Comparative Analysis of Flexural Performance of Recycled Concrete Two-way Composite Slab and Ordinary Concrete Two-way Slab

Zhongwei Li¹, Zhengchao Jin¹* and Guangxiu Fang¹
¹Department of Structural Engineering, College of Engineering, Yanbian University, Yanji, Jilin, China
*Corresponding author’s e-mail: jinzhengchao@ybu.edu.cn

Abstract: Based on the full-scale model test of ordinary concrete two-way slab and recycled concrete two-way composite slab with beam column support, the failure mode, stiffness and deflection changes of ordinary concrete two-way slab and recycled concrete two-way composite slab under concentrated load are analyzed, and the similarities and differences of bending performance of the two components under the same conditions are proposed. The results show that: under concentrated load, the failure mode and deflection change trend of recycled concrete two-way composite slab are basically the same as that of ordinary concrete two-way cast-in-place slab. The deflection of recycled concrete two-way composite slab increases greatly after cracking, which is related to the secondary stress. The bending stiffness of recycled concrete two-way composite slab before cracking can be calculated according to the elastic theory.

1. Introduction
Traditional construction methods also gradually reveal many problems, such as low construction efficiency, long construction period, subject to natural factors, geographical factors and artificial quality and other factors, the project quality is difficult to control, so in order to accelerate the rapid development of the construction industry, the government takes prefabricated construction as a major strategy of the 13th five year plan [1]. As a common component in prefabricated building, laminated slab has the advantages of saving formwork and convenient construction compared with ordinary cast-in-place slab, which is in line with the development direction of "modernization of construction industry and green building" advocated by our country [2]. At present, many universities and construction units have made research on the laminated plate, and proposed the mechanical performance analysis of different structural forms of laminated plate [3-5], but most of the scale models or one-way slab members without support are still insufficient compared with the application in practical engineering.

In this experiment, full-scale models of ordinary concrete two-way slab and recycled concrete two-way composite slab with beam column support are made respectively, and their bending performance is analyzed and compared, which provides further reference for the application of composite slab in practical engineering.

2. Test materials and design

2.1. Mix proportion design of recycled concrete
The strength grade of recycled concrete is C30, the water-binder ratio is 0.46, and the sand ratio is
43%. 30% fly ash is used instead of cement. The mixing ratio is shown in Table 1.

| Name                | Water | Cement | Fly ash | Sand  | Gravel | Recycled coarse aggregate | Water reducer |
|---------------------|-------|--------|---------|-------|--------|---------------------------|---------------|
| Recycled concrete   | 171.67| 315    | 75.33   | 796   | 736.73 | 316.5                     | 3.6           |

2.2. Mix proportion design of ordinary concrete
The strength grade of ordinary concrete is C30, the water binder ratio is 0.46, the sand ratio is 43%, and the fly ash replaces 30% cement, as shown in Table 2.

| Name                | Water | Cement | Fly ash | Sand  | Gravel | Recycled coarse aggregate | Water reducer |
|---------------------|-------|--------|---------|-------|--------|---------------------------|---------------|
| Recycled concrete   | 171.67| 315    | 75.33   | 796   | 1053.23| 0                         | 3.6           |

2.3. Full scale model design
According to the literature research, the recycled concrete two-way composite slab is made. The specimen size is as follows: the length of the slab is 3600 mm, the width is 3000 mm, and the thickness is 120 mm. The thickness of the bottom precast layer is 60 mm, and the thickness of the cast-in-place layer is 60 mm. Because the precast slab is a splicing slab, the reinforcing bars at the splicing place are reinforced according to the code for design of concrete structures. The full-scale model and its reinforcement are shown in Figure 1.

A) Full scale model

Figure 1.full scale model and reinforcement diagram of recycled concrete two-way composite slab

B) reinforcement figure

The full-scale model and reinforcement of ordinary concrete two-way slab are shown in Figure 2.
The specimen size of ordinary concrete two-way slab is as follows: the slab length is 3600mm, the slab width is 3000mm, and the slab thickness is 120mm.

3. Experimental loading and failure modes

3.1. Measuring point layout and data acquisition
The displacement meter is arranged at the middle of the span and 1/4 of the long span, and the measuring points of the displacement meter are arranged along the long span interval of 900mm from the middle of the span. The arrangement of the measuring points of the plate displacement meter is shown in Figure 3.

3.2. Test loading
By adopting the loading scheme of concentrated load on the middle of the slab, the cracking load of the bidirectional composite slab of recycled concrete is preliminarily calculated as 25KN, and the cracking load of the bidirectional composite slab of ordinary concrete as 35KN. According to the loading of each stage of 5KN, the loading process is divided into two stages according to literature [5], namely pre-loading and formal loading.

3.3. Failure mode
According to the experimental observation, the failure crack morphology of ordinary concrete two-way slab is shown in Figure 4. When the load is 0 ~ 35KN, there is no obvious change in the specimen, and the deflection value of the slab increases linearly; when the load is 35KN, a small crack of about 0.06mm begins to appear at the midspan position of the slab bottom; with the continuous increase of the load, the crack at the slab bottom appears along the 45 ° angle, and three main cracks appear at the midspan position. When the load is 65kn, the sound of concrete cracking can be clearly heard at the bottom of the slab. The main crack has extended to the inner side of the beam, and the crack is about 0.3mm. Due to safety reasons, the loading is completed.
Figure 4. failure crack pattern of bottom of ordinary concrete two-way slab

The failure crack morphology of recycled concrete two-way composite slab is shown in Figure 5. Through inspection, it is found that the crack development morphology of recycled concrete two-way composite slab is basically the same as that of ordinary concrete two-way slab; when the load is 0 ~ 25KN, the specimen has no obvious change, and the deflection value of slab increases linearly; when the load is 25KN, small cracks begin to appear at the bottom of slab, and the crack width is about 0.07mm; with the increase of load, the crack width is about 0.07mm. The crack development form and width of recycled concrete two-way composite slab is slower than that of ordinary concrete two-way slab, and the crack width is relatively small, and three main cracks are also formed at the slab bottom; when the load is 60KN, the main crack has extended to the inner side of the beam, at this time, it can be obviously felt that the displacement in the middle of the slab span suddenly increases, accompanied by some slight damage sound, and the crack width at the slab bottom is 0.3 mm.

Figure 5. cracks at the bottom of two-way laminated plate

From the above tests, it can be seen that although the cracking load of ordinary concrete two-way slab and recycled concrete two-way composite slab is different, their crack development is very similar. The difference in cracking load is due to the fact that the precast layer of composite slab already bears part of the load when pouring the cast-in-place layer. At the same time, there is no relative slip between the precast layer and the cast-in-place layer during the loading process, which indicates that the shear capacity of the composite plate is guaranteed under the condition of truss.

4. Analysis of test results

4.1. Bending stiffness analysis

The load deflection curve of ordinary concrete two-way slab and recycled concrete two-way composite slab is shown in Figure 6.
Figure 6. load displacement curve in the middle of slab

When the load of ordinary concrete two-way slab is 0-35kn, the deflection basically increases linearly, which indicates that the cast-in-place slab is in the elastic stage; when the load of concrete is 35kn-65kn, the deflection basically increases nonlinearly, which indicates that the cast-in-place slab is in the elastic-plastic stage, the concrete is out of work, and the steel bars bear all the load.

When the load of recycled concrete two-way composite slab is 0-25kn, the deflection growth rate is basically the same as that of cast-in-place slab, at this time, the composite slab is in the elastic stage; when the load of concrete is 25kn-60kn, the deflection growth rate of recycled concrete two-way composite slab is higher than that of ordinary concrete two-way slab, at this time, the composite slab is in the elastic-plastic stage, and the concrete is out of construction Make steel bar to bear the load completely.

It can be seen from the above that the deflection change characteristics of recycled concrete two-way composite slab conform to the deflection change characteristics of ordinary concrete two-way composite slab, and the stress stage is divided into two stages. According to literature [7], the deflection of ordinary concrete two-way composite slab in elastic stage and plastic stage is slightly less than that of recycled concrete two-way composite slab, which is due to the fact that the bottom of precast slab of composite slab is double panel and the splicing joint is small. The stiffness of the composite plate is reduced to a certain extent.

4.2. Flexural stiffness at uncracked stage

The uncracked stage belongs to the elastic stage. At this time, the deflection value and its variation of the recycled concrete two-way composite slab are basically the same as that of the ordinary concrete two-way composite slab:

\[ B_s^{(1)} = \frac{E \cdot h^3}{12(1-\mu^2)} \]

According to the bending stiffness formula given in formula (1), the deflection value of the laminated plate in the elastic stage is calculated. During the calculation, the concentrated load is converted into uniform load according to reference [8]. The calculated and measured deflection values are shown in Table 3, and the deflection values are basically consistent.

| Load value (KN) | 5   | 10  | 15  | 20  | 25  |
|----------------|-----|-----|-----|-----|-----|
| Calculation of deflection (mm) | 0.25 | 0.50 | 0.76 | 1   | 1.26 |
| Measured deflection (mm)        | 0.2 | 0.4 | 0.7 | 1   | 1.3 |

4.3. Bending stiffness of working stage with cracks

After the cracking of the recycled concrete bidirectional composite slab, the increase of its deflection is
greater than that of the ordinary concrete bidirectional composite slab. Therefore, the flexural rigidity calculated according to the elastic theory is not applicable to the calculation of the flexural rigidity of the composite slab. Therefore, further theoretical and computational analysis is needed to determine the reduction coefficient.

5. Conclusion
(1) Under concentrated load, before the full-scale model cracks, the deflection value of recycled concrete two-way composite slab is basically consistent with that of ordinary concrete two-way slab.
(2) Compared with the common composite slab, the stress distribution of the two-way composite slab is slightly higher than that of the common composite slab.
(3) Through the full-scale model test of ordinary concrete two-way slab and recycled concrete two-way composite slab, the failure crack morphology and deflection under concentrated load, the bending stiffness in the uncracked stage and the bending stiffness in the working stage with cracks are compared and analyzed. The calculated deflection of the uncracked stage is basically consistent with the measured deflection. After cracking, the increase of deflection of recycled concrete two-way composite slab is larger than that of ordinary concrete two-way slab.
(4) In the elastic stage, the stiffness formula can be calculated according to the elastic theory, but in the plastic stage, the stiffness formula needs to be further studied.

Acknowledgements
This paper is supported by the key research project of the Science and Technology Development Plan of Jilin Province Science and Technology Development Plan (20170204032SF).

References
[1] Sun,L. (2020) Development status and Prospect of prefabricated building. Mass standardization,7:24-26.
[2] Jia,J,W. (2020) On the current situation and development of prefabricated buildings in China. Encyclopedia forum e-magazine,7:406-407.
[3] Jin,L.Z.,Lian,D.M.,Li,L.(2020) Experimental study on flexural behavior of reinforced truss ultra high performance concrete composite slabs. Industrial Building,3:69-75.
[4] Lin,Y.,Song,J.K.,Zhong,C.T. .(2020) Experimental study on mechanical properties of laminated plates with different joint construction measures. Industrial Building,6:45-50.
[5] Wu,F. (2014) Experimental study on mechanical behavior and stiffness of composite plate with steel truss. Anhui Jianzhu University.
[6] GB/T 50152-2012, Standard for test methods of concrete structures.(2012) China Construction Industry Press.
[7] Cui,Y.T., Shen,X.P. (2014) Experimental analysis and Research on deflection variation law of laminated two way slab. Journal of Anhui Institute of architecture and Technology (NATURAL SCIENCE EDITION),2:51-54.
[8] Liu,W.H.(2015) A simple method for calculating equivalent load of two-way slab under concentrated load. Sichuan Architecture,4:137-139.