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Study on Distortion of Bi-Steel Concrete Beam

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***Abstract*—**As an economic and safe structure, Bi-steel is widely used in reinforced concrete with less consumption of steel. In this paper, III Bi-steel concrete beam has been analyzed. Through careful observation and theoretical analysis, the new calculating formulae for structural rigidity and crack have been formulated for this Bi-steel concrete beam. And structural rigidity and the crack features have also been theoretically analyzed.

***Keywords*—**Bi-steel, concrete beam, crack, rigidity.

I. Introduction

Bi-Steel was invented and patented by the EVG developing Ltd of Austria. Ladder Bi-steel is a structure welded by two longitudinal paralleled bars and short vertical transverse bars. Compared with the prestressed concrete beam, ladder Bi-steel concrete beam have the following features: 1. It has a shorter maintenance time. If the strength reaches 50% of the ultimate strength, it can be easily demoulded with high quality. 2. It has better ductility and adaptation. 3. It has a better fire resistance. If the common prestressed concrete beam is heated, it will collapse rapidly. On the other hand, under 600ºC, the ladder Bi-steel concrete beam will not be affected by heat. Due to the obvious merits, Bi-steel concrete beam has been widely used in the field of civil engineering. However, there are only a few reports about the use of Bi-steel concrete beam (cold-drawn low carbon steel wire, cold-rolled low carbon steel bar) in larger reinforcement structures. Furthermore, application of III hot rolled ribbed steel bar in Bi-steel concrete beam has scarcely been reported in the world. To study the behaviours of Bi-steel members, main factors which affect the development of crack of Bi-steel concrete beam have been analysed. And a new theoretical model and design method will be established to deal with Bi-steel concrete beam's deformation and cracks.

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II. Experiment

A. Equipment

The equipment includes the following parts: MTS simulating power test system, dial indicator, DH3815static strain gage, inclinometer, displacement sensor and so on.

B. Loading procedure

In this test, the load is applied in the midspan. The load will increase until the fatigue failure (crack) of beam appears. And each step load accounts for 10% of the desired fatigue load. In order to obtain a more accurate crack load, the dial indicator is employed to observe the deformation until the crack occurs. When the dial indicator shows a discontinuous change, the first crack will occur, and then the loading process will stop. The cracks will be traced by the magnifier. The data from dial indicator and strain gauge will be recorded.

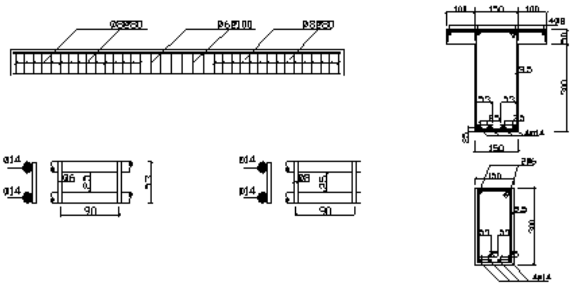

Fig. 1 Schematic diagram of reinforcing component

III. Experimental results and analysis

There are three stages in the whole loading process (Fig. 3). The first stage is the elastic stage in which cracks will not appear. The deformation in first stage is elastic. With the increase of load, the cracks will appear in the chewing area, and a flexural point will be formed in the curve of P-f. Second stage refers to the stage in which cracks will appear. Second stage is the elastic-plastic stage. In this stage, the deformation of the reinforced concrete is elastic-plastic. With the increase of load, the deformation of reinforced concrete will reach the fatigue limit. Then the component will enter the third stage (fatigue failure). Third stage is the stage in which fatigue failure will appear. In this stage, the ultimate strength will be obtained. With the increase of load, the effective working section decreases. Moreover, the average strain of the chewing area and the pressing area show an agreement to the assumption of the flat section. It can be obtained in the whole process that, with a decrease of the crack width, the service life of ladder reinforced concrete is much longer than that of ordinary concrete.

Fig. 2 Photo of MTS

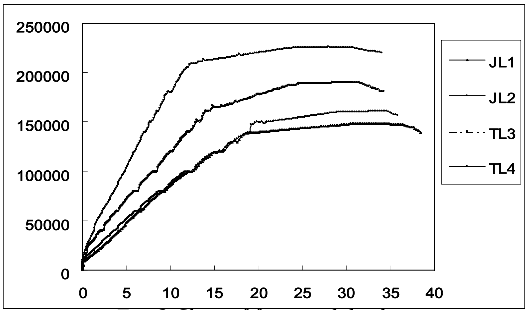

Fig. 3 Chart of force and displacement

IV. Calculating Formulae of Cracks

A. Calculating formula of cracks in the ordinary reinforced concrete beam

The distance calculating formula of the average cracking can be expressed as

$$l_m = 1.89c + 0.077\frac{d}{\rho_{te}} \tag{1}$$

Where, l_m is the average cracking distance, c the distance between the external edge and tensile hemline, d the diameter of steel bar, ρ_{te} the reinforcement ratio (A_s / A_{te}). The calculating formula of maximum crack width will be established as

$$W_{\max} = 2.1\psi\frac{\sigma_s}{E_s}l_m \quad \psi = 1.1 - \frac{0.65 f_{tk}}{\rho_{te}\sigma_s} \tag{2}$$

where, $W_{\max}$ is the maximum crack width, ψ the strain no uniformity coefficient of tensile steel bar, f_{tk} the tensile strength of concrete beam, σ_s the tensile stress of longitudinal steel bar, E_s the elastic modulus of steel bar.

B. Calculating formula of cracks in Bi-steel concrete beam (II cold-rolled ribbed steel)

The calculating formula of average distance between cracks can be expressed as [1]

$$l_m = 2.0c + 0.046d / \rho_{te} \tag{3}$$

And the calculating formula of maximal crack width can be obtained as

$$W_{\max} = 2.1\psi\frac{\sigma_s}{E_s}l_m, \ \psi = 1.05 - \frac{0.6 f_{tk}}{\rho_{te}\sigma_s} \tag{4}$$

C. Calculating formulae of cracks in Bi-steel concrete beam (III hot-rolled steel)

The formulae are on the basis of the two above-mentioned methods. So the calculating formulae of average distance between cracks (which is suitable for hot-rolled steel III, Bi-steel) with revised correlation coefficients can be expressed as [2]

$$l_m = 1.74c + 0.057\frac{d}{\rho_{te}} \text{ (rectangle-shaped beam)}, \ l_m = 1.74c + 0.042\frac{d}{\rho_{te}} \text{ (T-shaped beam)} \tag{5}$$

The calculating formula of maximal crack width can be obtained as [2]:

$$W_{\max} = 2.1\psi\frac{\sigma_s}{E_s}l_m, \ \psi = 1.1 - \frac{0.61 f_{tk}}{\rho_{te}\sigma_{ss}} \tag{6}$$

Table I
Comparison Of Calculating And Test Data Of Average Space Of Cracks

Component number	Experimental distance between cracks l_{ms} (mm)	Calculating distance between cracks l_m (mm)	l_{ms} / l_m
JL1	79.18	72.73	1.089
JL2	72.64	72.73	0.999
TL3	74.44	78.10	0.953
TL4	78.09	78.10	1.000

If the value of l_{ms} / l_m is 1.01, the testing results agree with the calculating results very well.

TABLE II
MAXIMAL CRACK WIDTH AND EXPERIMENTAL CRACK WIDTH

Component number	Maximal experimental crack width $W_{max}{}^{s}$ (mm)	Maximal calculating crack width W_{max} (mm)	$W_{max}{}^{s}$ / W_{max}
JL1	0.25	0.273	0.916
JL2	0.27	0.273	0.989
TL3	0.28	0.295	0.949
TL4	0.30	0.295	1.017

It can obtain from Table II that, the value of $W_{max}{}^{s} / W_{max}$ is 0.968. The calculating precision is acceptable.

V. CALCULATING FORMULAE OF RIGIDITIES

Three calculating formulae of structural rigidities are mentioned in this study.

A. Calculating formulae of rigidities for the armoured concrete beams

The calculating formulae of rigidity can be expressed as

$$B_s = \frac{E_s A_s h_0^2}{1.15\psi + 0.2 + \frac{6\alpha_E \rho}{1+3.5\gamma_f^{'}}}, \quad \frac{\alpha_E \rho}{\zeta} = 0.2 + \frac{6\alpha_E \rho}{1+3.5\gamma_f^{'}} \quad (7)$$

Where, B_s is the rigidity, A_s the section area, α_E the ratio of steel bar's elastic modulus and concrete's elastic modulus, ρ the reinforcement ratio of tensile steel bar, ζ the coefficient of colligation of concrete's mean strain, $\gamma_f^{'}$ the reinforced coefficient of the compressive flange, h_0 the effective height of cross section.

B. Calculating formulae of rigidities for the Bi-steel concrete beams

This rigidity calculating formula is only suitable for the cold-drawing, low carbon Bi-steel bar with small diameter. It can be obtained as

$$B_s = \frac{E_s A_s h_0^2}{1.10\psi + \frac{0.1+6\alpha_E \rho}{1+2\gamma_f^{'}}}, \quad \psi = 1.05 - \frac{0.65 f_{tk}}{\rho_{te}\sigma_s},$$

$$\frac{\alpha_E \rho}{\zeta} = \frac{0.1+6\alpha_E \rho}{1+2\gamma_f^{'}} \quad (8)$$

C. Calculating formulae of rigidities for II cold-drawing Bi-steel concrete beams

This calculating formula of rigidity has been brought forward by Zhao and his colleagues [1]. It can be established as

$$B_s = \frac{E_s A_s h_0^2}{1.11\psi + 0.15 + \frac{6\alpha_E \rho}{1+3.5\gamma_f^{'}}}, \quad \eta = 0.9,$$

$$\psi = 1.05 - \frac{0.6 f_{tk}}{\rho_{et}\sigma_s},$$

$$\frac{\alpha_E \rho}{\zeta} = 0.15 + \frac{6\alpha_E \rho}{1+3.5\gamma_f^{'}} \quad (9)$$

D. Calculating formulae of rigidities for III cold-drawing Bi-steel concrete beams

On the basis of two above-mentioned methods, the revised calculating formula can be expressed as

$$B_s = \frac{E_s A_s h_0^2}{1.09\psi + 0.10 + \frac{6\alpha_E \rho}{1+3.5r_f^{'}}}, \quad \eta = 0.92,$$

$$\psi = 1.1 - \frac{0.61 f_{tk}}{\rho_{te}\sigma_s}, \quad \frac{\alpha_E \rho}{\zeta} = 0.10 + \frac{6\alpha_E \rho}{1+3.5r_f^{'}} \quad (10)$$

TABLE III
CALCULATING AND EXPERIMENTAL RESULTS OF RIGIDITIES

Component number	B_s^s from experiment (×1012Nmm^2)	B_s from calculation (×1012Nmm^2)	B_s^s / B_s
JL1	4.979	4.969	1.002
JL2	5.204	4.969	1.047
TL3	8.954	8.907	1.005
TL4	9.164	8.907	1.029

It is shown that the experimental results show a good agreement with the calculated results.

VI. CONCLUSIONS

The conclusions can be obtained as

(1) Because the transverse section is short, the structural stress can be adjusted easily. The velocity of the neutral axis in the structural section will be changed slowly. With the application of the Bi-steel concrete beam, the rigidity of ladder-reinforced steel concrete beams can be improved effectively. And the width of crack will decrease significantly.

(2) The fixing capacity of ladder-reinforcement concrete beam is influenced by the spaces between principal bars. If space between the principal bars could not be changed, the space between transverse bars will decrease. Furthermore, if the crack density increases, the crack width will decrease. If the spaces between principal bars in the concrete beams decrease, the cracks will be dense and narrow.

(3) Under the same load, the practical rigidities of

ladder-reinforced Bi-steel concrete beams will increase by 12%. In the meanwhile, the average space between cracks will decrease by 10%, and the maximal crack width will decreases more than 41%. It can be obtained from the experiment that compared with the common concrete beam, the ladder-reinforced concrete beam can control the crack development by the upper longitudinal reinforcement stresses.

References

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