Study on the mechanical property of precast reinforced concrete sandwich insulation walls

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Abstract: In this paper, a finite element analysis model of a precast reinforced concrete sandwich insulation wall (PRCSIW) is established according to the out-of-plane static load test of the wall. With the consideration of the structural characteristics of PRCSIW, the influences of insulation layer thickness, insulation material type, fastening piece type and fastening piece distribution mode on the mechanical performance of the wall is analyzed. Our work gives a theoretical basis for the optimal design of precast sandwich insulation walls.

1. Introduction
Precast reinforced concrete sandwich insulation wall is a kind of prefabricated energy-saving insulation wall integrating the functions of enclosure, insulation and decoration. PRCSIW is composed of a reinforced concrete board with inner and outer blades, a heat preservation board and connecting parts of the three boards, thus featuring the advantages of heat preservation, durability and fire resistance. At present, some scholars have conducted some studies on its performance [1-3], however, the force and deformation of the wall are complex. In this paper, a model of the wall is established according to its static test data. The influences of insulation layer thickness, insulation material type, fastening piece type and fastening piece distribution mode on the mechanical performance of the wall is analyzed to provide theoretical basis for the optimal design of precast sandwich insulation walls.

2. Establishment of finite element model
In this paper, the wall model is established according to the specimen and test conditions in reference [4]. Wall size: 3200×2800mm×190mm, in which the thickness of the reinforced concrete plate inside and outside the blade is 60mm, and the thickness of the insulation layer in the middle is 70mm, and the reinforced concrete plate adopts two-way reinforcement; the connecting parts are FRP plate fastening pieces, which are arranged in a comprehensive staggered way in the wall plane. The supporting method of the wall is simply supported by four sides, and the loading method is graded uniform loading. The grading situation is as follows: from the design load of 28kN to 27 times of the design load of 768kN, the grading is divided into 17 levels.

In the wall model, the element types of concrete slab, thermal insulation slab and FRP plate fastening pieces are set as three-dimensional solid units, and the element types of steel reinforcement and w-type FRP fastening pieces are set as three-dimensional truss units. The material type of each component shall be set according to the test and actual material properties; in the constraint...
relationship, the binding constraint is set between the insulation board and the concrete board, and the embedded regional constraint is set between the reinforcement and the concrete board, and the fastening piece and the concrete board. When setting boundary conditions, according to the displacement characteristics of the ball and cylinder when the wall is deformed, the constraint mode of them in X, Y and Z directions is set.

3. Model’s validation

In order to verify the effectiveness of the established model, the finite element model is firstly established in accordance with the prefabricated sandwich wall in the test. Among them, the materials of all parts of the model are set strictly in accordance with the materials of the specimen in the test. Meanwhile, the same constraints, supporting conditions and external loads are given to the model and the test.

The load-midspan bottom deflection curve, load-midspan bottom concrete tensile strain curve and test data curve extracted from simulation results are shown in figure 1.

From figure 1, it can be seen that both load-deflection curve and load-strain curve have a trend of close to direct proportion, indicating that the wall is deformed evenly in the whole process of stress.

Under the design load, the deflection value of the midspan bottom plate of the wall in the simulation results is 1.05mm, and the deflection value in the test is 1.16mm, and the simulation results are 9% smaller than the experimental results. Under the maximum load, the deflection value of the midspan bottom plate of the wall in the simulation results is 25.9mm, while the deflection in the test is 28mm. The simulation results are 7.5% smaller than the experimental results. Under the maximum load, the strain values of the midspan bottom plate of the wall are 228με (for short span direction) and 282με (for long span direction). The strain value in the test are 252με (for short span direction) and
325με (for long span direction). The error values of the two data are 9.5% and 13.2%, respectively. In conclusion, the error of simulation results and test results is within the allowable range, and the model is effective.

4. Analysis of force performance of wall

4.1 Influence analysis of insulation thickness

The thickness of insulation mortar layer is changed and the mechanical performance of wall board under different thickness of insulation layer is analyze. Among them, model 1 is the model established in accordance with the test conditions, and the others are models with different insulation layer thickness. The specific parameter Settings are shown in table 1.

| The model number | Insulation layer thickness (mm) | Type of insulation material | Fastening piece type | Attachment arrangement |
|------------------|---------------------------------|----------------------------|---------------------|------------------------|
| 1                | 70                              | Thermal insulation mortar  | FRP plate fastening piece | Crisscross layout     |
| 2                | 75                              | Thermal insulation mortar  | FRP plate fastening piece | Crisscross layout     |
| 3                | 80                              | Thermal insulation mortar  | FRP plate fastening piece | Crisscross layout     |
| 4                | 85                              | Thermal insulation mortar  | FRP plate fastening piece | Crisscross layout     |
| 5                | 90                              | Thermal insulation mortar  | FRP plate fastening piece | Crisscross layout     |

Under the maximum load, the load-deflection curve of the wall model with the thickness of 80mm insulation layer is shown in figure 2.

Under the design load, the midspan deflection of the bottom of model 1-5 is as follows: 1.05mm, 0.8mm, 0.55mm, 0.43mm and 0.35mm respectively. With the increase of the thickness of insulation board layer by 5mm, the midspan deflection of the bottom of the board decreases by 23%, 47%, 59% and 66% respectively. Under the maximum load, the mid-span deflection of the bottom of model 1-5 is as follows: 25.9mm, 25.3mm, 24.6mm, 23.7mm and 22.5mm respectively. With the increase of the thickness of the insulation layer by 5mm, the mid-span deflection of the bottom decreases by 2.3%, 5.0%, 8.5% and 13% respectively. It can be seen that the deflection of the wall under load decreases with the increase of insulation thickness.
4.2 Influence analysis of other parameters
The insulation material type, fastening piece type and fastening piece distribution mode of the wall model are changed. The change of the mechanical performance of the wall board under various conditions is analysed. The specific parameter setting is shown in table 2.

| The model number | Insulation layer thickness (mm) | Type of insulation material | Fastening piece type | Attachment arrangement |
|------------------|---------------------------------|-----------------------------|----------------------|------------------------|
| 6                | 70                              | EPS                         | FRP plate fastening piece | Crisscross layout     |
| 7                | 70                              | Thermal insulation mortar   | W-shaped FRP tendons    | Vertical and horizontal arrangement |
| 8                | 70                              | Thermal insulation mortar   | FRP plate fastening piece | Plum arrangement      |
| 9                | 90                              | EPS                         | FRP plate fastening piece | Vertical and horizontal arrangement |

The load-deflection curves comparison between model 6-8 and model 1 are shown in Figure 3.

It can be seen from figure 3(a) that the deflection of the model 6 is different from the growth trend of the model 1 as the load value is increased, but always greater than the deflection produced by Model 1. Under the design load, the deflection value is 1.3mm, and under the maximum load, the deflection value is 32.1mm, which is 24% and 19% higher than that of Model 1 respectively. It can be concluded that the mechanical properties of EPS insulation board is worse than that of the inorganic insulation mortar board, but under a certain external load, the phase difference is not very large, and the deflection value generated under the design load is also meet the requirements. Therefore, for the non-load-bearing peripheral protective wall, when the thermal insulation performance of the wall needs to be considered, the organic material with better thermal insulation performance is used as the thermal insulation layer, while improving the insulation performance of the wall, and the overall force...
performance of the wallboard can be met.

It can be seen from Figure 3(b) that the deflection generated by the model 7 during the load growth process is always smaller than the deflection generated by the model 1. Under the design load, the deflection generated is 0.8 mm and at the maximum load, the deflection generated is 22.2 mm, which is 24% and 14% lower than that of Model 1. When using lattice W-shaped fastening piece, if the fastening pieces and the concrete are well restrained and there is no relative slip, the lattice connectors are better than the plate fastening pieces in improving the overall mechanical properties of the wall plates.

It can be seen from Figure 3(c) that the deflection generated by the model 8 during the load growth process is not much different from the deflection produced by the model 1. Under the design load, the deflection value produced is 1.4 mm, which is 21% higher than that of Model 1. When the load is at its maximum, the deflection is 26.1 mm, which is basically the same as Model 1. The fastening pieces arranged in a plum blossom shape do not improve the overall mechanical performance of the prefabricated sandwich wallboard. It can be concluded that the effect of the plum blossom arrangement and the staggered arrangement of the fastening pieces on the overall mechanical performance of the wall panel is not much different.

In order to analyze the influence of the increase of EPS plate thickness on the mechanical performance of the wall, the thickness of EPS plate in the insulation layer of the wall model is increased to 90 mm. At this point, the displacement and stress cloud diagram of the wall model under the maximum load is shown in figure 3(d). Under the maximum load, the midspan deflection of the bottom of the wall slab with two thicknesses is 32.1 mm and 27.0 mm respectively, and the deflection is reduced by 15%. Therefore, when the thickness of EPS board in the prefabricated sandwich insulation wallboard increases within a certain range, it is of great help to improve the overall mechanical properties.

5. Conclusion
In this paper, we established a finite element model of PRCSIW by ABAQUS. Utilizing this model, the influences of insulation layer thickness, insulation layer type, fastening piece type and fastening piece distribution mode on the mechanical properties of the wall was analyzed. In a certain range, the increase of the thickness of the insulation layer of the sandwich wall is beneficial to improve the mechanical performance of the wall. The wall possesses basically identical mechanical performance when the fastening pieces are arranged in a comprehensive staggered way or in the shape of a plum pattern. After replacing the fastening piece with the lattice type W-shaped fastening piece, the mechanical properties of the wall have been improved to some extent. Application of EPS as insulation material increases the deflection of the sandwich wall, which however still meets the requirements of the code under the presence of design load. According to the above results, insulation materials with both good thermal and mechanical properties, and proper fastening pieces, are two considerable directions for the optimal design of PRCSIW.

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