Automation in Construction 37 (2014) 196–202

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Experiment and analysis of flexural capacity and behaviors of pre-stressed composite beams

Hu Shaowei *

Department of Materials and Structural Engineering, Nanjing Hydraulic Research Institute, Nanjing 210029, China

ARTICLE INFO

Article history:
Accepted 20 August 2013
Available online 20 September 2013

Keywords:
Pre-stressed composite box beam
Load deflection behaviors
Serviceability limit state
Ultimate flexural capacity
Interface slip
Experiments research on bending behaviors
Calculation of deflection
Bearing capacity

ABSTRACT

At present, there is no design specification for the pre-stressed composite beam. To research the bending mechanical behaviors of pre-stressed steel–concrete composite box beams and provide corresponding design specification and requirements, the tests of ten pre-stressed composite box beams were finished, and the effects on flexural behaviors were given for different initial pre-stress levels, the forms of reinforcement placement and loading method and so on. Design calculation methods under serviceability and bearing capacity limits were mainly discussed. Test results indicated that the pre-stressed composite beam displays a lot of advantages compared with ordinary composite beams. The flexural capacity of the composite beams through using pre-stressed technology was greatly increased. The elastic-plastic analysis of the pre-stressed composite beams was finished; what's more, the equations of deflection and elastic bearing capacity with consideration of interface slip were derived out. Calculating equations for ultimate banding capacity were derived with consideration of pre-stress increments. Finally, the calculated values met precise requirements when compared with the test results. This study provides advisory opinions for the designer to analysis and design of the pre-stressed composite beams.

1. Research significance

In recent years, the use of pre-stressed composite beam structures has increased significantly with various types of bridges being used in urban overpasses, and railway and highway bridges [1]. Advantages of the pre-stressed composite box beams include large flexural rigidity, torsion rigidity, good integral performance and high stability and so on. In 2005, Liu, Hanbing [2] provided the structural behavior of eight external pre-stressed steel–concrete composite beams with 4.0 m span from symmetric loading and bending tests. Nie, Hu (1999)[3] presented the experimental studies of the flexural behavior of steel–concrete composite beams, and four simply supported composite beams subjected to two-point concentrated loads were tested and compared to investigate the effect of high strength engineering materials. However, there is no design provision for the pre-stressed composite beam in the current standards [4,5]. In the past, the study on the flexural behavior of composite beams had focused mainly on non-prestressed section beams ([6], [7], [8]). In this paper, to understand the flexural behavior of pre-stressed steel–concrete composite box beams, the tests of ten full-scale pre-stressed composite box beams were conducted. Furthermore, real-time measurement and loading of the pre-stressed tension process were performed, mainly measuring changes in strain, interface slip and deflection of feature positions. The practical calculation formula for deflection and bearing capacity under serviceability limit state and bearing capacity were derived out; theoretical and experimental results were compared according to the stress characteristics of beams. Results from this paper provide the foundation for further improvements in design theory and analysis of pre-stressed composite box beams.

2. Pre-stressed composite box beams experiment

2.1. Test design

Ten pre-stressed steel–concrete composite box beams with number 15 to 24 were designed. The specimen cross-sectional structure, parameters and the loading apparatus were shown in Fig. 1, Table 2 and Fig. 2, respectively. The cross-sectional size was determined mainly by its elastic neutral axis location. Generally, the neutral axis was set in the precast slab above the interface and as close as possible to the steel beam to promote the favorable attributes of the two kinds of material. The hydraulic servo machine was used, and the force values of two hydraulic jacks were the same using the bleeder (Table 1).

2.2. Test results and analysis

The bearing capacity decreases with concrete crushing at the section of maximum bending (see Fig. 3). In Table 2, M_y, δ_y and ΔP_y are the mid-span moment, mid-span deflection and pre-stressed reinforcement force increment, respectively. When the steel beam bottom yielded, M_u, δ_u and ΔP_u is the mid-span moment, mid-span deflection and pre-stressed reinforcement force increment in the limit state of the bearing

* Tel.: +86 2585829601.
E-mail address: hushaowei@nhri.cn.

0926-5805/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.autcon.2013.08.004

capacity, respectively. P_u is the pre-stressed reinforcement force in the limit state of the bearing capacity.

From Table 2, the pre-stress expands the elastic scope of the beam and increases bearing capacity when compared with an ordinary composite beam. For the linear-type composite PCB-15 and PCB-17 without limit block, the load increases from 247.23 to 262.31 kN m when the steel beam bottom yields. Similarly, as for the fold-line type pre-stressed reinforcement placement, the pre-stressed reinforcement of PCB-20 is two times as that of PCB-19. Although initial effective pre-stress is relatively low, its limit bearing capacity is relatively high. As for the linear-type with limit block such as PCB-23, the increment in pre-stress reinforcement force is 167.8 kN due to its increase in steering block function and eccentricity. Comparing PCB-19 with PCB-23 shows that when the effective pre-stress is the same as the eccentricity, fold-line type M_y with reinforcement placement is relatively large. For the pre-stressed composite beam without limit block at the limit state, the yield ratio and ductility ratio are lower than the ordinary composite beam, but as for the pre-stressed composite beam with limit block or steering block, the yield and ductility ratios are higher than other beams. Figs. 4 and 5 show the slip distribution in longitudinal direction and the slip increase for PCB-15 and CB-16.

Fig. 4 shows that the slip distribution is similar in both the pre-stressed and ordinary composite beams. From Fig. 5 it can be seen that the load–slip curve of the pre-stressed composite beam can be divided into three stages. Initially, no slip occurs at the interface. In the second stage, the increase of slip is relatively slow. In the third stage, concrete surrounding the studs is gradually drawn to the crack, and bending of the stud and crack of the concrete is the main sources of slip and the slip increases fast relatively.

3. Serviceability and bearing capacity limit states

3.1. Determination of the shear rigidity of the stud

In China's current standard, Code for Design of Steel Structures (GB 50017-2003), the influence of slip on the flexural rigidity of composite beam is considered with the reduced rigidity methods. Both the rigidity reduction coefficient ζ and the composite functioning coefficient ϕ are related to the shear rigidity k of the stud connector. Various shear–slip curves have been proposed for the stud connector. The proposed model in the paper is comprehensively applied as follows:

$$V = V_u\left(1-e^{-ns}\right)^m \quad (1)$$

V_u is the limit bearing capacity of the studs, s is the slip, and m and n are parameters achieved from the test.

The anti-slip rigidity of the stud can be said to equal its limit i.e.

$$k = N^c_{v,k}. \quad (2)$$

In this case, $N^c_{v,k}$ is the standard value of the bearing capacity rather than the bearing capacity of the studs.

ECCS1981 Composite Structures provides an equation to calculate the standard value of the stud shear bearing capacity

$$N^c_{v,k} = 0.46A_s\sqrt{f'_{ck}E_c} \le 0.7f_uA_s \quad (3)$$

The stud bearing capacity equation as given by European standard EC4 has been changed into a design value expression equation

$$N^c_v = \frac{0.37A_s\sqrt{f'_{ck}E_{cm}}}{\gamma_v} \le \frac{0.8f_uA_s}{\gamma_v} \quad (4)$$

China's Code for Design of Steel Structures (GB50017-2003) states that the design value of the stud bearing capacity is

$$N^c_v = 0.43A_s\sqrt{f_cE_c} \le 0.7f\gamma A_s = 1.169fA_s \quad (5)$$

f'_{ck} is the characteristic value of the compressive strength of a 150 × 300 mm concrete cylinder; E_{cm} is the average elastic modulus of the concrete; γ_v is the resistance factor of the stud bearing capacity (1.25 is suggested for EC4); A_s is the cross-sectional area of the stud; f_u is the limit tensile strength of the stud material; f is the design value

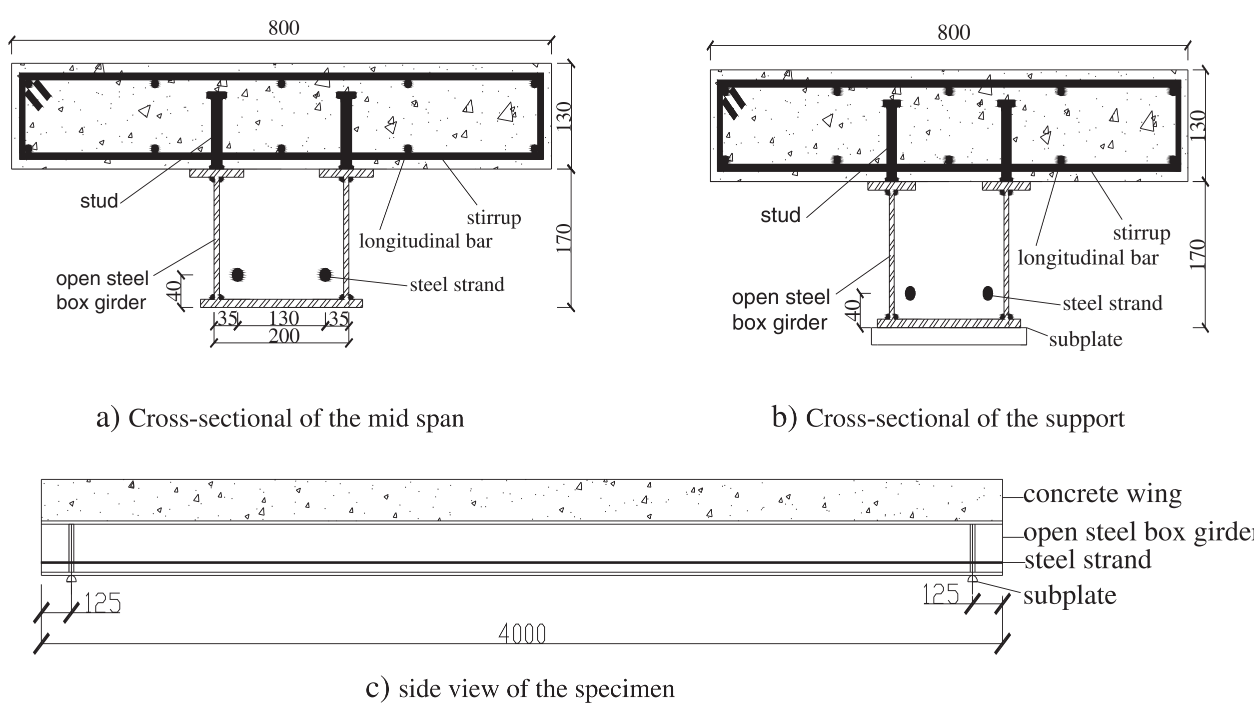

Fig. 1. Cross-sectional details of beam specimen. (a) Cross-sectional of the mid span. (b) Cross-sectional of the support. (c) Side view of the specimen.