evaluating the degree of sandwich wall panel combination: evaluation method of degree of rigidity combination (Ps) in the uncracked concrete stage, that is, the ratio of the actual inertia moment (EIr) of the member cross-section to the theoretical inertia moment (EI) of the complete combined panel (i.e. initial flexural rigidity ratio) is used to evaluate [10]; evaluation method of degree of bearing capacity (μ), μ = (Ma - Mnc)/(Mfc - Mnc) [11]. But in common design methods [12], one of the most important parameters is the initial flexural rigidity [1].

Take the load before cracking and the corresponding displacement to calculate the degree of rigidity combination. See Table 2 for details.

| Specimens | Iexp  | b | Ps  |
|-----------|-------|---|-----|
| QB-1      | 728.96| 1092.30 | 66% |
| QB-2      | 641.48| 1434.12 | 44% |
| QB-3      | 280.70| 1840.63 | 14% |

According to the current energy-saving standards, 80mm thick EPS thermal insulation layer and 10mm thick cavity layer can meet the requirements. This type of panel is designed according to the current shear connector design method; it is difficult to achieve the rigidity performance of the complete combined panel in actual.

5. Conclusions
The experimental analysis of precast concrete sandwich wall panels with different thicknesses of cavity layer leads to the following conclusions:

1. Wall panels with different thicknesses of cavity layer show one-way slab failure modes. When loading according to the standard serviceability load value of the building envelope at a height of 100m, no cracks appear in the member, and the deflection meets the requirements of the serviceability
limit state of the code of our country.

2. The thickness change of cavity layer within 0 to 70mm will affect the degree of rigidity combination of this type of wall panel. As the thickness of the cavity layer increases, the degree of rigidity combination of the panel decreases significantly, and a linear fitting formula is recommended.

3. This type of wall panel is partially combined wall panel. According to the current national energy-saving standards, it is recommended that the degree of rigidity combination takes 60% of the complete combined rigidity.

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