Experimental Analysis and Research on New Concrete Multi-ribbed Beam Hollow Floor

Wang Dunqiang¹, Li Jingyu¹

¹School of Civil Engineering, Shandong Jianzhu University, Jinan 250101, China
Corresponding author’s e-mail: jingyuli1993@163.com

Abstract. The new concrete ribbed beam hollow floor cover based on the two-way ribbed beam is suitable for projects with large loads or large spans on the upper part. This paper mainly introduces the characteristics and composition of concrete ribbed beam hollow floor, collates and analyzes the test data obtained from the static loading test of the floor, obtains the structural performance of the test piece, and obtains the vertical overall displacement of the floor. The vertical displacement of the mid-span and the development of the crack, the ultimate bearing capacity of the hollow slab with the rib beam is obtained through the failure test. Under the normal load, the new ribbed hollow floor has good integrity. It is concluded that the hollow ribbed hollow floor cover has the characteristics of large bearing capacity and good overall rigidity.

1. Introduction
Compared with other structural forms of the floor, the new ribbed beam hollow floor has the advantages of beautiful appearance, high clearance efficiency, lightweight, easy factory processing and low material consumption. Under the premise of reducing the weight of the floor, the hollow floor cover technology can continue to maintain the rigidity and strength of the floor. It is a major innovation in the field of building structure in China and has potential social and economic value. In recent years, the use of new types of concrete ribbed girder hollow floor building forms has increased, such as underground parking lots, shopping malls, office buildings, schools and other buildings, while the application area of hollow floor covers has gradually increased [1].

2. Brief description of the new concrete ribbed beam hollow floor

2.1. Basic composition
The cross-section of the new concrete ribbed beam hollow floor is made of I-shaped section, which is made up of prefabricated hollow box, post-cast rib beam and top plate [2]. The hollow floor cover and the traditional ribbed beam cover use the same force system, but the new two-way ribbed beam hollow floor cover adds a bottom plate [3].

There are various forms for setting the box size of this new type of hollow floor. According to the actual needs of the upper load and the span of the floor, the appropriate height of the box is selected between 1.8 and 14 m. This box is not only a component, but also the side mold of the bottom of the floor and the side dies of the ribs [4], wherein the width of the ribs ranges from 100 to 150 mm. The thickness of the prefabricated base plate is set to 30 mm regardless of the force. The ribbed beam hollow floor slab should be combined with the rib beam ribs around it to calculate the force of the corresponding bottom plate extension ribs.
3. Test plan

3.1. Test equipment
The loading equipment mainly uses pressure sensors and one hundred tons of jacks; the strain gauges of steel and concrete in the test are B×120-1AA and B×120-100AA respectively; the strain gauge data is collected by the static strain device of model DH3816N; The displacement of the test piece was measured by an electronic dial gauge with a numerical interval of 0-100 m; the crack of the test piece was measured using a professional test device of the ZH7293 model.

3.2. Related parameters and design of the test piece
The planar dimensions of the prototype specimen are 6.84m×6.84m, and the dimensions of the hollow floor specimen are 3.42m×3.42m, which is simplified by the scale of the prototype specimen. The entire hollow floor is divided by the rib beam into the area shown in Figure 1, and the undivided position is in the form of a cast-in-place solid board.

The thickness of the floor cover of the test piece is 200mm, and the height of the combined box is 160mm. The prefabricated base plate is 25mm thick. The corner column has a cross-sectional dimension of 340 mm × 340 mm and a column height of 1200 mm. Ensure that there is at least one longitudinal rib in each rib to facilitate the lashing of the stirrups in the rib [5]. The specimen size chart and the component reinforcement diagram are shown in Figure 2-3.

![Figure 1](image1.png)
Figure 1. Plane dimensions of the test piece and the layout of the hollow box

![Figure 2](image2.png)
Figure 2. Rib beam reinforcement diagram

![Figure 3](image3.png)
Figure 3. Corner column reinforcement diagram
3.3. Material performance indicators

3.3.1. Material properties of steel bars. The tensile test of the steel bars of different diameters is carried out [6], and the average value of the yield strength and ultimate strength of the steel bars is calculated as the final measurement result. The specific data are shown in Table 1 below.

| Reinforced category | 14   | 12   | 10   |
|---------------------|------|------|------|
| Yield Strength/MPa  | 506.0| 484.0| 441.0|
| Ultimate strength/Mpa | 629.0| 624.0| 614.0|
| Elongation/%        | 23.56| 30.01| 32.02|

3.3.2. Material properties of concrete. For the 150 × 150 × 150 standard cubic concrete produced on the same batch of concrete, the measured compressive strength $f_{cu}$ and compressive strength standard value $f_{cu.k}$ of the cube are tested by test equipment. The specific result data is shown in Table 2 below.

| Concrete strength | $f_{cu,k}$/MPa | $f_{cu}$/MPa |
|-------------------|----------------|--------------|
| C30               | 40.04          | 26.78        |

3.4. Displacement test test point arrangement

In this test, the test piece and the loading are symmetrical, and the test points can be arranged only in the quarter area, and the other areas are only arranged with important control points for checking [7]. In order to obtain the relationship between the load deflection curves in the test of the hollow floor, the arrangement of the displacement meter is shown in Figure 4.

![Figure 4. Test piece displacement meter layout](image)

3.5. Loading methods and systems

3.5.1. Test method. The four main loads are placed around the center of the test piece to set the static loading mode. The center point of the test piece is taken as the coordinate origin, and the coordinate positions of the four points are (-270, -270), (270, -270), (-270, 270), (270, 270), in mm. The load procedure of this experiment is divided into two phases: the preload phase and the formal loading phase [8].

3.5.2. Arrangement of measuring points of steel strain gauges. The number of the measuring point of the specific strain gauge is shown in Figures 5 - 6 below.
3.5.3. Concrete strain gauge measuring point arrangement. The specific strain gauge measurement points are shown in Figures 7 and 8 below.

4. Test results and analysis

4.1. Test phenomenon

4.1.1. Test phenomenon during normal use. The division of the bottom plate is shown in Figure 9.

The phenomenon is as follows:

There was no phenomenon after the first stage was loaded. As the load was applied to 10 KN, a 45° angle crack appeared on the plate 3 and the plate 19, and the crack spread from the center of the plate to the periphery, and was not found on the other plates. Continue to load to 15KN, the crack begins to extend, and a slight crack perpendicular to the direction of the rib beam appears for the first time in the plate 3. When loaded to 20 kN, the cracks appearing in the plate 3 began to extend toward the plate angle, the width was 0.2 mm, and new cracks were found in the plate 3. A slight extension of the micro cracks in the direction parallel to the rib beam in the slab 4, the slab 16 and the slab 16 is observed, and cracks of about 15 cm in length are found on the slab 11, the slab 19, and the slab 21. Continue to load to 25KN, visible cracks can be seen on the bottom plate, the largest rib beam crack width is 0.05mm. The cracks of the first cracked plate 1 and the plate 3, the plate 19 and the plate 21 are widened and extended as the load is applied, and the width is increased to a maximum of 0.4 mm.
It can be seen from the test phenomenon that under the normal load, the cracks of the ribbed beam are mainly found on the rib beam and the prefabricated floor, and are not at the joint of the prefabricated floor and the rib beam, indicating that the joint can be reliably connected, the floor cover is better overall.

4.1.2. Test phenomenon in the destruction stage. Adding the load to 50 KN reveals that the crack in the plate 19 extends continuously to the intersection of the rib beam and the plate. When loaded to 75KN, the crack at the bottom of the prefabricated plate continues to grow and new cracks appear perpendicular to the rib beam. When loaded to 100KN, the new crack continues to increase and prolong, but the horizontal crack at the junction of the bottom plate and the cast-in-place rib beam is still in a stable state. When loaded to 125KN, the vertical crack continues to increase. Although the oblique crack at the intersection of the rib beam and the bottom plate does not continue to develop, the crack width at the bottom of the plate continues to increase. Loaded to 150KN, cracks appear on the solid plate near the support and develop toward the prefabricated floor in the direction of a 45 degree oblique crack, with the maximum crack width increasing to 0.5 mm. When loaded to 175KN, the crack continues to deepen and extend, the vertical crack width reaches 0.8mm, and the four corner cracks extend to the side of the dark beam. When loaded to 200KN, the cracks of some rib beams and adjacent plates appear to pass through. When loaded to 225KN, there is no damage at the joint between the plate and the rib beam. The damage is caused by the pressed concrete around the distribution beam, and some of the rib beams between the adjacent plates are sheared and the test is terminated.

4.2. Analysis of results

4.2.1. Analysis of load deflection results. According to the actual measured deflection value of the measuring point, draw the load-deflection curve and the comparison chart of the two measuring points of 9, 10, as shown in Figure 10 and Figure 11 below:

As can be seen from the graph analysis, the shape of the prefabricated floor and rib beam and the shape of the parabola are nearly identical, and the overall vertical displacement of the concrete ribbed hollow floor is roughly in the shape of a bowl [9]. From the comparison of the two measuring points of 3.3W9 and W10 in the above figure, it can be seen that the shape of the cast-in-place rib beam and the prefabricated bottom plate are consistent at the intersection, indicating that there is a certain cooperation ability between the two. When the load reaches 150KN, the deflection value of the mid-span of the floor can reach 10.90mm < L0/200=15.4mm, which is not beyond the normal range; when the load reaches 175KN, the deflection can reach a maximum of 17.02mm, has exceeded the normal range. When the load is continuously increased to the limit value of the load, the corresponding deflection value continues to increase, and the maximum deflection is 26.30 mm < L0/50 = 61.6 mm. After the specimen is unloaded and its data is zeroed, certain cracks and deformations will still be found in the specimen, and it is concluded that the specimen has obvious signs of deformation and good ductility in the process of increasing the load [10].
4.2.2. Test results and analysis of concrete strain. The load strain curve is drawn according to the strain values of the concrete 4, 6, 7, and 9 points, as shown in Figure 12-15.

Through the observation and analysis of the above figure, it can be concluded that before the crack of the test piece, the strain change of the concrete located at the mid-span tends to be linear and the increment is small. When the crack occurs in the test piece, the load-strain curve The slope in the tank is significantly increased. When the loading is continued to the ultimate load, the concrete strain on the floor does not reach its ultimate compressive strain. Comparing Figure 13, Figure 14, and Figure 15, it is concluded that the joint force between the prefabricated floor and the cast-in-place rib beam is good and the connection can be reliably connected.

4.2.3. Test results and analysis of steel strain. The load strain curve is drawn according to the strain values of the 3, 5, 4y, and 16y points of the steel bar, as shown in Figure 16-19.

4.2.4. Cracking load value in the test specimen. Through the above test, the description of the position, quantity, distribution state, width and development trend of the crack of the test piece[11], combined with the corresponding crack load method, ultimate load method, load-deflection curve analysis It can
be seen that when the weight of the floor and the weight of the distribution beam are not considered as factors in the test piece involved in the test, the value of the cracking load of the test piece is 25KN, and the value of the ultimate load is 200KN.

5. Conclusion
The conclusions are as follows:
(1) In the initial stage of loading, the test specimens are still in the approximate elastic working process. At this time, the cracks at the prefabricated floor and the cast-in-place ribs are evenly developed, and the cast-in-place roof near the support has a wider width. The large oblique crack indicates that the test piece is subjected to a large force at the four corners, so the reinforcement near the top plate of the support should be reasonably strengthened.

(2) According to the concrete load-strain relationship, the intersection between the cast-in-place rib beam and the prefabricated floor has a certain ability to cooperate and can bear the load together. Through the study of the relationship between load-deflection, it can be concluded that the displacement direction of the prefabricated floor and the cast-in-place rib beam is basically the same when in the vertical displacement, and the precast base and cast in the concrete rib beam hollow floor. The rib beams work together and have good integrity.

References
[1] Huang Jian. Theoretical research and practical engineering analysis of multi-ribbed hollow floor[D]. Shandong Jianzhu University, 2012
[2] ZHOU Xu-hong, CHEN Wei. Study on the stiffness of concrete hollow slab assembled with two-dimensional ribbed concrete[J]. Journal of Building Structures, 2011, (09); 75-83
[3] Wu Fangbo, Wang Youlin. Experimental Research on Hollow Floor of Concrete Multi-ribbed Beam[J]. Journal of Building Science and Engineering, 2006, (01): 1-5
[4] Zhang Huagang, Mark Wei, Lu Yaqin, Tian Zidong. Design and Application of Cast-in-place Concrete Hollow Floors[J]. Journal of Guizhou University of Technology, 2008 (04); 44-50
[5] Wang Jiakai. Experimental Research and Analysis of Assembled Hollow Floor of Concrete Multi-ribbed Beam[D].Master's thesis of Shandong Jianzhu University, 2017
[6] National Standard of the People's Republic of China. Tensile Test Method for Metallic Materials at Room Temperature (GB/T228.2002) [M]. Beijing: China Building Industry Press, 2002
[7] Yuan Qing. Experimental study on structural performance of multi-ribbed hollow floor[D]. Master's thesis of Shandong Jianzhu University, 2016
[8] HUANG Yong, Marc Wei, ZHANG Huagang et al. Research and application of reinforced concrete hollow sandwich panel floor system[J]. Journal of Building Structures, 1997, (06): 55-64
[9] Xie Zunran. Theoretical analysis of steel-concrete composite hollow floor[D]. Shandong Jianzhu University, 2013
[10] Wu Fangbo, Zhang Hang. Experiment on Mechanical Behavior of Concrete Hollow-ribbed Floor with Different Box[J]. Journal of Architecture and Civil Engineering, 2016, (02) 7-14
[11] Zheng Jianjun Wang Dajun. Analysis on crack of cast-in-place dense rib hollow ceiling of a concrete frame [J]. Building structure, 2010, (04): 31-33