Construction and Building Materials 188 (2018) 833–849

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental study on fatigue performance of composite beam with steel-plate-concrete composite decks

Ruyue Liu *, Yong Yang, Xianwei Zhou

Department of Civil Engineering, Xi'an University of Architecture and Technology, Shaanxi 710055, China

HIGHLIGHTS

- A new type of composite deck was used in the composite beam.
- The calculation method for stiffness of composite beam under fatigue loading was proposed.
- The fatigue behavior of composite beam under positive and negative bending moment was tested and analyzed, respectively.

ARTICLE INFO

Article history:
Received 31 May 2018
Received in revised form 9 August 2018
Accepted 17 August 2018

Keywords:
Composite beam
Steel-plate-concrete composite deck
Fatigue performance
Failure mode
Experimental study

ABSTRACT

In order to study the fatigue performance of composite beam with steel-plate-concrete composite deck under fatigue load, both static test on two specimens and fatigue test with constant-amplitude fatigue load on six specimens were conducted. The influence of the upper limit and lower limit of fatigue load as well as the amplitude of fatigue load on the failure mode and failure damage was studied both under sagging moment and hogging moment. In addition, for the tested specimens under fatigue load, the dynamic deflection, residual deflection, strains of concrete and steel plates, strain of steel beam, residual capacity and the flexural stiffness were recorded and analyzed. The experimental results demonstrated that the failure mode of specimens under sagging moment was the fracture of steel plate of composite beam, resulting in the concrete crush in compression region, however, the specimens under hogging moment developed good fatigue behavior with comparatively high bearing capacity and stiffness and no fatigue failure was found finally. The fatigue life was directly affected by the stress amplitude of fatigue load while the upper limit and lower limit of fatigue load had little influence on it. The conclusion obtained in the paper was helpful for the design of this type of composite beam.

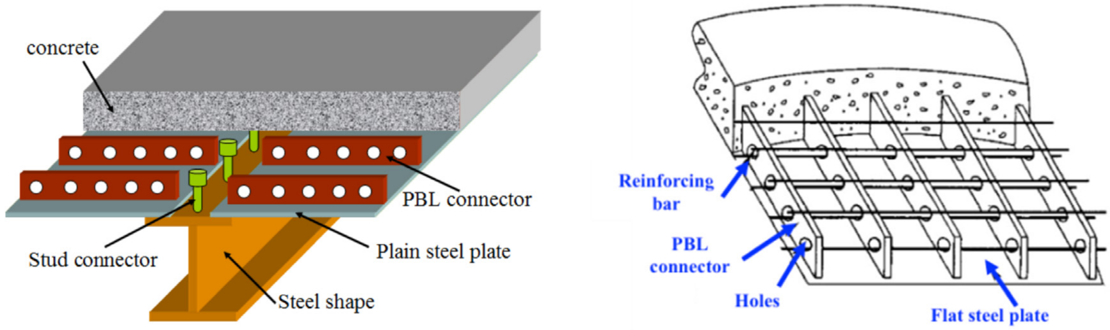
0. Introduction

As an innovative type of composite beam with steel-plate-concrete composite deck (abbreviated as composite beam in this paper for brevity), the H-shaped steel beam was connected with the composite deck by studs (shown as Fig. 1a), and for the composite deck, the steel plate was connected with concrete by steel plate with openings (shown as Fig. 1b). This new type of composite beam takes the advantage of component materials, obtains efficient lightweight components, and solves the problem of temporary framework and scaffoldings with the steel plate, reducing the construction period and saving costs. Moreover, with steel-plate-concrete composite deck, the composite beam could be used in beam with larger span without necessary excessive secondary beams.

It is known to us that for steel-plate-concrete composite deck, it is important to ensure the shear force transferring between the steel plate and the concrete, therefore, it is of significance to set up reliable interaction between these two members. For the steel-plate-concrete composite deck mentioned in this paper, a type of perforbond shear connector (abbreviated as PBL shear connector in this paper for brevity) was used to connect the steel plate and the concrete together with the steel-plate with openings. The PBL shear connector could be used as stiffeners for the flat steel-plate under construction to enhance the flexural stiffness and bending capacity. Besides, considering that the PBL shear connector could work together well with the concrete and develop significant stress under external load, it could be taken as the transverse reinforcement. Therefore, it is unnecessary for other reinforcing bars and reduces the construction cost, and it could also effectively

* Corresponding author.
E-mail address: lry18pig@163.com (R. Liu).

https://doi.org/10.1016/j.conbuildmat.2018.08.108
0950-0618/



(a) composite beam (b) composite deck

Fig. 1. Details of configuration of composite beam with composite deck.

solve the problem of insufficient shearing capacity of concrete in case of unsuitable configuration of transverse reinforcing.

Because of the advantages of this new type of composite beam, it has been gradually applied in the civil construction and industrial construction especially for the large-span bridges [1]. With the rapid development of transportation, it is common that the bridge always suffered from the cyclic load and dynamic load and the demand on tonnage and speed of the vehicles over the bridges grows as well. Although many researches on static performance or the seismic performance of the composite beam have been conducted [2–4], rare study of the fatigue behavior of the composite beam due to the repeated load or dynamic load was performed. According to the statistics, until the end of 2006, a large quantities proportion of 500 thousands existed bridges were designed without taking the fatigue into consideration. If the structure which suffered from fatigue load was designed only with static load, it was of high possibility that unexpected fatigue failure would occur during service period and put threat on the life safety and even brought undesirable losses. Consequently, it was of great significance to study the fatigue performance of composite bridge decks to better understand the mechanism of the fatigue performance of the composite decks and the vibration mechanism under dynamic load [5]. It would be helpful to ensure the safety of the composite beams in service period, and improve the durability and the fatigue-resistance capacity based on the study of fatigue behavior [6].

Strength degradation and stiffness degradation caused by the loss of bounding between concrete and shear stubs were studied [7,8] and the fatigue behavior of stub shear connectors and the crack on concrete deck were also studied [9,10]. The residual deflection behavior of steel-concrete composite beam under negative bending moment was analyzed and the analytical model for the residual deflection was put forward and verified [11]. In addition, considering that different strengthened method were used in old structures to improve the fatigue behavior, Nie and Yu also performed experimental research on the strengthened reinforced concrete beams [12,13]. However, these researches concentrated on the mechanical behavior under positive bending moment. For continuous composite structural members, the composite components would experience both positive and negative bending moment, and it is unfavorable that the composite deck would generate tensile stress under negative bending moment, resulting in serious cracking of concrete and the final collapse. Therefore, it is essential to investigate the fatigue behavior of the composite beam and the influence of negative bending moment on the mechanical behavior of composite deck to ensure the normal working function, the life safety and service life of bridges [14,15]. It had been verified that both the incremental slip at the interface of steel beam and concrete deck and the cracking of the concrete deck would impair the durability and service life of composite beam [16,17]. Besides, combining the influence of sagging moment and high-cycle repeated loadings, the decrease of both static and fatigue resistance would be serious and the ductility and service life of composite beams might be unfavorably affected.

Based on this background, a series of fatigue tests with 3 composite beams under sagging moment and 3 specimens under hogging moment were conducted. Besides, static test for specimen under sagging moment and hogging moment and the final static test after fatigue test were also performed to furthermore investigate the influence of different load pattern on the fatigue behavior of such type of composite beams.

1. Test program

1.1. Specimens design

Eight composite beams were designed for the test, including 2 for the static test and 6 for the fatigue test. Table 1 listed the major

Table 1
Parameters of composite beam specimens.

Specimen No.	L/mm	T/mm	W/mm	λ	Layout of stubs	steel plate with openings	Longitudinal reinforcement	f_{cu}/MPa
CBP-1200-0	3300	350	1200	3.41	Φ16 × 65@50	14 × 70 × 565@240	2,15Φ12	17.48
CBP-1200-1	3300	350	1200	3.41	Φ16 × 65@50	14 × 70 × 565@240	2,15Φ12	
CBP-1200-2	3300	350	1200	3.41	Φ16 × 65@50	14 × 70 × 565@240	2,15Φ12	
CBP-1200-3	3300	350	1200	3.41	Φ16 × 65@50	14 × 70 × 565@240	2,15Φ12	
CBN-1200-0	3300	350	1200	3.85	Φ16 × 65@50	14 × 70 × 565@240	2,15Φ12+1,4Φ10	34.12
CBN-1200-1	3300	350	1200	3.85	Φ16 × 65@50	14 × 70 × 565@240	2,15Φ12+1,4Φ10	
CBN-1200-2	3300	350	1200	3.85	Φ16 × 65@50	14 × 70 × 565@240	2,15Φ12+1,4Φ10	
CBN-1200-3	3300	350	1200	3.85	Φ16 × 65@50	14 × 70 × 565@240	2,15Φ12+1,4Φ10	

Note: For CBP(N)-1200-X, CSB = the composite beam, P = the positive bending moment and N = the negative bending moment, X = the number of specimen; L = span of slab; T = thickness of slab; W = width of slab; t = thickness of steel plate; λ = nominal shear span ratio; f_{cu} = average compressive strength of cubic concrete.