Calculation Method of Deflection Recycled Concrete Two-way Composite Under Concentrated Load

Zhongwei Li¹, Guangxiu Fang¹* and Pengjie Hu¹

¹Department of Structural Engineering, College of Engineering, Yanbian University, Yanji, Jilin, China

*Corresponding author’s e-mail: gxfang@ybu.edu.cn

Abstract: In this experiment, a full-scale model of recycled concrete two-way laminated slab with a 30% replacement rate of recycled coarse aggregate was used. Through concentrated load loading tests, the mechanical properties of recycled concrete two-way laminated slabs were studied, it includes bearing capacity, crack distribution, stiffness and deflection. According to its stress characteristics and on the basis of the current specifications, the stiffness formula is adjusted, and the deflection value is calculated theoretically. By comparing the measured value with the theoretical calculation value, the modified formula of the deflection of recycled concrete two-way composite slab is put forward.

1. Introduction

Construction waste is generally mainly concrete, so the reuse of concrete is the primary task to solve construction pollution. Chen Zongping [1] carried out an experimental study on the bearing capacity of ordinary recycled concrete two-way slabs under the conditions of different replacement rates of recycled aggregate, which provides a reference for further research on recycled concrete slab members. Recycled concrete is to reprocess the waste concrete to restore its original performance, and repeatedly put it into the structure, which not only solves the problem of resource consumption, but also avoids the environmental pollution caused by construction waste. In recent years, prefabricated buildings are more and more widely used in practical projects. However, the composite board materials in prefabricated buildings in China are made of natural aggregate. If recycled aggregate is used instead of natural aggregate, resource consumption and environmental pollution can be reduced, and the theme of "modernization of construction industry, green building" advocated by China is also met[2-4].

In this paper, recycled concrete is applied to the fabricated two-way composite slab. Through the loading test of the full-scale model of the recycled concrete two-way composite slab, based on the current national formula for calculating the deflection of the unidirectional composite slab in the middle of the span, a formula for calculating the deflection of the recycled concrete two-way composite slab with a correction factor is proposed.

2. Test materials and design

2.1. Test materials

(1) Cement: PO42.5 ordinary portland cement produced by Jilin Yatai Cement Co., Ltd;
(2) Fly ash: Yanji City secondary fly ash, produced by Yanji Tienan Heating Company;
(3) Sand: medium coarse sand with particle size of 5mm and below;
2. Natural coarse aggregate: natural gravel with particle size of 5-25mm;
3. Recycled coarse aggregate: the waste concrete test block from Yanbian Residential Construction Inspection Center is used, which is crushed and screened by jaw crusher, and the recycled aggregate particle size range is 10-25mm;
4. Water: tap water of Yanji City;
5. Additive: high efficiency polycarboxylate superplasticizer produced by Fangsheng building materials Co., Ltd;
6. Reinforcement: 6mm diameter HRB335 reinforcement.

2.2. 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           |

2.3. Design of recycled concrete two way composite slab
The size of the specimen is as follows: the thickness of the bottom precast layer is 60mm, and the thickness of the cast-in-place layer is 60mm. As the precast slab is a splicing plate, the reinforcement at the splicing position shall be arranged according to the code for design of concrete structures, as shown in Figure 1.

![Figure 1. reinforcement drawing of laminated plate](image)

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 Fig2.

3.2. Test loading
The loading scheme of concentrated load on the middle of the slab is adopted. The initial calculation results show that the cracking load is 25kN, and each stage is loaded with 5KN. After each stage of loading, the crack condition at the bottom of the slab is observed, the displacement and strain values are
recorded, and the crack observation control network is drawn at the bottom of the plate, so as to observe the crack situation. According to the literature [5], the loading process is divided into two stages, namely preloading and formal loading.

![Image](image1.png)

**Figure 2. arrangement of displacement meter**

3.3. Failure mode
Through the experimental observation, the development of cracks at the bottom of the composite slab is basically the same as that of the ordinary recycled concrete two-way slab. When 0 ~ 25kn, there is no obvious change in the components, and the deflection value of the slab increases linearly; when 25KN, the cracks begin to appear at the bottom of the slab, and three main cracks appear in succession with the increase of load, and the deflection value in the middle of the slab span occurs inflection point, and shows a nonlinear growth; when 60KN, the main crack has At this time, it can be felt that there is a slight change in the middle span of the beam. The cracks at the bottom of two-way laminated slab are shown in Fig. 3.

![Image](image2.png)

**Figure 3. cracks at the bottom of two-way laminated plate**

4. Analysis of test results

4.1. Bending stiffness analysis
The relationship between the load and deflection measured in this test is shown in Fig. 4. It can be seen that when the applied load is 0 ~ 25KN, the deflection of the recycled concrete bidirectional composite slab increases linearly, and the growth is slow, indicating that the composite slab is in the elastic stage at this time. When the applied load is 25 ~ 60KN, the deflection of the composite plate increases rapidly,
showing a nonlinear growth, and with the continuous increase of the load, the deflection increases gradually, indicating that the composite plate is in the plastic stage at this time.

Figure 4. load displacement curve in the middle of slab

4.2. Flexural stiffness at uncracked stage

Because the precast slab has been subjected to stress and displacement when the cast-in-place layer is poured, the bending rigidity of the composite slab before cracking is lower than that of the cast-in-place slab. It can be seen that the bending stiffness of the composite plate before cracking should be multiplied by a reduction factor on the basis of the uniform elastic material plate, and the reduction coefficient should refer to the reference [6].

\[ B_s^{(1)} = \frac{0.9E_e h^3}{12(1-\mu^2)} \]  \hspace{1cm} (1)

The calculated and measured deflection values are shown in Table 2, and the deflection values are basically consistent.

Table 2. The calculated and measured deflection in uncracked stage

| Load (KN) | Calculated value (mm) | Measured value (mm) |
|-----------|-----------------------|---------------------|
| 5         | 0.25                  | 0.2                 |
| 10        | 0.5                   | 0.4                 |
| 15        | 0.76                  | 0.7                 |
| 20        | 1                     | 1                   |
| 25        | 1.26                  | 1.3                 |

4.3. Bending stiffness of working stage with cracks

According to the current code, the short-term bending stiffness formula of composite plate members is:

\[ B_s^{(2)} = \frac{E_s A_s h_0^2}{h_1 + \frac{635\sigma_{ep}}{1 + 3.5Y_f}} \]  \hspace{1cm} (2)

The above formula is applicable to one-way slab. The deflection of one-way slab is larger than that of two-way slab, but the stiffness is opposite. Therefore, it is necessary to multiply the stiffness formula of unidirectional slab with a magnification factor to obtain the calculation formula of bi-directional laminated plate. According to reference [7], the coefficient is 2.19.

\[ B_s^{(2)} = \frac{2.19A_s h_0^2}{0.7 + 0.6\frac{\sigma_{ep}}{h_1} + \frac{635\sigma_{ep}}{1 + 3.5Y_f}} \]  \hspace{1cm} (3)

In this paper, the precast slabs are jointed with joints and supported by beams and columns on four sides, which has a certain impact on the stiffness of the composite plates. Therefore, it is necessary to introduce a reduction coefficient to adjust the stiffness of the composite plates with recycled aggregate.

Referring to the manual of static calculation of building structure, the deflection calculation formula of ordinary reinforced concrete two-way composite slab is determined as follows.
The ratio between the calculated deflection value of ordinary reinforced concrete composite slab and the deflection test value of recycled concrete bidirectional composite slab in this paper is the reduction factor $\zeta$. According to reference [8], the concentrated load is transformed into equivalent uniform load.

According to the calculation, the value of the condition coefficient under the load of each grade in the working stage with cracks is determined as shown in Fig. 5.

![Figure 5. Stiffness correction factor](image)

The slope of the correction coefficient curve has little change, so the correction coefficient curve is fitted as a function curve $\zeta = 9.66836X^{-1}-0.0564$, The deflection formula of recycled concrete two-way composite slab is.

$$f = \frac{Kq t^4}{\zeta B_s}$$

(5)

The deflection values calculated by the modified formula and the measured values are shown in Table 3.

| Load (KN) | 30  | 35  | 40  | 45  | 50  | 55  | 60  |
|----------|-----|-----|-----|-----|-----|-----|-----|
| Calculated value (mm) | 1.62 | 2.3 | 3.1 | 4.08 | 5.3 | 6.7 | 8.2 |
| Measured value (mm)   | 1.7  | 2.5 | 3.8 | 4.7  | 5.7 | 7.4 | 8.1 |

The comparison between the deflection value calculated by the above formula and the test value is shown in Fig. 6.

![Figure 6. Test and calculation values of displacement in the middle of slab](image)

It can be seen from the figure that the calculated value is in good agreement with the test value,
indicating the rationality and feasibility of the formula.

5. Conclusion
(1) When the load reaches 25kn, cracks appear at the bottom of the member, and the cracks continue to extend to the inner side of the beam with the continuous increase of concentrated load. Before cracking, the deflection increases linearly and is in the elastic stage; after cracking, the deflection increases nonlinearly and is in the plastic stage.

(2) Under concentrated load, the flexural stiffness of recycled concrete two-way composite slab before cracking is multiplied by the reduction factor of 0.9 on the basis of elastic theory calculation; the flexural stiffness of working stage with cracks is multiplied by the reduction factor of $\zeta = 9.66836X^{-1} - 0.05644$ on the basis of existing one-way composite slab stiffness formula in the code, and the deflection formula of recycled concrete two-way composite slab is determined as $f = \frac{KqL^4}{\zeta_B}$. 

(3) The modified deflection formula is suitable for the recycled concrete two-way composite slab with joint. The application of full-scale model makes the test results closer to the actual engineering.

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] Chen,Z.P.,Yang,Y.B.,Zheng,S.F. (2013) Experimental study on bearing capacity of reinforced recycled concrete floor. Industrial buildings,43:52-56.
[2] Li,H.Q.,Du,T.,Wu,X.G.(2001) Study on recycling recycled aggregate concrete from construction waste. Journal of Huazhong University of science and technology,29:83-84.
[3] Deng,S.C.,Zang,X.B.,Luo,Y.D.(2006) The present situation analysis and research prospect of waste concrete recycling. Concrete,11:20-24.
[4] Huang,W.,Luo,B.,Li,B. Experimental study on flexural behavior of green concrete composite slabs with different structures,46:35-44.
[5] GB/T 50152-2012, Standard for test methods of concrete structures.(2012) China Construction Industry Press.
[6] Wu,X.L. (2011) Design theory and experimental study on assembled integral two way slab. Doctoral Dissertation of Southeast University
[7] Xu,J.R.(2017) Study on structural performance of a new type of joint concrete composite two-way slab. Master Thesis of Inner Mongolia University of science and technology
[8] Liu,W.H.(2015) A simple method for calculating equivalent load of two-way slab under concentrated load. Sichuan Architecture,4:137-139