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Deflection Test of Post-tensioned Unbonded PC Beam

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***Abstract*-A PC beam was made and different prestressing force was inflicted to the beam to research the relationship between the prestressing force and the short-term stiffness of the full-PC beam and the partial-PC beam. Under all levels of prestressing force, a concentrated force is exerted at third point. At the same time, the deflection of this beam was collected under different kinds of concentrated load value. Through the calculation and analysis of the calculated deflection value, it is found that the short-term stiffness of the beam increases with the increasing of the prestress, which leads to a certain deviation from the calculation formula of the short-term stiffness of PC beams in which, no cracks ,are stipulated in Code for Design of Concrete Structures and Specification for Design of Highway Reinforced Concrete and Prestressed Concrete.In order to calculate the deformation performance of the PC beams more accurately, the paper suggests that it needs to take the influence of prestressing force into account in the calculation of short -term stiffness.**

Keywords-prestressed concrete beam; deflection; short-term stiffness; test

I. INTRODUCTION

The short-term stiffness of the full-prestressed concrete beam is an important parameter to calculate the deflection of the beam and the dynamic performance of the beam. The second paragraph of article 7.2.3 of *Code for Design of Concrete Structures*(*GB50010-2010)*prescribes that[1]: The short-term stiffness Bs of prestressed concrete flexural member without cracks is equal to $0.85E_cI_0$. The second paragraph of article 6.5.2 of S*pecification for Design of Highway Reinforced Concrete and Prestressed Concrete (JTG D62-2004)* prescribes that[2]: The short-term stiffness of flexural member of full-prestressed concrete and prestressed concrete of chass A, B_0 , is equal to 0.95 E_cI_0. But in fact there are a lot of literatures which indirectly prove that the prestressing force is related to the stiffness of the beam[3,4,5]. The relationship between the short-term stiffness and the prestress of PC beams was researched by making the load -deflection test of PC beams in this paper. The result can provides reference basis for PC beam in its structure design[6], construction[7], maintenance of normal use period, safety monitoring, etc[8,9].

II. TEST DESIGN

A. Test Component Design

A non-bonded prestressed concrete beam, made in the laboratory of Structural Laboratory of Taizhou University in March 2016, is used to make a loading experiment, which helps to study the influence of the existing prestress on the short-term stiffness of the concrete beam.In the first place, pull the prestressing tendon and exert prestress of different levels to the beam and simulate the size of the existing prestress in the prestressed beam .Under each level of prestress, load at the third point of the beam and collect the mid span deflection. Analyze the deflection variation of beams at different loads under prestress of different levels. The size of beam section and other parameters are shown in Fig. 1. Among those, the size of the regular reinforcement is 4Φ6, and the type of the reinforcement is HPB300; The size of the prestressed steel strand is $7\Phi^S5$, and f_{ptk}=1720MPa.

In order to minimize the influence of cracks and other factors on the stiffness of beams,it is required that there is no crack in the beam under the action of prestress,and the buckling failure and compression failure cannot be produced.Under the above several conditions, it is easy to determine the size of the tensile stress, and the maximum value of the actual tension cannot be greater than 101kN.It is necessary to use the maximum tensile strength of 90kN to ensure safety.

Start from prestress of 0, and pull the tension to the maximal tension of 90kN by dividing the tension into 5 levels on average .Go on multi-stage loading process after pulling the tension to the scheduled prestress, then collect the deflection value of the beam and pull the tension to the next level after collecting. Actual tensioning levels are shown in Tab. 2.

TABLE I. THE CLASSIFICATION OF NON-BONDED PRESTRESSED TENSIONS

Stretching force P(kN)	Standard values of prestressed steel strand strength f_{ptk}(MPa)	Prestressed steel strand area A_p(mm^2)	Control stress for prestressingσ_{con} (MPa)	σ_{con}/f_{ptk} (%)
0	1720	139	0	0
16.7	1720	139	120.1	6.99
34.9	1720	139	251.1	14.60
52.5	1720	139	377.7	21.96
69.0	1720	139	496.4	28.86
88.3	1720	139	635.3	36.93

B. Cracking Load Calculation

The load size should be controlled, and the beam bending failure or shear failure should be avoided, when beam is put the third points loading. The preliminary design in the third points loading is 0.49 kN. The bending moment of beam span is:

$$M(x) = R_A x - 0.5qx^2 + Fx - F(x - l/3) \quad (1)$$

M reached maximum value is required:

$$\frac{dM(x)}{dx} = 0 \quad (2)$$

Equations (5) available: $x = l/2$ and $M_{\max} = 0.587\text{kN.m}$
Maximum normal stress of the beam section is:

$$\sigma_{\max} = \frac{M_{\max}}{I_0} y_{\max} \quad (3)$$

The I0 above is cross section moment of inertia of the beam. ymax is the distance of section centroid to the edge.

The parameters were put into the formula to calculate, and the result is:

$$\sigma_{\max} = 1.73\text{N/mm}^2$$

The tensile strength of C40 concrete material stated value is $f_{tk} = 2.39\text{N/m}^2$, so the PC beam won't appear cracks.

C. Beam End Partial Pressure Calculation

Local compression bearing capacity of PC beam which place the grid type or indirect spiral reinforcement shall meet the following requirements:

$$F_l \le 0.9(\beta_c \beta_l f_c + 2\alpha \rho_v \beta_{cor} f_{yv}) A_{ln} \quad (4)$$

The area of the steel plate under the anchorage is110mm×110mm, so:

$$A_{ln} = 110 \times 110 - (15.2^2 \times \pi)/4 = 11918.6\text{mm}^2 \quad (5)$$

Put $\beta_c = 1.0$, $\beta_l = 1.0$, and $f_c = 19.1\text{N/mm}^2$ into equation (4):

$$F_l = 90\text{kN} < 0.9(\beta_c \beta_l f_c + 2\alpha \rho_v \beta_{cor} f_{yv}) A_{ln} = 204.87\text{kN} \quad (6)$$

The results meet the provisions of the code for concrete structure design.

III. TEST RESULT

A. Determination of Strength

Leave a set of 150mm cube test blocks when pouring the model beam, and conduct a compressive strength test of concrete after standard curing for 28 days. Then use the cube test blocks to conduct an elastic modulus test with a set of 150mm×150mm×300mm prism test block.

Evaluate the strength of concrete with the methods that are stipulated according to Standard for Inspection and Evaluation of Concrete Strength: The arithmetic mean value of the compressive strength of the three specimens is used as the compressive strength value of the specimen, which is accurate to 0.1MPa. As is shown in Tab. 2.

TABLE II. THE MEASURED VALUE OF STRENGTH OF CONCRETE TEST BLOCK

Block 1 /MPa	Block 2 /MPa	Block 3 /MPa	Average value of strength /MPa	Standard deviation /MPa	Intensity value fcu,k /MPa
41.1	41.1	45.7	42.6	2.17	40.9

B. Determination of Stress-strain Relationship of Concrete

The ratio of stress to strain of concrete is not a constant value. The stress-strain relationship of concrete prism is shown in Fig. 2 (the maximum value of concrete prism loading is about 50% of its compressive strength limit).As can be seen from Fig. 1, the stress-strain curves of concrete under single loading is approximately a straight line, $\bar{\sigma} / \bar{\varepsilon} = 2.5388 \times 104\text{N/mm2}$.

C. Prestressed Concrete Deflection Test

Exert load at third point of the test beam, and the peak load which is confirmed through preliminary determination is 50kg. After checking the load, it is obvious that there will be no load crack in the beam. Exert prestressing force to PC beam according to their levels, at the same time put load on third point of the beam, then collect the mid span deflection after holding load for 5 minutes. The measured value of deflection is shown in Tab. 3.

TABLE III. EFLECTION VALUE OF PRESTRESSED BEAM

Stretch force/kN	Load in a third place/kg					
	0	10	20	30	40	50
0	0	0.099	0.188	0.253	0.353	0.461
16.7	0	0.085	0.165	0.217	0.301	0.428
34.9	0	0.081	0.146	0.203	0.283	0.401
52.5	0	0.080	0.130	0.198	0.278	0.354
69	0	0.071	0.127	0.183	0.265	0.348
88.3	0	0.060	0.121	0.178	0.240	0.342

IV. THEORETICAL ANALYSIS

A. *Calculation Formula of the Code*

The short-term stiffness of PC beam was calculated according to Code for Design of Concrete Structures (GB50010-2010). The expression can be shown in the following:

$$B_0 = 0.85E_C I_0 = 4.804\times10^{11}\,\text{N.mm}^2 \quad (7)$$

The short-term stiffness of PC beam was calculated according to the Code of Concrete Highway Reinforced Concrete and Concrete Bridge Design(JTGD62-2004):

$$B_0 = 0.95E_C I_0 = 5.369\times10^{11}\,\text{N.mm}^2 \quad (8)$$

Calculate the mid span deflection by the material mechanics formula, then exert two concentrated forces to the third point of the beam. The mid span deflection value is:

$$f = (2Fl/144B_0)(3l^2 - 4l^2/9) \quad (9)$$

The calculated deflection values are shown in Tab. 4.

TABLE IV. DEFLECTION CALCULATION OF PC BEAM

Load of the third point P(N)	98	196	294	392	490
Code 1 f(mm)	0.077	0.154	0.231	0.308	0.386
Code 2 f(mm)	0.069	0.138	0.207	0.276	0.345

B. *Comparison of Experimental Results and Calculation Value*

Take the deflection of the prestressed beam with tension force of 88.3kN as an example, when the load is 392 N at third point ,compared with the calculated values of the two codes ,the error between the deflection value calculated by the stiffness of the Code for Design of Concrete Structure (GB50010-2010) and the deflection value from the test is 28.33%.And the error between the deflection value calculated by the stipulation of Specification for Design of Highway Reinforced Concrete and Prestressed Concrete and the deflection value from the test is 15%. As is shown in Figure III, the deflection value that is calculated by the standard is close to the deflection value without prestressing force. Under the larger prestressing force, the error of the deflection of beam that is calculated by the short- -term stiffness with the specification is much larger.

V. CONCLUSIONS AND RECOMMENDATIONS

It can be seen from the experimental results that prestress has a significant impact on the short-term stiffness of the full- prestressed beam. The greater the prestress is, the greater the stiffness of the beam will be, and under the same load, the deflection of the beam will be smaller. And yet the existing literature or the specification does not consider the effect of prestress on the short-term stiffness of the beam. Therefore, the authors suggest that the influence of prestress on the stiffness should be considered in the design of the component with more precision. In addition, according to the results of the test it can be seen that there is a close relationship between the deflection increment of the full-prestressed beam and the prestressing force, thus the increment of deflection can be utilized to predict the loss of prestressing force.

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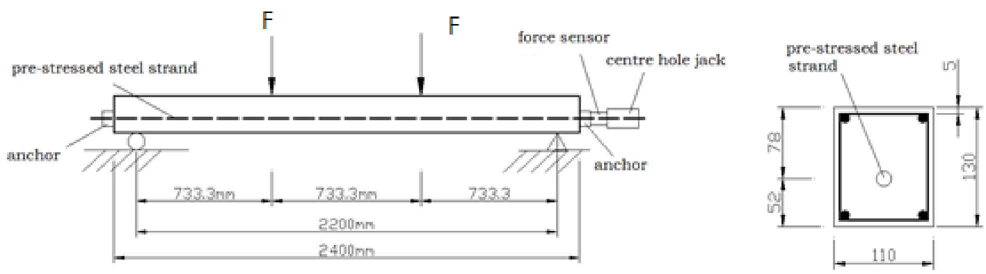

Figure 1. Schematic diagram of test beam

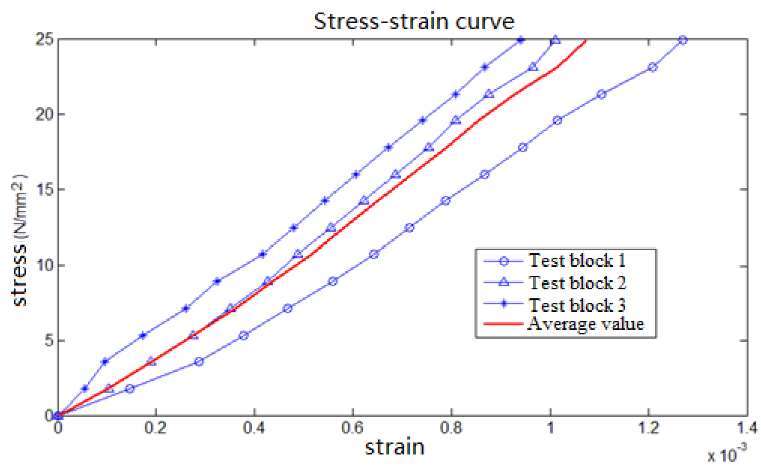

Figure 2. Stress strain curve of concrete test block

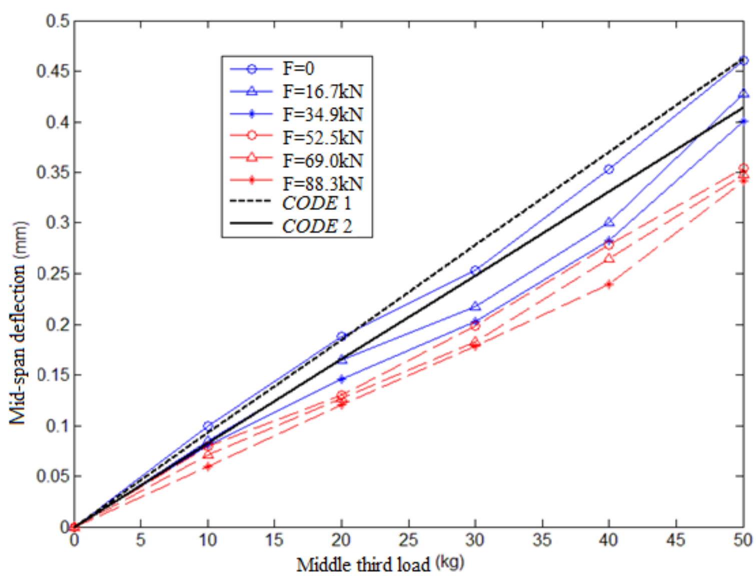

Figure 3. Comparison between experimental results and calculated results

Note: F is the stretching force on the PC beam.
CODE 1 is Code for Design of Concrete Structures (GB50010-2010).
CODE 2 is Code for Design of Highway Reinforced Concrete and Prestressed Concrete (JTGD62-2004).