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The Design of Prefabricated Thermal Insulation Infilled Wall System with Hollow Structure and Its Construction Method’s Research

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Abstract: In view of the problems existing in the filled wall system of the frame structure at present and combining with the technical requirements of the prefabricated building pushed by the state, this paper puts forward a kind of prefabricated infilled wall system with hollow thermal insulation. The main research contents include the structural design of the prefabricated infilled wall, the connection design between the infilled wall and frame beam and column, and the construction technology research of the prefabricated infilled wall system, which makes the fabricated infilled wall system studied have good insulation, heat insulation and sound insulation performance, as well as good seismic performance, thus possessing applicable value in engineering.

1. Introduction
As an important part of the building envelope system, the infilled wall has a significant impact on the building's energy conservation and insulation. On the other hand, the influence of the infilled wall on the seismic performance of the frame structure cannot be ignored. On the construction market at present, most of the frame structure infilled walls are built up with some small hollow blocks or porous brick masonry and connected with the main structure by setting up tie bars, ring beams and structural columns [1], which has serious defects in energy-saving, thermal insulation, seismic performance and construction performance. From the perspective of building energy conservation and insulation, enclosure structure especially the infilled wall system, is a key link affecting the energy-saving insulation of buildings. However, most of the existing masonry and masonry materials cannot meet the requirements of the energy-saving insulation of walls that additional insulation treatment is required on the wall surface [2]. In terms of seismic performance, the tensile, shear and flexural strength of masonry infilled walls are low [3], which is not conducive to structural seismic resistance and masonry infilled wall is rigidly connected with the main frame structure of building which will produce constraint effect and stiffness effect that might make the building structure appear seismic weak parts [4], thus seriously affecting the seismic performance of the building structure. From the aspect of construction performance, pilling up masonry is time-consuming and laborious, with high labor cost but low construction efficiency, which does not meet the requirements of China's construction industrialization. Moreover, serious waste of resources still exists in the construction process of masonry infilled wall’s built, which is contrary to the requirements of green building [5].

In summary and combing with a series of advantages of fabricated building, especially the
fabricated infilled wall system [4], it is necessary to develop and design a new type of prefabricated infilled wall system to improve the current situation. The author considers comprehensively the insulation performance of the infilled wall and the seismic performance of the infilled wall system, and made innovative design of the structure form of the wall, so that the precast infilled wall has good insulation and sound insulation performance. The anti-seismic capability of the frame infilled wall system is improved by greatly reducing the weight of the wall itself and adopting flexible connection technology.

2. Structural design of prefabricated infilled wall

2.1 Design principles

The following principles should be followed in the design of the new fabricated infilled wall system [6]: (1) The precast wall should have reliable connection between all parts of materials and simple construction and easy to be manufactured. (2) The precast wall should have good insulation performance and achieve the goal of structural insulation integration. (3) The prefabricated infilled wall system should have good seismic performance.

2.2 Mechanical design

There is a built-in hollow insulation box in the precast infilled wall to achieve the goal of structural insulation integration. The hollow insulation box is made of waste plastics and the interior of the box is divided into several hollow cavities evenly and vertically with dry air and desiccant in it, so as to enhance the rigidity of the infilled wall. Due to the thermal conductivity of airtight air is quite small, only 0.023 W/(m•k) [7], therefore, it can be considered that the hollow insulation box’s thermal insulation performance is pretty good.

The left and right sides of the box are concave to form a groove to strengthen the bonding with concrete, and the dampers are installed in the groove that the dampers can have enough working distance in the limited distance between the infilled wall and the frame column. Four plastic cushion blocks are bonded on each side of the box (or formed integrally with the box body) on the contact surface with the concrete, and there is a channel in the middle of each cushion block which can be interspersed with reinforcing bars. The organigram of this hollow insulation box (without top cover plate) is shown in figure 1.

![Figure 1. Organigram of hollow insulation box construction without top cover plate.](image)

Two edge horizontal reinforcing bars are interspersed between the channels of the plastic cushion blocks on the two sides of the hollow insulation box, then binding the vertical reinforcing bars on the two horizontal reinforcing bars. Attention should be paid here, the distance between the edge of the channel on the cushion block and the edge of the cushion block should be less than or equal to the diameter of the vertical reinforcing bar, so as to ensure that the steel mesh does not deform when the steel mesh is tied on the vertical reinforcing bars, thereby affecting its working performance. After the vertical reinforcing bar is tied, the intermediate horizontal reinforcing bar should be tied on the inner side of the vertical reinforcing bars, then bending the horizontal reinforcing bars to a certain angle in the groove at the edges of the box (so that the dampers can have sufficient working distance in the
limited distance between the infilled wall and the frame column). Then welding the horizontal reinforcing bars on both sides of the box and the dampers together to form a three-layer framework of steel reinforcement with dampers on both sides, after that, two short vertical reinforcing bars should be welded together on each side of the framework of steel reinforcement to limit its vertical displacement. At the top of the box, short reinforcing bars are welded between each two corresponding vertical reinforcing bars and hoisting rings are welded on them. The organigram of the hollow insulation box, dampers and the reinforcing bars is shown in figure 2.

Figure 2. Organigram of the hollow insulation box, dampers and the reinforcing bars.

After the framework of steel reinforcement is made, the layer of steel wire mesh should be tied on both sides of the framework of steel reinforcement to enhance the bond between the hollow insulation box and the concrete. After the above steps are completed, the concrete can be poured. Special attention should be paid to the location of the bottom of the infilled wall when pouring concrete, because there are holes reserved for positioning during construction hoisting. The organigram of holes reserved at the bottom of the infilled is shown in figure 3.

Figure 3. Organigram of bottom construction of precast infilled wall.

This new type of fabricated infilled wall is made of foam concrete. The foam concrete and the hollow insulation box can provide good thermal insulation and sound insulation performance of the infilled wall. At the same time, the weight of the foamed concrete itself and the air inside the hollow insulation box are lighter, the dead weight of the fabricated infilled wall has also been greatly reduced, which is beneficial to reduce the earthquake action of the frame construction. The schematic diagram of the new type of fabricated infilled wall is shown in figure 4.

Figure 4. Overall effect diagram of the fabricated infilled wall.

3. Connection design of the fabricated infilled wall and the frame beam and column

The new fabricated infilled wall system adopts the following flexible connection method:

① The upper side of prefabricated infilled wall is completely separated from the upper frame
beam.

② The two sides of prefabricated infilled wall are connected with the frame columns through dampers. One end of the dampers is fixed on the framework of steel reinforcement inside the infilled wall, and the other end is fixed with the built-in fittings on the frame columns through bolts. At the same time, the distance between the two sides of the infilled wall and the frame columns is kept no less than 20 millimeters, and polystyrene foam lath or polyurethane foam material is filled in the gaps.

③ The bottom of the infilled wall is connected with the lower frame beam by mortar.

The schematic diagram of the connection structure between the frame beam and column and the infilled wall is shown in figures 5 to 7.

Figure 5. Schematic diagram of concrete frame construction.

Figure 6. Overall effect diagram of concrete frame and the filled wall.

Figure 7. Detail drawing of frame column and infill wall connection structure.

4. Key construction technology of new fabricated infilled wall system

4.1 Fabrication technology of precast infilled wall

The key to the fabrication of the prefabricated infilled wall lies in the fabrication of the hollow insulation box. In order to ensure the best thermal insulation effect of the hollow insulation box, the working environment should be kept dry in the factory, and the drying agent should be put into the box to ensure the dryness of the air inside the box. The process flow chart of the precast infilled wall is shown in Figure 8.
4.2 Key construction technology of new fabricated infilled wall system

The construction of fabricated building has the characteristics of factory production of components, on-site assembly construction, high utilization ratio of machinery and low labor intensity. The fabricated infilled wall system studied in this paper not only has the advantages of the above-mentioned fabricated building, but also fully considers the structural characteristics of the new system itself, and forms a set of construction technology suitable for the fabricated infilled wall system of frame structure. The concrete steps are as follows.

Step 1: Laying the mortar layer on the bottom frame beam.
Step 2: Hoisting the precast infilled wall with the lifting ring to make the reserved holes in the lower part of the wall panel fit firmly with the embedded steel nails on the lower frame beam and making the dampers’ end fit firmly with the embedded parts on the frame columns, and fix them with nuts.
Step 3: Hoisting the frame beam and make it reliably connected with the frame columns.
Step 4: Filling the polyethylene or polystyrene foam board between the infilled wall and the frame columns and the upper frame beam, and use the building sealant to do the sealing treatment.

5. Technical analysis

5.1 Analysis of construction performance

The construction of the traditional masonry infilled wall often includes setting-out positioning, mixing mortar, brick masonry, reinforcing bar implantation, concrete pouring and other steps which has the complex construction process and the difficult operation. For example, when brick masonry, the modulus requirements of masonry and mortar joint should be strictly followed, and at the same time, the reasonableness of bond patterns also should be ensured. It can be seen that the construction of traditional masonry infilled wall is not only complicated in process and steps, but also requires workers to have a good level of skills. As a result, it has a great dependence on professional masonry workers, so it is difficult to guarantee the construction quality of the wall.

The components of this new fabricated infilled wall system are prefabricated in the factory and assembled at the construction site. The production processes of the prefabricated components are simple, easy to be operated, and low in skill level of workers. The construction method of assembly construction is characterized by low technical content, low labor intensity, fast construction speed, little influence by human factors and easy guarantee of construction quality.
In conclusion, the new type of prefabricated infilled wall system has obvious advantages in construction performance.

5.2 Mechanics property analysis
On the one hand, this new type of prefabricated infilled wall system connects the infilled wall and the frame column through the dampers, and sets a certain distance to make the system not only has a good energy dissipation capacity under earthquake, but also can maximally ensure that the infilled wall does not produce cracks under earthquake, so as to achieve the effect that the infilled wall is not affected by earthquake. On the other hand, due to the innovative construction of the new type of prefabricated infilled wall, the dead load of the wall is greatly reduced, thus greatly reducing the seismic effect of the structure. Therefore, the new type of prefabricated infilled wall system has good mechanical properties, and successfully avoids a series of problems of the traditional masonry infilled wall system under seismic force.

5.3 Physical performance analysis

5.3.1 Analysis of sound insulation performance. From the perspective of architectural acoustics, existence of the air layer will increase an additional sound insulation for the wall. When the thickness of the wall is below 80 millimeters, the larger the air layer is, the greater the sound insulation is. At the same time, the enclosed air layer makes the concrete layer on both sides form a double-wall structure, and the elastic deformation of the enclosed air layer will weaken the vibration of the inner page wall after being subjected to acoustic wave action, so as to improve the overall sound insulation of the infilled wall. Therefore, the new type of prefabricated infilled wall system has good sound insulation performance.

5.3.2 Analysis of thermal insulation performance. On one hand, this new prefabricated infilled wall adopts the construction form of built-in hollow insulation box to form a closed air layer inside the wall whose thermal conductivity is only 0.023 W/(m•k) \(^7\). On the other hand, the concrete layer of this infilled wall adopts foam concrete with self-insulation effect, which further strengthens the insulation performance of the wall. Therefore, the new type of prefabricated infilled wall system has good insulation performance.

6. Conclusions
Aiming at the problems of complicated construction, time-consuming, high dead weight, low heat preservation and sound insulation performance of the existing masonry infilled wall system, this paper optimizes the design of the existing masonry filling wall structure and puts forward a new infilled wall system which can be applied to fabricated buildings. At the same time, the structure form, connection technology and construction technology of this new type of prefabricated infilled wall system are also studied in this paper. The main conclusions are as follows.

(1) The prefabricated infilled wall is constructed with a built-in hollow insulation box, using closed air for insulation and sound insulation. At the same time, the thermal insulation and sound insulation properties of the foam concrete are also used to achieve the structural insulation integration. Theoretically speaking, it has good thermal insulation, heat insulation and sound insulation properties, and the thermal conductivity of the wall can be reduced to below 0.023W/(m•k).

(2) The new type of prefabricated infilled wall system adopts the method of flexible damping connection that effectively avoids the poor seismic performance and a series of problems caused by the restraint effect and stiffness effect of the traditional masonry infilled wall system, and improves the aseismic capability of the prefabricated infilled wall system of frame structure.

(3) Comparing with the traditional masonry infilled wall system, the new prefabricated infilled wall adopts the technological process of factory preproduction and field assembly construction, which has the advantages of rapid construction, few construction personnel, low technical content, low labor
intensity, little influence by human factors and easy guarantee of construction quality.

In summary, the prefabricated thermal insulation infilled wall system with hollow structure has practical engineering value and broad prospect.

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