Experimental study on static behavior for assembled monolithic reverse-rib slab

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Abstract. In this paper, the static loading test of two assembled monolithic reverse-rib slabs is carried out, and the cracking process, mechanical mechanism and performance under different load combinations are emphatically studied. The test results show that the development of cracks of the assembled monolithic reverse-rib slab is fitted with the characteristics of the two-way plate. The rib beam and the floor slab between the rib beams can work well together, which can meet the requirements of normal use limit and bearing capacity limit.

1. Introduction
The large-scale promotion of prefabricated buildings can effectively improve construction efficiency, shorten construction period, and reduce environmental pollution, which is of great significance for promoting urbanization in China [1-2]. As an important component of the whole building structure system, the floor slab in the building structure mainly bears the vertical load and is an important part of the assembled building [3]. At present, the most commonly used assembled floor slabs are composite slabs, but some problems have been exposed with the large-scale use of composite slabs, such as low prefabrication rate of the slabs, excessive joints between the slabs, and a large number of reserved reinforcements around the prefabricated slab [4-8].

These problems are contrary to the concept of industrialization of buildings, and they also restrict the development of fabricated building [9]. Based on this, this paper presents a kind of the assembled monolithic reverse-rib slabs which is composed of ribbed beam and multi-ribbed hollow slab composed of rib beam grid. The rib beam is on the upper part of the district slab, and the reinforced bar is arranged in the compression zone to reduce the area of the concrete. It can effectively reduce the quality of the floor, because only the rib beam is connected with the surrounding components. It can directly reduce the floor reinforcement rejection and improve the connection efficiency.

In order to study the load-bearing performance test of the four-sided fixed support of the assembled reverse rib floor slab, the full-scale static load test of the two assembled reverse rib slabs was carried out to study the deflection, steel strain and crack development under static load, and to analyze the force performance under the combination of load standard and basic load.

2. Overview

2.1. Specimen design
The dimensions of the assembled reverse rib floor slab specimens in this study are based on the design of an open room in an ordinary family home. The dimensions are 3400 mm × 4300 mm, the rib height
is designed to be 180 mm, the rib width is designed to be 150 mm, and the rib beam is square. The rib beam spacing (the distance between the central axes of the rib beams) is 860 mm, and the thickness of the rib beam panel is 50 mm. See table 1 for the specimen’s parameters.

**Table 1. Specific parameters of the specimens.**

| Specimens number | Prefabricated reverse rib floor slab size (mm) | Post-casting strip width (mm) | Floor name size (mm) | Rib form | Boundary conditions |
|------------------|---------------------------------------------|-----------------------------|---------------------|----------|---------------------|
| FL-1             | 4300×3400                                   | 500                         | 4500×3600           | prefabricated part | The prefabricated part is free of stirrup, and the rib beams and plates are prefabricated by the additional steel bars and the surrounding beams. Only the rib beam is cast, and the edges of the four corners of the slab are integrally prefabricated by the additional steel bars and the surrounding beams. |
| FL-2             | 4300×3400                                   | 500                         | 4500×3600           | prefabricated Rib beam | |

In order to ensure that the assembled anti-ribbed floor can be reliably anchored into the support, and it is convenient to simulate the boundary conditions of the four-sided fixed support, after the prefabricated component is completed, the member is poured into the 300 mm support side beam, and at the same time, in order to prevent the four corners of the floor early cracking, pouring concrete on the four corners of the floor and arranging the steel mesh at the four corners, as shown in figures 1 and 2.

### 2.2 Material mechanical properties

The type of reinforcement used for the specimen is HRB400, and the measurement method is based on GB228.1-2010 "Metal material tensile test method at room temperature". The measured values of steel bar strength are shown in table 2.

**Table 2. Measured values of steel bar strength.**

| $D$ (mm) | $f_y$ (MPa) | $f_u$ (MPa) | Elongation (%) |
|----------|-------------|-------------|----------------|
| 8        | 477         | 600         | 23             |
| 10       | 443         | 616         | 23             |
| 14       | 462         | 631         | 24             |

The concrete strength grade of the assembled reverse rib floor slab specimens is C30 (this strength is measured according to Chinese specifications), and the measured values of concrete strength are shown in table 3.
Table 3. Measured values of concrete strength.

| Compressive strength (MPa) | Poisson's ratio | Elastic Modulus ($\times 10^4$ MPa) |
|----------------------------|----------------|------------------------------------|
| 32.1                       | 0.3            | 3.0                                |

Figure 1. Specimen FL-1 plan: (a) plan view, (b) 1-1 section.
1- Prefabricated part of floor slab, 2- rib beam area panel, 3-rib beam of the assembled reverse rib floor slab 11- Extension support post post-poured strip.

(a)

1- Prefabricated part of floor slab, 2- rib beam area panel, 3-rib beam of the assembled reverse rib floor slab 11- Extension support post post-poured strip.

(b)

Figure 2. Specimen FL-2 plan: (a) plan view, (b) 1-1 section.

2.3 Test equipment

Figure 3. Test equipment.
The boundary condition of this test is four-sided fixed support. In order to simulate the force of the slab in actual engineering, the boundary condition of four-sided fixed support is realized by the bottom beam-floor-pressure beam mode.

The bottom beam is used, the pressure beam is prefabricated, and the screw is clamped. The form ensures that the bottom beam, floor slab and pressure beam are not closely separated, and the loading device is shown in figure 3. In figure 3, the first diagram is the schematic diagram, and the second diagram is the actual loading diagram.

3. Static test

3.1. Loading test plan
In this test, the weights were piled up. The loaded test blocks were iron and brick, of which the weight of each iron block is 20 kg, and the weight of each brick is 4.2 kg. Since the reverse rib floor slab is applied in practical engineering, the inter-ribbed zone will be filled with lightweight materials. In order to simulate the working state of the actual use of the slab, sand is pre-filled and compacted in the rib beam zone before loading [10]. This is the first stage load and record the data, as shown in figure 4. The number of weight iron blocks arranged in each layer is 98, which is equivalent to a uniform load of 1.34 kN/m² applied to each layer. The loading layout is shown in figure 5.

![Figure 4. Filled the hole with sands.](image1)

![Figure 5. The load layout.](image2)

![Figure 6. Displacement meter layout.](image3)
After each stage loading is completed, it should last for 10 min - 15 min; under standard loads, the duration shall be 30 minutes. During the duration, the occurrence and development of cracks should be observed, as well as the slippage of reinforcement; at the end of the duration, each reading should be observed and recorded.

In order to study whether the rib beam and the rib beam area grid work together, the displacement meter arrangement is shown in figure 6. At the same time, in order to observe the stress of the steel bar in the plate, the strain gauge is attached at the key part, and the arrangement is as shown in figure 7.

![Diagram of displacement meter arrangement](image1)

**Figure 6.** Displacement meter arrangement.

![Diagram of strain gauge layout](image2)

**Figure 7.** Rebar strain gauge layout: (a) slab reinforcement sheet layout, (b) rib beam reinforcement strain gauge layout.
3.2. Failure criteria
According to the research purpose, the signs of normal use of ultimate load and ultimate capacity of bearing capacity are as follows:

One of the following two conditions is met: the normal use limit load is reached:
- the mid-span deflection reaches $L_0/200$ ($L_0$ is the calculated span of the board, and the two-way board is calculated by short span);
- the maximum crack width is 0.2 mm.

One of the following four conditions is met: the bearing capacity limit state is reached:
- the main rib is pulled or strained to 0.01;
- the concrete in the compression zone is crushed or strained to 0.0033;
- the mid-span deflection reaches $L_0/50$;
- the maximum crack width at the main rib is 1.5 mm.

3.3. Data collection
The uniform load value of this test can be directly converted by the weight of the iron block without collecting.

The deflection of the critical point of the test piece and the strain of each measuring point are obtained by connecting the displacement meter and the resistance strain gauge to the UCOM-70A data acquisition analyzer.

4. Test phenomena and results analysis

4.1. Test phenomena
When the test blocks are stacked to 4 floors, the uniform load value is 6.3 kN/m$^2$. When the quasi-permanent combination of loads is reached, the specimen FL-1 is in the elastic stage, but the first crack occurs in the mid-span position of the specimen FL-2, and the crack direction develops along the long-span direction; when the load is added to the fifth layer, the uniform load value is 7.64 kN/m$^2$, and the first long-side crack occurred in the long span of the FL-1 specimen, and the crack was 1500 mm away from the east bearing.

When the load is added to the sixth layer, the uniform load value is 8.98 kN/m$^2$ at this time, and the standard combination of the loads is reached.

The mid-span deflection of the two floor specimens is less than 17 mm ($L_0/200$), and the crack width at the bottom plate is also it has not reached 0.2 mm, indicating that the two slabs meet the normal use requirements under the load of this stage.

When the load continues to be loaded to the 7th floor, the uniform load value of the floor is 10.32 kN/m$^2$ and the basic combination of loads is reached. At this time, the first crack in the FL-1 specimen crosses further and small cracks appear in other parts of the bottom plate, but the crack width is small and does not start to communicate.

The mid-span deflection is 3.86 mm and less than 68 mm ($L_0/50$). The strain of the main rib is 162, and the maximum crack width at the bottom of the plate has not reached 0.2 mm, and the load capacity limit state has not been reached.

FL-2 floor cracks begin to communicate and develop from the middle crack to the four corners, cracks appear in the short span direction, the maximum width of the crack reaches 0.2 mm, reaching the normal use limit state; when the load is added to the 11th layer, the load is applied to 229.3 kN (limit when the bearing capacity calculation value is 55%), the first crack width of the FL-1 specimen reaches 0.2 mm, reaching the normal use limit state.

When the load is fully applied, the load is applied to 342.5 kN (82% of the calculated ultimate bearing capacity), the mid-span deflection of the FL-1 floor specimen reaches 16.85 mm, and the maximum crack width is 1.0 mm; the mid-span deflection of the FL-2 specimen reached 21.8 mm and the maximum crack width was 1.2 mm, which did not reach the limit of bearing capacity.
4.2. Test results
The load-deflection curve of FL-1 specimen and FL-2 specimen is shown in figure 8. It can be seen from the curve that the deflection of the two test pieces is almost the same, indicating that the post-cast concrete rib beam has little effect on the deflection of the floor.

![Load-deflection curve](image)

Figure 8. Load-deflection curve.

![Specimen span - deflection curve](image)

Figure 9. Specimen span - deflection curve: (a) specimen FL-1 span-deflection curve (long span), (b) specimen FL-1 span-deflection curve (short span), (c) test piece FL-2 span-deflection curve (long span), (d) specimen FL-2 span-deflection curve (short span).

Figure 9 is a mid-span deflection curve of the FL-1 and FL-2 specimens. As shown in the figure, under the same load, the deflection of the two specimens increases smoothly along the span direction, and there is no significant change at the intersection between the rib beams and the rib beams, indicating that there is not rib joint between the rib beam and the rib beam.
Due to the intersection of the transverse longitudinal beams, the joint work is affected; the deflection curve develops in a parabolic shape, and the deflection of each measuring point does not change greatly, indicating that the deflection between the beams is not affected by the influence of the surrounding rib beams. The bottom plate between the beam and the rib can work together.

As shown in Figure 10 and Figure 11, the cracks of the specimen FL-1 and FL-2 are not developed in the long-span direction after the first-span mid-span crack develops to a certain extent in the long-span direction, but in the $45^\circ$ direction.

Extending to the four corners of the floor, all the cracks penetrate when the load is fully applied. However, the cracks in the bottom plate of the FL-1 specimen show that the crack spacing is larger and the number is smaller, while the crack in the bottom plate of the FL-2 specimen shows that the crack spacing is smaller and the number is larger.

It can also be seen from Figure 10 and Figure 11 that the crack development of the integrated integral anti-rib floor slab is that the first crack appears parallel to the long side direction in the span, and extends from the mid-span crack to the four corners along the $45^\circ$ direction, and the crack develops. The law conforms to the characteristics of the two-way floor.

![Figure 10. Crack development of specimen FL-1: (a) crack real view, (b) crack detail.](image-url)

![Figure 11. Crack development of specimen FL-2: (a) crack real view, (b) crack detail.](image-url)

The figure below shows the load-strain curve of the steel bar at the typical position of the two specimens.
As shown in Figure 12, the strain of D6 of the FL-1 specimen is not much increased before the crack of the slab. This is because the concrete has not cracked the steel and the concrete works together.

When the slab cracks, the load-strain curve slope changes suddenly, indicating that this when the concrete at D6 exits the work, the stress at this time is all borne by the steel bars.

Under the same load, the strain of the steel increases with the distance of the bearing, which indicates that the span of the fabricated concrete anti-ribbed slab is the largest.

![Figure 12. The load-strain curve of the FL-1 specimen (long span).](image)

It can be seen from the load-strain curve of the rib beam of the FL-2 specimen in Figure 13 that the measuring point L7 is the closest point to the bearing, where the steel strain is the largest and the steel strain is positive, indicating that the rib beam of the floor is close to the branch.

The seat is pulled and the closer to the support, the greater the bending moment. The strain of the steel bar at the measuring point L7 is positive, and the strain of the steel bar at the measuring point L8
is negative, indicating that the rib beam is pulled at L7 without being pressed at L8, and it can be judged that the zero bending moment of the rib beam is located between L7 and L8. Therefore, the negative bending moment area of the slab is taken as 10/5 (10 is the short span), and it is also the lowest value of the negative bending moment steel of the rib beam prefabricated anti-ribbed floor; the measuring point L8 is compared with the measuring point L4 steel strain. Positive value, the measuring point L8 is pulled here, and the negative bending moment moment area of the upper corner of the floor is larger than the middle position.

Therefore, the negative bending moment steel at the four corners should be appropriately lengthened in the design of the floor.

5. Conclusions
In this paper, the static performance test of two assembled monolithic slabs is carried out, and the following main conclusions are obtained:

- under the uniform load, the cracks at the bottom of the slab appear in the span, parallel to the long side direction, and the cracks clearly show the crack characteristics of the two-way plate;
- it can be seen from the deflection curve that the post-cast concrete rib beam has little effect on the deflection of the slab, and the floor between the ribbed beam and the ribbed beam can work well together;
- under the action of the basic combination load, the assembled monolithic reverse-rib slab is assembled to meet the requirements of the normal use limit state and the ultimate bearing capacity state, and can be used for the prefabricated building.

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