Experimental study on bending constitutive relation of steel box-concrete combined member

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Abstract

According to the direct homogenization theory of inhomogeneous material, a single medium homogenization constitutive model of the confined concrete in the steel box-concrete combined member has been established, and model parameters have been determined by the measured data of the bending test. By analyzing the theoretical ultimate strength and overall process curve, the results obtained is consistent with the curve measured by the test, which proves the bending constitutive relation of steel box-concrete combined member is correct.

Keywords*: *Experimenter, steel box-concrete combined member , bending constitutive relation

1. INTRODUCTION

When the restrained concrete is acted upon by lateral pressure, its ultimate compressive stress and ultimate compressive strain are improved significantly. Since 1903 when Considere first proposed that using spiral hoop can constrain axial-compression column effectively, people has studied the constitutive model of the restrained concrete for one hundred years. Meantime, many stress and strain constitutive models have been put forward, such as Chan's model, Sargin's model, Kent – Park's model, Zhang Xiuqin's model, Saatcioglu's and Vallenas' model, Sheikh's model, Mander's model, Fafitis' model, Lin Tongyan's model, Xing Qiushun's model, and so on1. Zhang Xiuqin's model2 is based on the research of the work of plain concrete, and studied the stress - strain curves of the restrained concrete under different steel ratios by experiment, besides, and obtained the corresponding equation. In Sheikh's model3 , the strength and ductility of four axial-compression restrained concrete members with different composite reinforcement section form, reinforcement ratio , stirrup spacing has been studied, and stress - strain skeleton curves of the restrained concrete have been put forward. Kent – Park's model4 is also based on the research of ordinary reinforced concrete, without the consideration of the effect of stirrup layout styles on the mechanics properties of concrete. Saatcioglu's 5 is based on the experiment of the memembers with the constraints of circular hoop, simple square hoop, composite reinforcement, or rectangle hoop. However, the ascent stage form adopted is not appropriate, when the strain is approaching to the zero, stiffness will be close to infinity. The expression of Mander's model 6 is concise, with a clear mechanics concept, which can well reflect the phenomenon that concrete ultimate strength and peak strain increases and descending branch changes gently with the increase of effect of restraint .

The steel box-concrete combined member is a new type of stucture, the model mentioned above can not be applied completely to its constitutive relation .Based on the similarity between concrete with the restraint of stiffening rib, steel box and stirrup and concrete with the the restraint of stirrup , this paper adopted the direct homogenization theory of inhomogeneous material 7 and used constitutive model of restrained concrete under a single axle load put forward by Mander et al for reference. The constitutive relationship of restrained concrete under the restraint of stiffening rib, steel box and stirrup has been put forward combined with the characteristics of constraint mechanism

of concrete under the restraint of stiffening rib, steel box and stirrup, which has been verified by experiment.

2. EXPERIMENT DESIGN

2.1. Manufacture of Experiment Specimen:

The experimental material is Q235 ordinary hot rolled steel plate, with the depth of 2.5mm, the measured value of tensile strength is 290Mpa. The maximum grain size of the microconcrete is 10mm， and the measured value of concrete cube fc is 49.3Mpa. Four first grade steel bars have been allocated in the concrete, including two steel bars with the diameter of 8mm above and two steel bars with the diameter of 4mm below. PBH rigid connection was used between concrete and steel box. The specific dimensions are shown in Table 1.

Table 1. Parameter Table of Experiment Specimen

Number	Length (mm)	Width (mm)	Height (mm)	Thickness of the steel plate (mm)	Concrete width (mm)	Eccentricity (mm)	Concrete strength (MPa)	Strength of the steel plate (MPa)	Annotation
M-1	1300	120	180	2.5	60	-	49.3	330	Pure bending beam
M-2	1300	120	180	2.5	60	500	49.3	330	Bending beam
M-3	1300	120	180	2.5	60	220	49.3	330	Bending beam

2.2. Loading Project of Experiment

The experiment of bending beams including pure bending beam and bending beam. In order to get the pure bending section, four points loading method was used while distribution beams were allocated under the lifting jack for loading. As shown in Figure 1.

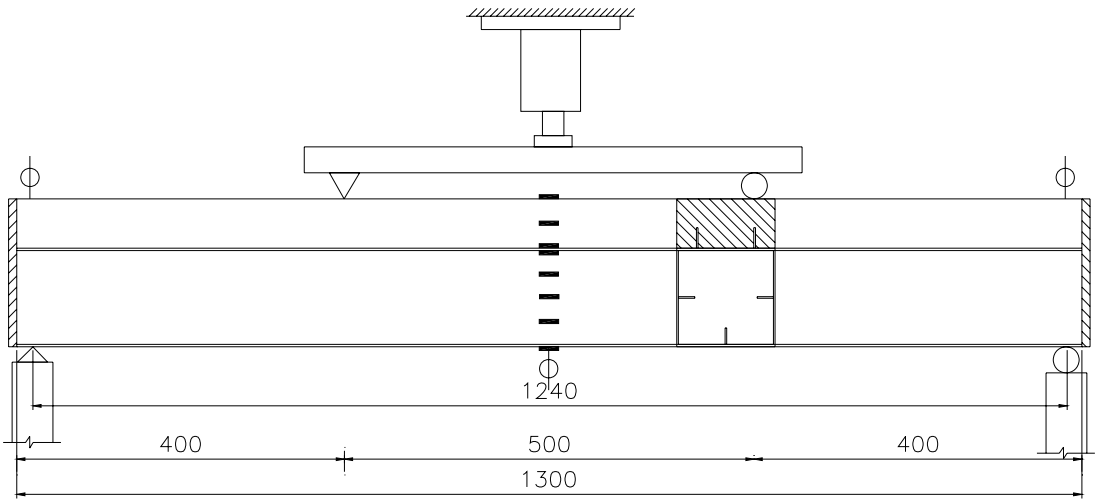

Fig. 1. Loading modes of bending beam in the experiment

The applied force of load , deflection and strain data have been tested during the whole process of the experiment. The concentrated force F was obtained by the force cell. The deflection has been obtained by the dialgage, which has been installed at the supports at the two ends and midspan. The strain of the concrete has been

read by the foil gauge with the gauge length of 50mm, and the strain of the steel plate has been read by the foil gauge with the gauge length of 2 mm.

2.3. Experimental results

The maximum measured values of the strain of steel box and concrete have been shown in Figure 2.

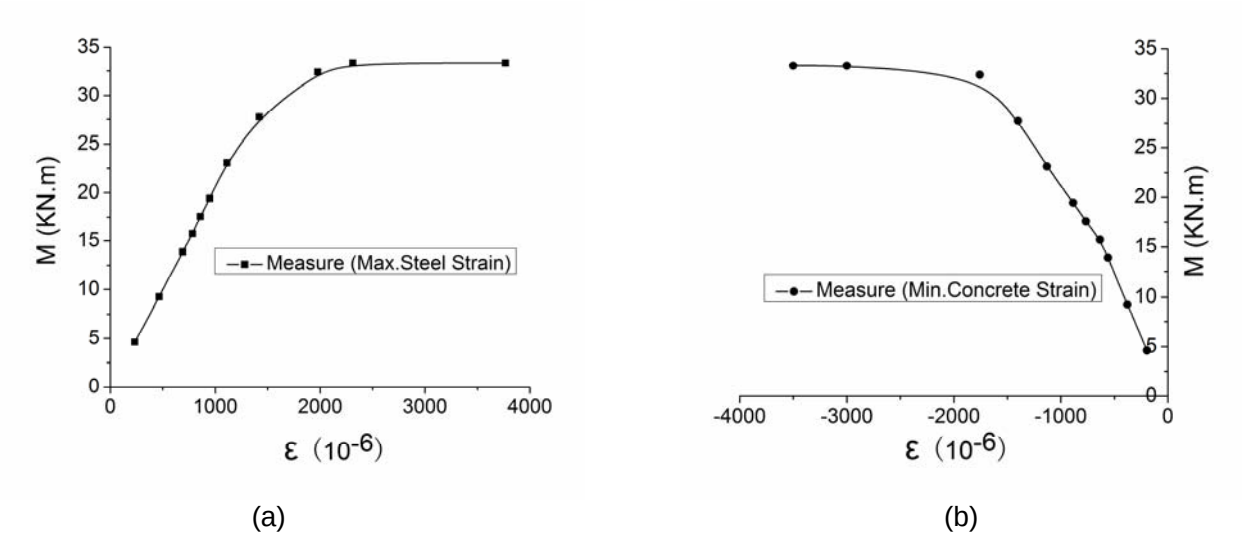

Figure 2. Measured values of the strain. (a) Measured values of the max steel strain (b) Measured values of the min concrete strain

The strain of every section under load is shown in Figure 3. As shown in Figure 3: When the load increases, the strain value increases gradually along the depth of the section, but the profile of the strain is basically touching angle, which consists with section assumption, and there is no obvious strain change at the boundary. Besides, there is a trend that neutral axis ascends a little.

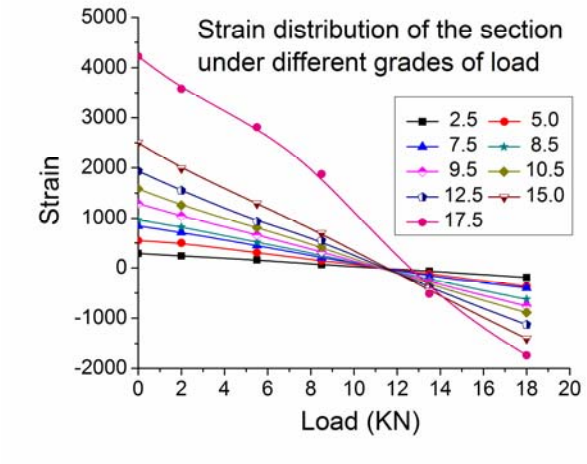

Figure 3 Profile of the strain for each section

3. DETERMINATION OF CONSTITUTIVE MODEL PARAMETER

Mander model is shown in Figure 4, the formulation of each curve is as follows:

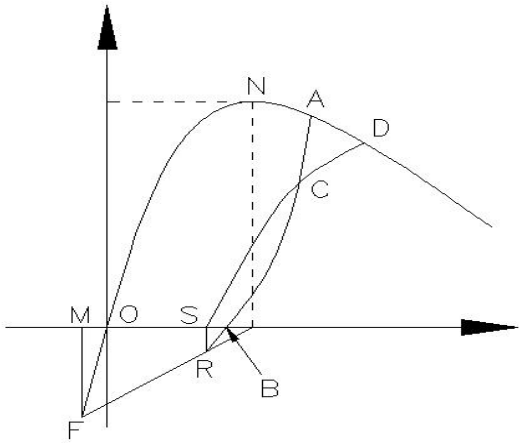

Figure 4. Mander's Model

3.1. The formula of skeleton curve ONAD is as follows:

$$\begin{cases} f_c = \dfrac{f_{cc} x r}{r - 1 + x^r} \\ x = \varepsilon / \varepsilon_{cc} \\ \varepsilon_{cc} = \varepsilon_{c0}\left[1 + \eta\left(\dfrac{f_{cc}}{f_{c0}} - 1\right)\right] \end{cases}$$

3.2. The formula of unloading curve AB is:

$$\sigma = \sigma_u - \frac{\sigma_u x_2 r_2}{r_2^2 - 1 + x_2^{r_2}}$$

Thereinto, $r_2 = \dfrac{E_u}{E_u - E_{\sec 2}}$;

$$E_{\sec 2} = \frac{\sigma_u}{\varepsilon_u - \varepsilon_{pl}} ;$$

$$x_2 = \frac{\varepsilon - \varepsilon_u}{\varepsilon_{pl} - \varepsilon_u} .$$

Eu is the initial tangent modulus of unloading curve.

3.3. The reloading curve is composed of two parts, and SC is straight line, CD is cubic parabola.

The formula of straight line is :

$$\sigma = \sigma_r + E_r(\varepsilon - \varepsilon_r)$$

The formula of curve is:

$$\sigma = \sigma_{re} + E_{re} x_3 + A x_3^2$$

Thereinto, ： $E_r = \dfrac{\sigma_r - \sigma_{new}}{\varepsilon_r - \varepsilon_u}$ ； $x_3 = \varepsilon - \varepsilon_{re}$ ；

$$A = \frac{E_r - E_{re}}{-4\left[\left(\sigma_{new} - \sigma_{re}\right) - E_r\left(\varepsilon_u - \varepsilon_{re}\right)\right]}$$

fc, ε are the axial stress and strain of core concrete respectively, and f_{c0}, ε_{c0} are axial compression strength and peak strain of unconstrained concrete respectively. f_{cc}, ε_{cc} are axial compression strength and peak strain of confined concrete respectively. η is corrected parameter of peak strain. Ere is the tangent modulus of point D on the skeleton curve in Figure 6-9. σ_{new} is the corresponding stress of point C.

By means of pilot calculation , homogenization material constitutive relation of the restrained reinforced beam in the steel box-concrete combined bending member has been obtained after many calculations. The key parameters are as follows: fc0=1.20fck、εc0=0.002； fcc=1.81fck、εcc=0.007056；η=0.5.

4. VERIFICATION OF CONSTITUTIVE RELATION

Overall process analysis have been made for the bending moment- deflection curve and bending moment-strain curve, and the curves are compared with the actual measurement overall process curve (Figure 5 and Figure 6).As shown in Figure 5 and Figure 6, The overall process curves are in good agreement .

The bending moment- deflection curve is as follows.

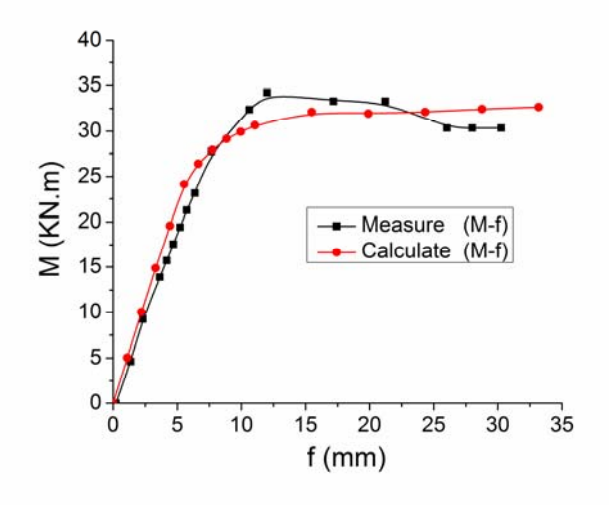

Figure 5: Comparison between experiment value and theoretical value of M-f curve

The bending moment-strain curve is as follows.

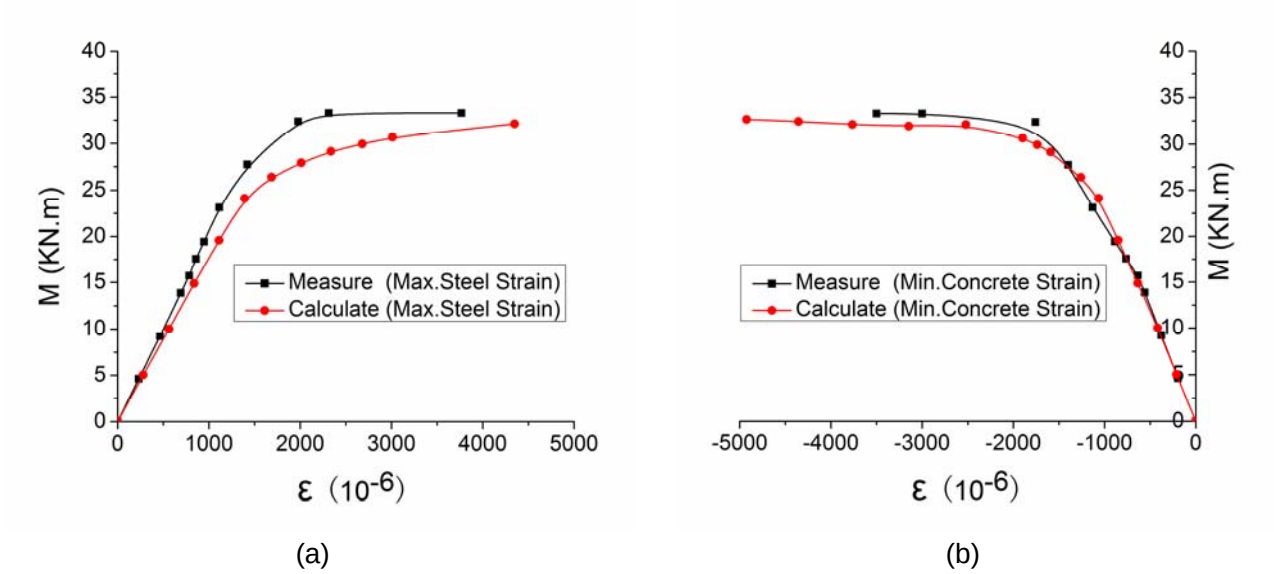

Figure 6: Comparison between theoretically calculated curve and test curve. (a).Comparison between experiment value and theoretical value of the maximum tension strain for M-steel box. (b). Comparison between experiment value and theoretical value of the maximum compression strain for M-concrete

5. CONCLUSION

1) As shown in Figure 5 and Figure 6, the calculated curve is very similar with the test curve in shape, and there is little difference. The calculated strain for the steel box is a bit larger than the test value. This is partly because that the measurement of strain is not the maximum value absolutely, but the average value along the length of foil gauge. The test value of the maximum compression strain for the concrete is in good agreement with the calculated value .

2) The over process curve and test curve of the ultimate strength are in good agreement, which indicates that the constitutive model in the article is suitable for the structural analysis of steel box-concrete combined bending member.

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