Experimental Study on Flexural Capacity of Ultra-High Performance Concrete-Concrete Composite Simply Supported Beam

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Abstract. In order to study the flexural capacity of prestressed ultra-high performance concrete-normal concrete (UHPC-NC) composite beams, a four-point bending test of a 13 m full-scale prestressed UHPC-NC composite I-beam was carried out. The test recorded the main results of the test beam from the loading to the failure stage: the stress process of the UHPC-NC composite beam, the strain distribution of the mid-span section, the crack development mode and the failure mode.

Keywords: Ultra-high performance concrete composite beam; bending bearing capacity; prestressed concrete structure; experimental study

1 Introduction

Ultra-high performance concrete (UHPC) is a new type of fiber reinforced cement composite material. Compared with ordinary concrete, it has many excellent properties such as high strength, small creep and good durability [1-5]. In order to improve the brittleness of its matrix, the incorporation of steel fiber in the matrix can effectively improve its tensile properties, strength and toughness [6].

Some scholars proposed a new type of NC-UHPC composite beam structure with UHPC as the tension zone and ordinary concrete (NC) as the compression zone. The prefabricated UHPC beam element is connected with the NC bridge deck through shear connectors. The UHPC-NC composite beam bridge can make full use of the superior tensile properties of UHPC and the excellent compressive properties of NC.

At present, the research on the flexural bearing capacity of prestressed UHPC-NC composite beams in China is not perfect, and the research results of full-scale model beams are less. Therefore, in order to accurately predict the performance of prestressed UHPC-NC composite beams in the whole process of bending resistance, and provide guidance for the design of prestressed UHPC-NC composite beam bridges. In this paper, the full-scale flexural bearing capacity model test of UHPC-NC composite beam is carried out.

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2 UHPC-NC Composite Beam Test

2.1 Test Structure

The main girder of the composite structure is an UHPC-NC composite I-beam. The beam includes a prefabricated UHPC prestressed I-beam element, and is covered with a UHPC bridge deck and a C50 ordinary concrete bridge deck at its top. These components are connected by shear key reinforcement embedded in the UHPC beam element. In this paper, the UHPC-NC composite I-beam is 13 m long. The arrangement spacing of transverse steel bars in the bridge deck is 100 mm, and HRB400 steel bars are used. In this paper, 16 (7Φs15.2) 1860 grade steel strands are arranged in UHPC-NC composite beams. The size structure of UHPC-NC composite beam is shown in Figure 1.

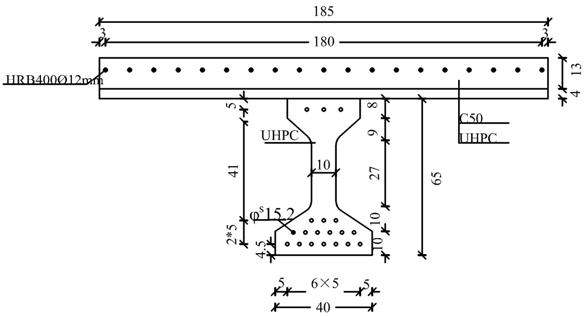

Fig. 1. UHPC-NC composite beam structure diagram

2.2 Test Beam Material and Production

The main components of UHPC used in this paper include cement, quartz sand, quartz powder, silica fume, steel fiber and other dry powders. The length of steel fiber is 13 mm, the diameter is 0.2 mm, the ratio of length to diameter is 65, and the volume content is 2 %. The ordinary concrete used is C50 concrete. The prestressed steel strand of main girder adopts high strength and low relaxation steel strand. Its technical standard conforms to the relevant regulations and specifications of grade II relaxation (low relaxation) steel strand in the current national standard. The diameter is Φs15.2 and the tensile strength is 1860 MPa.

2.3 Testing Apparatu

In the test shown in Figure 2, the four-point bending test method is used to load, and two 100-ton hydraulic jacks are used to apply the load. The pure bending section of the test beam is 3.06 m long, and the shear bending section is 4.98 m long. In the initial stage of loading, each stage is loaded with 50 KN, and after the load is increased to 600 KN, each stage is increased by 25 KN. The on-site loading of the test beam is shown in Figure 3.

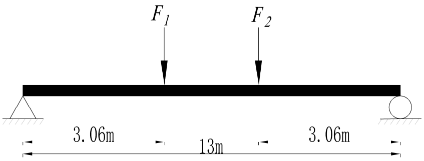

Fig. 2. Loading diagram of test beam

Fig. 3. Field loading diagram of test beam

2.4 Test Plan

The test content mainly includes the collection of data such as load-displacement curve, load-stress curve, cracking load, yield load, ultimate load and the development of specimen failure cracks. The pressure sensor is arranged under the jack to test the size of the load. Along the longitudinal direction of the beam, displacement sensors are arranged at the mid-span and quarter-point of the beam bottom to collect the deflection of the test beam. The arrangement of measuring points is shown in Fig.4. Five typical sections of the whole test beam were selected for strain test, including mid-span section, L / 4 section, 3L / 4 section and fulcrum section. The arrangement of strain gauges in each section is shown in the Figure 5.

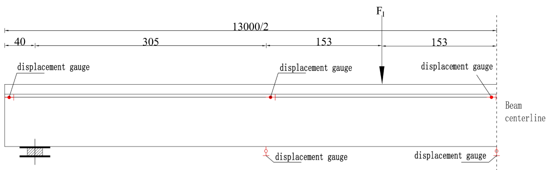

Fig. 4. Displacement measuring point arrangement of test beam

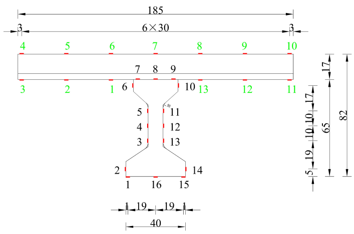

Fig. 5. The cross section diagram of strain gauge (strain flower) arrangement of test beam

3 Experiment Results and Analysis

3.1 Load Displacement Analysis

The load-midspan deflection curve of the test beam from loading to failure is shown in the Figure 6. The curve can be roughly divided into three stages :

Linear elastic stage, crack development stage, prestressed reinforcement yield stage.

Elastic stage (OA stage) : When the load is small, the relationship between the load and the mid-span deflection is linear, and the composite beam is in the linear elastic stage. The stiffness of the composite beam is provided by the uncracked UHPC matrix, C50 and prestressing tendons.

Fracture development stage (AB section). With the increase of load, when the strain of UHPC material in the tensile zone of the section exceeds the elastic limit strain, the test load reaches 880 KN, and the mid-span displacement of the corresponding test beam reaches 28 mm. Multiple micro-cracks are gradually generated in the test beam, and the beam is heard from time to time. Visible cracks begin to appear in the pure bending section of the test beam, and the sound of steel fiber tearing in the beam becomes more and more obvious. The overall stiffness of the test beam decreases significantly, the number of visible cracks increases gradually, and the width and length of cracks also increase gradually . The limiting effect of prestressed tendons on cracks is weakened.

Prestressed tendon yield stage (BC section). At this time, the test load reaches 1500 KN, and the mid-span displacement of the corresponding test beam reaches 120 mm. The stress (or strain) of the prestressed tendon exceeds the yield strength (or yield strain) as the load increases. Macroscopically, the slow growth of bearing capacity and the rapid growth of deformation are presented. The continuous increase of the deformation of the prestressed tendons after the yield of the test beam shows that the test beam has good ductility. The continuous increase of the test load leads to the rapid expansion of the main cracks in the section, and the UHPC powder continues to fall from the cracks. When the test load approaches the peak value of 1550 KN, the jack continues to apply pressure, and the deflection of the beam increases continuously. The main crack develops rapidly until the top of the main beam, accompanied by the great sound of the bottom prestressed reinforcement breaking, and the test beam is finally damaged by bending, as shown in the Figure 7.

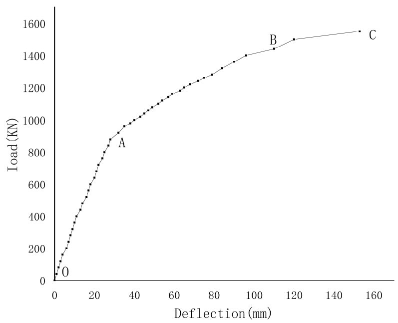

Fig. 6. Mid-span load-deflection curve

Fig. 7. The destruction of the experimental beam

In this paper, the load when the visible crack is generated is defined as the cracking load, the load when the prestressed tendon reaches the yield is defined as the yield load, and the maximum load in the test is defined as the ultimate load. The elastic ultimate load, yield load, ultimate load and corresponding displacement of the test beam are summarized in Table 1.

Table 1. Main test results

	load at first crack	yield load	failure load
load（KN）	880	1500	1550
mid-span moment（KN•m）	2015.20	3435	3549.5
mid-span displacement（mm）	28	135	152.92

3.2 Load Strain Analysis

Seven strain gauges are arranged along the transverse direction on the top surface of the mid-span, which are A4, A5, A6, A7, A8, A9 and A10 strain gauges. The relationship between roof strain and load is shown in Figure 8. At about 880 kN, the slope of the curve in the load-roof longitudinal strain diagram begins to change, indicating that the stiffness of the test beam changes here, and cracks appear in the beam. With the increase of load, the strain distribution in each transverse position is not uniform, and the strain at the intersection of bridge deck and web (A7 # strain gauge) is the largest, which has a certain shear lag phenomenon. The difference between the compressive strain at the root and the end of the flange before the failure of the test beam reached 216.29, reaching 22 % of the maximum strain at the root of the flange.

The strain distribution of the roof and web on the left side of the mid-span section of the pure bending section along the beam height is drawn as shown in Fig.9. The results in the figure show that at a lower load level, the strain of the test beam is linearly distributed along the beam height, and the distribution map is approximately triangular, which basically satisfies the plane section assumption. When the load is greater than the cracking load, the subsequent strain gauge data can no longer reflect the true strain of the test beam.

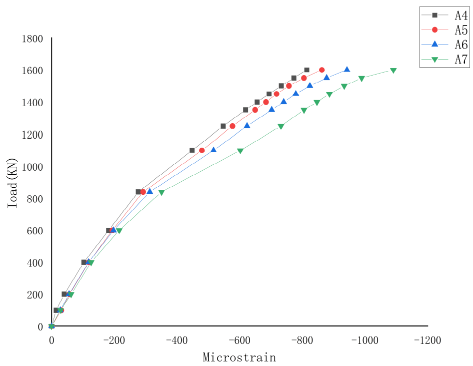

Fig. 8. Mid-span load-roof longitudinal strain relationship diagram

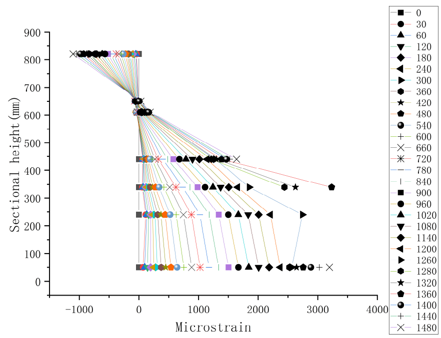

Fig. 9. Height-strain curve diagram of mid-span section

4 Conclusions

1. The flexural failure mode of UHPC-NC composite beams can be divided into three stages : linear elastic stage, crack development stage and prestressed reinforcement yield stage. The strain distribution of the cross section of the test beam satisfies the plane section assumption.
2. The UHPC-NC composite beam has a certain shear lag phenomenon. The influence of shear lag cannot be ignored in the design of the main beam of this new composite structure.

References

1. Graybeal B. Material Property Characterization of Ultra-High Performance Concrete[J].creep, 2006.
2. Kong Lingfang, Shao Xudong, Liu Rong. Finite Element Analysis of Flexural Performance of Steel-UHPC Lightweight Composite Beam Bridge Decks. Journal of Highway and Transportation Research and Development, 2016, 33(10): 88-95.
3. Chen Liang, Yang Lifei, Xu Weimin, et al. Optimization of Steel Fiber Content in UHPC Based on Mechanical Performance Tests and Cost-Effectiveness Analysis. Journal of Highway and Transportation Research and Development, 2021, 38(S1): 18-25.
4. Shao Xudong, Fan Wei, Huang Zhengyu. Application of Ultra-High Performance Concrete in Structures. China Civil Engineering Journal, 2021, 54(01): 1-13.
5. Shao Xudong, Qiu Minghong, Yan Banfu, et al. Research and Application Progress of Ultra-High Performance Concrete in Bridge Engineering Both Domestically and Internationally. Materials Review, 2017, 31(23): 33-43.
6. BASTIEN-MASSE M,DENARIE E,BRUHWILERE.Effect of fiber orientation on the in-plane tensileresponse of UHPFRC reinforcement layers[J]. Cementand Concrete Composites,2016,67: 111-125.