Static Performance Analysis of Special-Shaped Lightweight SI Floor Slab

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Abstract. The special-shaped lightweight SI (skeleton and infill) floor structure studied in this paper is a kind of space reserved in the structure of the structure, and there is no need to erect a cavity in the later decoration process to realize the structure and the A new type of fabricated floor with separation of pipelines. In order to study the force mechanism and influencing factors of this new structure, this paper uses Midas FEA finite element software to analyze the deformation and stress of the structural element, and studies the influence of the number of slots and the size of the slots on the static performance of the structure. The analysis results show that the new floor slab performs well in static performance and can achieve a larger space span; under the premise of ensuring the same capacity, increasing the number of wire ducts and reducing the size of the wire ducts can effectively solve the stress concentration in the middle of the floor slab. Phenomenon, and improve the rigidity of the structure. The result of the parametric analysis is: the best structural layout is based on the transverse central axis, with 2 wire slots reserved on the upper board, 3 wire slots reserved on the lower board, and the specification of the wire slot is 70mm × 50mm × 20mm.

1. Introduction
Prefabricated building is to manufacture prefabricated components such as concrete walls, beams, plates and columns in the production workshop, and then transport the prefabricated components to the construction site for assembly [1]. Under the background of national policies to vigorously promote the industrialization and intellectualization of construction, the market scale of prefabricated building in China has been expanding in recent five years. Compared with China, prefabricated buildings in the United States, Japan, and some developed countries in Europe developed earlier, the Prefabricated and prestressed Concrete Association (PCI) in the United States has prepared the relevant design manuals and specifications; Japan has formulated a series of policies and standards in the field of prefabricated housing, which solves the contradiction between standardization, mass production and diversified demands. In Britain, Germany, after world war ii began to study to explore the construction mode of industrialization, actively promote precast construction way of design and construction, accumulated a lot of prefabricated building design and construction experience [2-4], and compiled a series of precast engineering standards and application manual, to promote the application of prefabricated building in the world plays a very important role in [5].

As a horizontal bearing component of the structure, the main function of the building floor is to transfer the vertical load of the floor to the beam and column, which plays an important role in the overall structure. At present, there are some common problems in the common triangular truss
composite floor: first, the traditional prefabricated floor can not realize the separation of pipeline and structural layer, which leads to problems such as untraceable, unreformed and uninspected. Second, the traditional prefabricated floor slab is very large, which greatly limits the span. The special shaped lightweight SI floor slab studied in this paper has light and lighter dead weight, which can achieve a large span. The groove position of the plate body is used for the installation of house pipelines and electricity in the later stage, which really realizes the separation of pipelines and structure, facilitating the replacement and maintenance in the later stage. At the same time, the mechanical properties can be compared with the traditional concrete floor slab. Effectively solve the existing pain points in the assembly industry [6-8].

2. Structural Element Construction

As shown in figure 1 below, the special-shaped pipeline separated lightweight floor slab reserved space for pipeline installation in the later stage in the structural layer. The floor slab was prefabricated on the die table and shaped into grooves through the die. The lower part of the slab was equipped with steel bars to bear the tensile stress of the structure, and the steel bars extended 50mm out of the plate body to connect the two plates in the later stage. The concrete used in this structure is lightweight foamed fiber concrete. The bulk density of C20 grade concrete is about 1500kg/m³, 0.6 times that of traditional concrete of the same grade. On the premise of ensuring the strength of the structure, the dead weight of the structure is reduced to achieve a larger span.

![Figure 1. Schematic diagram of floor unit.](image)

3. Establishment and Analysis of Finite Element Model

3.1. Finite Element Model

As shown in figure 2 below, the structural size of this model is 5000mm×2500mm×100mm, and the section of the reserved pipe groove of the plate body is an isosceles trapezoid of 90mm×70mm×25mm, which is the maximum size of the line groove commonly used in the market. According to the capacity of the cable groove of this model (20 8-core network cables can be placed), a cable groove is set on the upper surface of the model and two on the lower surface for simulation analysis. The strength grade of foamed concrete used in the model is C20, the elastic modulus is 25000Mpa, and the tensile strength is 1.88mpa.

The steel bar is C8HRB400, the longitudinal bar at the slot is encrypted, the bar spacing is 150mm, and the rest are 200mm.

The total strain crack model of concrete and von-Mises model of reinforcement were used in this finite element simulation. Without considering the restriction of floor ring beam, the boundary condition adopts four sides hinged support. According to the Code for Load on Building Structures [9], the standard live load value of civil residential buildings is 2.0kN/m², the coefficient of constant load is 1.3, and the coefficient of live load is 1.5. Considering the dead weight of the structure, the
uniformly distributed load of the converted floor is 9.1kN/m². In order to understand in detail the mechanical characteristics of the floor slab at each stage, the load is divided into 15 levels for loading. The size of the element mesh is 50mm.

3.2. Analysis of Calculation Results

3.2.1. Deformation Analysis

Based on the above model, the vertical deformation of special-shaped lightweight SI floor slab in the elastic-plastic yield stage was studied, and the analysis results are shown as follows.

As shown in figure 3, the maximum vertical displacement of the model element occurs in the middle of the span of the slab, the maximum displacement is 9.493mm, and the flexion-span ratio is 1/555, which far meets the requirements of 10/250=20mm in the design code of concrete structure, indicating that the new slab has relatively large vertical stiffness. A large space span can be achieved without increasing the thickness of the structure.

3.2.2. Stress Analysis

Based on the above integral finite element model, the stress of the concrete floor slab and the steel bar in the slab are studied respectively under the condition of normal use to make the structure yield.
Figure 4. Von -Mises stress cloud diagram of concrete.

As shown in figure 4, there is no obvious stress concentration in the upper concrete, and the larger stress is mainly distributed at the edge of the plate, namely the support position. The two ends of the slot along the longitudinal extension of the plate, there is a small range of stress concentration, because the concrete has been partially weakened, and the pressure from the support so there is a small range of stress concentration phenomenon. The maximum von-mises stress at the stress concentration was 8.426Mpa, which was lower than the design value of C20 concrete strength and belonged to the safe range.

Figure 5. Stress diagram of reinforcement element.

As shown in figure 5, since the size of the unit plate in this model is one-way plate, the stress of the transverse reinforcement under the simulated load is large, mainly concentrated at the transverse support and the middle of the transverse span. The maximum stress of the reinforcement is 377Mpa, which does not reach the critical yield stress of HRB400 reinforcement. And in the actual process of application, two adjacent floor slabs will be jointed processing, the actual working state should be another mode between one-way plate and two-way plate, so the actual stress state of steel bars is more uniform, the stress of transverse steel bars is less than the result of finite element simulation. In other words, the floor slab has good bending strength and meets the stress requirements.

4. Parametric Analysis of Static Performance

Further study of the new floor under the load of the mechanical characteristics, through adjusting the number and size of the slot on its parametric analysis, study the impact of structural deformation and stress, obtain the static factors affecting the performance of the structure, to provide a reference for the actual project as shown in table 1 and table 2.

In this part, the grooves selected by modeling analysis are determined according to the commonly used specifications of the grooves in the market, and the number of grooves to meet the actual engineering application as the criterion. In order to make the plate uniform force, the layout of the slot
selection staggered symmetrical layout.

Table 1. Common line groove specifications.

| Model | Size (mm) | Number of 8-core network cables that can be placed |
|-------|-----------|---------------------------------------------------|
|       | Upper bottom | The bottom | High |                                |
| C-1   | 30          | 15         | 7    | 2                                |
| C-2   | 40          | 20         | 10   | 3                                |
| C-3   | 50          | 30         | 15   | 6                                |
| C-4   | 60          | 40         | 15   | 8                                |
| C-5   | 70          | 50         | 20   | 12                               |
| C-6   | 90          | 70         | 25   | 20                               |

Taking the capacity of 60 8-core network cables as the standard, wire slots of different specifications are selected for combination, and a model is established for analysis.

Table 2. Trough combination.

| Serial number | Combination | Capacity | Slot number |
|---------------|-------------|----------|-------------|
| ZH-1          | C-6x3       | 60       | 3           |
| ZH-2          | C-5x5       | 60       | 5           |
| ZH-3          | C-4x4+C-5x3 | 68       | 7           |
| ZH-4          | C-3x5+C-4x4 | 62       | 9           |

The finite element model was established and the analysis results were plotted as follows:

Figure 6. Vertical displacement curve.

Figure 7. Von-Mises stress curve.

Figure 8. Reinforcement stress curve.
It can be seen from figure 6, 7 and 8 that the vertical displacement of floor slab, von-Mises stress and stress of reinforcement element all showed a decreasing trend with the decrease of the number of grooves and the size of grooves. The increase of the number of grooves makes the stress evenly distributed to both sides, and the vertical displacement of the plate body tends to ease. The reduction of the size of grooves makes the concrete weaken less and the bending resistance is improved. Compared with ZH-1, the vertical displacement, von-Mises stress and reinforcement element stress of ZH-2 were significantly reduced. The vertical displacement decreased by 65.55%, the von-Mises stress and the reinforcement element stress decreased by 43.69% and 57.53%, respectively. The simulation results show that the five grooves effectively disperse the stress of the structure and improve the stiffness of the structure obviously.

In conclusion, under the condition of ensuring the same standard capacity, increasing the number of grooves and decreasing the size of grooves can effectively improve the vertical stiffness and stress distribution of the structure. Combined with the actual engineering application, the ZH-2 combination is the most reasonable structural layout, that is, based on the horizontal central axis, two grooves are reserved for the upper plate surface and three for the lower plate surface. The specifications of the grooves are 70mm×50mm×20mm.

5. Conclusion

- The special-shaped lightweight SI floor slab has good structural stiffness and the stress concentration mainly occurs at the mid-span weakening;
- The stiffness and bearing capacity of the structure are negatively correlated with the number and size of grooves. Increasing the number of grooves and reducing the size of grooves can make the stress more evenly distributed, the vertical displacement of the plate body more relaxed, and the bending resistance improved;
- Under the condition of the same pipeline capacity, the combination ZH-2 structure is the most reasonable and conforms to the practical engineering application.

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