Experimental research on the precast concrete slab with additional reinforcement at slab end

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Abstract. In order to study the performance of the precast concrete slab with additional reinforcement at slab end, the vertical monotonic loading test was carried out on four double-span continuous slab specimens. By observing the failures and making a comparison between additional reinforcement end and extended reinforcement end in terms of stiffness and bearing capacity under vertical unidirectional loading, it can be concluded that the bearing capacity of the composite floor slab end with neither protruding rebars nor additional reinforcement is obviously lower, but the additional reinforcement at slab end could evidently enhance the bearing capacity and stiffness, even higher than that of slabs extending rebars into supports.

1. Introduction

Precast concrete slab is the floor bottom formwork for cast in-situ topping during the construction process, then becomes a concrete flexural component together with the cast in-situ topping. It hence has been the most extensively applied prefabricated components.

In aiming at a reliable anchorage of traditional slab reinforcement, longitudinal tensile rebars usually protrude into in-situ joint, which guarantees the requirements of bearing capacity and seismic performance. But the protruding rebars lead to high production cost, can easily be bent during transportation, and lower the hoisting efficiency during construction. In order to avoid all the said disadvantages, a new kind of precast slab with no protruding rebar at slab end was designed. The overlap joints between composite floor slabs without extending reinforcement into the support are recommended in the specification [1] and the National Building Standard Collective Drawing [2], but it is also emphasized that the thickness of cast-in-situ concrete layer is not less than 80 mm. In order to implement the automatic production, a kind of slab without protruding bars or bending the protruding rebars upward (Figure 1) is widely produced in Germany [3]. Figure 2, under DIN, shows a two-way concrete composite slab joint, instead of protruding rebars at slab ends, there are additional reinforcement between slabs [4], but the thickness of the floor is more than 18cm, even up to 25cm, on the contrary, the floor thickness in China is normally less than 15cm, to determine whether such structure is suitable for application and complying with seismic performance requirement in China or not, it requires further research.

Qian Jiaru [5] took a pseudo-dynamic substructure test on a 3-story full-scale model, it is found that precast slabs without protruding rebars at slab ends can also transfer horizontal seismic force effectively, as well as good integrity. It is not necessary for the longitudinal reinforcement of the bottom slab to extend into the support as long as the lab ends have enough bearing capacity. Xu Tianshuang [6] made experiments to explore the details and transmission properties of joints between superposed slabs. The results showed that both the overlapped joints and protruding rebars can transfer
moment, but the flexural capacity of the overlapped joints is a little lower, and that loss could be compensated by increasing reinforcement. Ye Xianguo [7] took experimental research on connection joints between composite floor slabs, the reverse bending capacity of which is obviously lower than that of cast in place concrete specimens. It is believed that the decrease of sectional effective height is the main reason.

In order to study the influence of the additional reinforcement on the composite floor slab without protruding rebars at slab end, four specimens have been designed and tested, among which three are precast slabs without protruding bars, and two of them have additional reinforcement in the cast-in-place layer, the last one specimen is traditional slab, and the bottom reinforcement protrude into supports. The tests focus on the influence of additional reinforcement on the composite floor slabs.

![Figure 1. Bending the protruding rebar upward detailing.](image1)

![Figure 2. Two-way composite slab joint.](image2)

2. Vertical unidirectional loading test

2.1. Specimen design
In this paper, four specimens were tested, all of which are two-span continuous slab with a net span of 3110mm, a support width of 200mm, concrete strength of C40 and rebar of HRB400. The thickness of the floor is 130mm with a precast slab of 60mm and a cast-in-situ concrete layer of 70mm. The reinforcement of every precast slab is 4C8+4C6, both the end supports and the intermediate support are 6C8, the detailed parameters are shown in Table 1.

| Specimen Number | Slab end detailing | Cubic compressive strength of concrete/MPa |
|-----------------|-------------------|------------------------------------------|
|                 | Protruding bar | Additional rebar | Precast slab | In-situ topping |
| CS1             | 4C8               | none               | 48.6         | 46.8           |
| CS2-0           | none              | none               | 48.6         | 46.8           |
| CS2-4           | none              | 4C8                | 48.3         | 47.2           |
| CS2-6           | none              | 6C8                | 48.3         | 46.8           |
CS2-4 and CS2-6 are designed with additional reinforcement, the arrangement of the additional rebars could be referred to in Figure 3. CS1 is a traditional precast slab, the longitudinal reinforcement of bottom slab protrudes into support, the arrangement of the protruding rebar is the same as the additional reinforcement of CS2-4, but at different height position on the bend section. The extending length into the cast-in-situ topping and the end support are 370mm and 120mm, respectively, while the intermediate support is penetrated through, the overlap length is in accordance with related specifications and norms to ensure the tension can be effectively transferred.

![Figure 3. The additional reinforcement detailing.](image)

2.2. Loading test

The vertical load is provided by the jack-distributive girder system, which offers 16 loading point to simulate uniform load on the slab, the loading device is shown in Figure 4. The first stage of the test is force controlling, when the longitudinal reinforcement yield, switch the force controlling into the displacement controlling, each stage load sustains as long as 15min. According to the Standard for Test
Method of Concrete Structure [8], it is considered that the specimen is destroyed and the load is to terminated when any of the following situations occurs, (1) The bending deflection is up to $1/50$ of the span. (2) The reinforcement is broken. (3) The crack width is more than 1.50mm or the steel strain is up to 0.01. (4) The concrete is crushed.

2.3. Measurement scheme

Displacement gauges are arranged at the support and mid-span (Figure 5), which can measure the deflection of the mid-span compared with the bearings, so we can get the load-deflection curves. Furthermore, the readings of displacement gauges in the mid-span are the basis for the displacement controlling. The vertical load comes from the jack, transferred to loading points via three-level distributive girders. It is roughly regarded that every jack has passed the load evenly to those 8 loading points, from which the uniform load onto the slab could be estimated.

![Figure 5. Displacement gauges arrangement.](image)

2.4. Experimental Phenomena

Four specimens failed in bending, the distribution of the initial cracks is on the bottom of the slab, which is close to intermediate support, cracks gradually appear at side supports and mid-span area. With the increase of loads, both the quantity and the width of the cracks get larger, both the slab top and bottom reinforcement are going yielded. Destroy configurations of specimens are shown in Figure 6 to Figure 9.

First, the cracks start at the plate surface of the intermediate support, and the longitudinal rebar of the plate surface get yielded. Then, the crack occurs at the bottom of the mid-span plate, and the longitudinal rebar at the bottom of the plate also get yielded. No concrete crushing is observed. The bearing capacity of the mid-span section has not been fully utilized.

![Figure 6. Destroy configuration of CS1: (a) Destroy configuration of mid-span; (b) Destroy configuration of mid-support.](image)

![Figure 7. Destroy configuration of CS2-0: (a) Destroy configuration of mid-span; (b) Destroy configuration of mid-support.](image)
Figure 8. Destroy configuration of CS2-4: (a) Destroy configuration of mid-span; (b) Destroy configuration of mid-support.

Figure 9. Destroy configuration of CS2-6: (a) Destroy configuration of mid-span; (b) Destroy configuration of mid-support.

2.5. Experiment Results and Analyses

Figure 10 shows the comparison of load-deflection curves of CS1 and CS2-4. The protruding rebars of CS1 has the same area as the additional reinforcement of CS2-4, but they are at different height position on the bend section. It can be seen from the figure that the stiffness of both test pieces is nearly the same when vertical load is under 40kN. As the vertical load increases, the CS2-4 test piece with additional reinforcement gives better stiffness characteristics. The ultimate bearing capacity of the CS2-4 specimen is 9.11% higher than that of the CS1 specimen. According to the analysis, the difference of bearing capacity between CS1 and CS2-4 results from the different height position of the longitudinal rebar extending into the support, the protruding rebar extending into the support is located in the compression zone, so it makes less contribution to the bending-resistance capacity, while the additional reinforcement of CS2-4 is closer to the tension zone and contributes more to the flexural bearing capacity.

Figure 10. The comparison of load-deflection curves of CS1 and CS2-4.
Figure 11 shows the comparison of load-deflection curves of three test pieces with no protruding bars at slab end. It can be seen from the figure that the stiffness of the test pieces is nearly the same when vertical load is under 40kN. As the vertical load increases, CS2-4 and CS2-6 test pieces with additional reinforcement gives better stiffness characteristics. The ultimate bearing capacity of specimens with additional reinforcement on the cast-in-situ topping is more than 30% higher than that of the specimen with neither protruding bar nor additional reinforcement.

The paper takes the minimum value of the peak testing load and the load corresponding to midspan deflection of 60mm as the ultimate load. The comparison of the experiment results and design value are shown in Table 2.

| Specimen Number | Test Value | Design Value | $q_d/q_t$ |
|-----------------|------------|--------------|---------|
|                 | Left span | Right span | Surface Load | Support | Midspan | Surface Load |         |
|                 | $F_l$/kN  | $F_R$/kN  | $q_t$/kN/m$^2$ | $M_s$/kN·m | $M_{qs}$/kN·m | $q_d$/kN/m$^2$ |         |
| CS1             | 89.40     | 91.31      | 26.60       | 8.63    | 11.50   | 11.55       | 0.43    |
| CS2-0           | 75.20     | 78.34      | 23.26       | 8.63    | 11.50   | 11.55       | 0.50    |
| CS2-4           | 95.36     | 105.11     | 29.68       | 12.58   | 11.50   | 12.99       | 0.44    |
| CS2-6           | 89.85     | 106.90     | 29.34       | 15.10   | 11.50   | 13.91       | 0.47    |

It can be seen from the table that the precast concrete slab with additional reinforcement at slab end are designed with enough safety reserve. Increasing the area of additional reinforcement can theoretically improve the flexural capacity, but the flexural capacity of CS2-4 and CS2-6 is basically the same, the possible reason is that there is difference in the tensile strength and the location of the additional reinforcement between design value and actual value.

3. Conclusions

Both the peak testing load and the load corresponding to midspan deflection of 1/50 of the span could be regarded as the ultimate load. Where the destruction is marked as the deflection value reaches 60mm:

1) The bearing capacity of the composite floor slab end with neither protruding rebars nor additional reinforcement is obviously lower than that of other test specimens.

2) The additional reinforcement at slab end could evidently enhance the bearing capacity and stiffness.
3) In the case of layout and indirect overlap length, increasing the area of additional rebars has no obvious effect on the bearing capacity and stiffness of the joint.

4) When the vertical load value is lower than 40kN, the specimens are in elastic state, and the stiffness of each specimen is basically the same.

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