Experimental study on deflection of recycled concrete two-way slab under concentrated load

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Abstract. In order to study the deflection calculation method of recycled concrete two-way slab under concentrated load, a full-scale model of recycled concrete two-way slab was designed, and the replacement rate of recycled coarse aggregate was 30%. Through the loading test, the failure mode of the two-way slab was observed, and the test data of the whole process curve of the deflection changing with the load value and the development of the mid-span deflection were obtained. Based on the current theoretical formula, this paper uses Origin software to simulate the deflection of recycled concrete two-way slabs under concentrated load on the basis of comparing the deflection test value and the theoretical calculation value, and proposes a correction coefficient for the two-way slab deflection calculation. For the proposed two-way plate deflection calculation correction factor, the existing test data is used to verify it. The results show that the deflection value calculated according to the method in this paper is relatively close to the test value. The research results can provide reference for follow-up experiments.

1. Introduction

In recent years, green concrete has been vigorously advocated by countries all over the world. The recycled concrete derived from the environmental protection concept of "energy saving, emission reduction, green and high efficiency" has attracted the attention of scholars at home and abroad, and conducted a large number of experimental studies. Some important results have also been achieved[1-2]. Floor slabs can be divided into one-way slabs and two-way slabs according to the direction of force. So far, the research on one-way slabs at home and abroad is very extensive, and the research on ordinary concrete two-way slabs is also relatively sufficient [3]. However, there are few reasonable and practical methods for calculating the deflection of recycled concrete two-way slabs. Therefore, it is of great significance for the experimental study of the failure form and deflection of recycled concrete two-way slabs. Based on the calculation method of deflection of two-way concrete slab in my country's current code, this paper puts forward the failure form of recycled concrete two-way slab and the correction coefficient of the deflection calculation formula in the current code through the experimental research of full-scale model.

2. Design of test plan

2.1. Experiment material

(1) Cement: PO 42.5 ordinary Portland cement, produced by Jilin Yatai Cement Co, Ltd;
(2) Fly ash: Produced by Yanji Tienan Heating Company, Grade II fly ash;
(3) Sand: River sand in Yanji City with a particle size of less than 5mm, medium-coarse sand;
(4) Natural coarse aggregate: Natural gravel with a particle size of 5-25mm;
(5) Recycled coarse aggregate: The waste concrete test block from the Yanbian State Housing and Construction Engineering Quality Inspection Center is crushed and screened by a jaw crusher, and the particle size of the recycled aggregate is 10-25mm;
(6) Water: Tap water in Yanji City;
(7) Water reducer: High-efficiency polycarboxylic acid water reducer produced by Yanji Fangsheng Building Materials Co., Ltd;
(8) Steel bar: HRB 335 steel bar with a diameter of 6mm.

2.2. Mix design
This test is based on the current industry standard[4], and the design strength grade is C30 recycled concrete. The final mixing ratio design of the laboratory after adjustment is shown in Table 1.

| Project       | Water (kg) | Cement (kg) | Fly ash (kg) | Sand (kg) | Natural gravel (kg) | Recycled aggregate (kg) |
|---------------|------------|-------------|--------------|-----------|--------------------|------------------------|
|再生混凝土    | 171.67     | 315         | 75.33        | 796       | 738.73             | 316.5                  |

2.3. Two-way plate test design
According to literature research[5], a full-scale model of the cast-in-situ recycled concrete slab is designed with a size of 3000mm×3600mm×120mm; The specific reinforcement is shown in Figure 1:

Figure 1. Reinforcement diagram of cast-in-place recycled concrete slab

3. Test loading and failure mode

3.1. Measuring point layout and collection

3.1.1. Layout of measuring points of displacement meter
Displacement gauges are arranged at the mid-span and 1/4 of the long span. Displacement measuring points are arranged at 900mm intervals along the long span from the middle of the span. A total of two measuring points W1 and W2 are arranged. The arrangement of the displacement measuring points is shown in Figure 2.

3.1.2. Data collector
The vertical displacement of the bottom of the board is measured by the domestic DH3817 displacement sensor, as shown in Figure 3.
Figure 2. Layout of displacement measurement points for cast-in-place recycled concrete slab

Figure 3. DH3817 dynamic and static test strain instrument

3.2. Test loading

3.2.1. Loading plan
The loading plan of the two-way slab is: load 10kN for each stage of the first, second, and third stage, load 5kN for each stage from the fourth stage, load a total of 10 stages of load, the cracking load is 35kN, the failure load is 65kN, and each load is loaded. After completion, hold the load for 10min-15min. In the last five minutes, record the deflection and strain of the bottom of the plate, and record the characteristic load when each crack appears, the change of crack length and width, and the development direction and trend.

3.2.2. Test preparation and loading
First, install the displacement meter and number it, and connect the displacement meter to the data acquisition instrument. Then, before the test, reconfirm each test acquisition instrument and equipment to prevent problems in later data analysis; record the initial reading of the dial indicator, reset the data acquisition instrument to zero, and then formally load it.

3.3. Destruction form
When the test is loaded to 35KN, at the mid-span position at the bottom of the slab, a number of micro-cracks along the long-span direction begin to appear, developing from the mid-span to both sides, with the maximum crack width When the load is 40KN, there are multiple cracks along the short span direction at the mid-span, and the number increases uniformly; when the load value reaches 45KN, the cracks continue to increase, the maximum crack width is 0.18mm, and one appears in the long-span direction When the main crack extends to point A in Figure 4, a diagonal branch is produced; when the load value reaches 55KN, the main crack extends to the inside of the beam, and the diagonal crack extends to the corner of the plate; When approaching failure, the two-way board loses its bearing
capacity, makes an abnormal noise of cracks and cracks, and the deflection increases greatly. The maximum crack width is 0.3mm. The failure mode of the two-way plate bottom is shown in Figure 4.

![Main crack](image1)

a) Diagram-1

![Diagram-2](image2)
b) Diagram-2

Figure 4. Schematic diagram of the damage pattern of the bottom plate

4. Test result analysis and deformation calculation

4.1. Result analysis

During the two-way plate loading process, when the vertical load is loaded to the fourth level (35KN), the maximum deflection of the bottom of the plate is 1.9mm, and the deflection of each measuring point in the plate increases slowly and linearly increases with the increase of the load value. The slab is in the elastic stage; then the load-deflection curve appears an inflection point, and the deflection growth rate gradually increases until the slab is broken and no longer changes linearly, indicating that the slab is in the plastic stage, and the deflection changes with load as shown in Figure 5.

![Load-deflection curve](image3)

Figure 5. Load-deflection curve

4.2. Deformation calculation

With reference to the current theoretical formula\(^6\), the interpolation method is used to obtain a deflection calculation coefficient of 0.00581. Therefore, the deflection calculation formula of the bidirectional plate is:

\[
B_c = \frac{Eh^3}{12(1 - \mu^2)}
\]  

(1)
According to the above calculation formula, calculate the deflection calculation value and deflection test value of the two-way plate in the normal use stage at all levels of load values as shown in Table 2.

| Load value (KN) | Deflection test value | Calculated deflection | \(f_l/f_C\) |
|----------------|-----------------------|-----------------------|-------------|
| 10             | 0.4                   | 0.78                  | 0.51        |
| 20             | 0.9                   | 1.56                  | 0.58        |
| 30             | 1.5                   | 2.34                  | 0.64        |
| 35             | 1.9                   | 2.73                  | 0.70        |
| 40             | 2.7                   | 3.12                  | 0.87        |
| 45             | 3.6                   | 3.51                  | 1.03        |
| 50             | 4.2                   | 3.90                  | 1.08        |
| 55             | 5.2                   | 4.29                  | 1.21        |
| 60             | 6.7                   | 4.68                  | 1.43        |
| 65             | 7.8                   | 5.07                  | 1.54        |

Divide the measured value of the deflection by the calculated value to obtain the correction coefficients at various load values, and then use the Origin software to perform fitting. The fitting curve obtained is shown in Figure 6.

\[
q = \frac{f^2}{f_a^2} \tag{2}
\]

\[
q_1 = \frac{\alpha(3 - \alpha^2)}{2} q \tag{3}
\]

\[
f = 0.00581 \frac{q \alpha^4}{B_C} \tag{4}
\]

The fitted curve equation is \(y = 0.51702 - 0.00418x + 3.1299 \times 10^{-4}x^3\), the degree of fit is 0.98649.

In summary, the calculation formula for deflection of recycled concrete two-way slab is

\[
f = y(0.00581 \frac{q \alpha^4}{B_C}) \tag{5}
\]

The comparison between the deflection value calculated by formula (4) and the test value is shown in Figure 7. It can be seen that the calculated value is relatively close to the test value, and the fitting result is good.
5. Conclusion

(1) For recycled concrete bidirectional slabs under concentrated load, the deflection curve increases linearly before concrete cracks appear, and the slab is basically in the elastic stage; when the load value increases to 35KN, the deflection increases non-linearly, and the plate changes from the elastic stage to the plastic stage, its failure form is similar to that of ordinary concrete two-way slabs.

(2) In this paper, through the full-scale model test of recycled concrete two-way slab, the deflection value of the slab under various load values is obtained. Then, referring to the current theoretical formula, the theoretical deflection calculation value is obtained, and the deflection test value is compared with the theoretical deflection calculation value. The deflection correction coefficient, using Origin, the deflection correction formula is $f = y(0.00581 \frac{qL^4}{Bc^4})$, which can provide a reference for subsequent experimental research.

(3) The formula obtained in this experiment is suitable for the deflection calculation of recycled concrete two-way slab, which can be used as a reference for subsequent research.

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