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Load transfer mechanism and fatigue performance evaluation of suspender-girder composite anchorage joints at serviceability stage

Yangqing Liu [a], Haohui Xin [a,b], Yuqing Liu [a,*]

[a] Department of Bridge Engineering, Tongji University, Shanghai, China
[b] Civil Engineering and Geosciences, Delft University of Technology, Netherlands

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ABSTRACT

To evaluate the mechanical and fatigue behavior of composite suspender-girder anchorage joints in arch bridges, fatigue tests of two composite joints including pure-shear and shear-compression types were conducted and the load transfer mechanisms were evaluated based on the static loading. The experimental results indicated that both proposed composite anchorage joints presented great combined behavior. The load ratio of PBLs dropped sharply with the increase of embedded depth. Approximately 1/3 of the suspender tensile load was carried by the PBLs in the first row. Due to the redundant PBLs and large embedded depth, few loads were resisted by the bearing plate. Before and after the fatigue loading process, the shear amplitude of PBLs and the vertical stress distribution of concrete were almost consistent, indicating the favorable fatigue performance of joints. Parameterized solid nonlinear finite element models were established and verified by the test results to investigate the effect of total row number of PBLs and presence of bearing plate on the load transfer mechanics. The numerical results showed that the increase of total row number of PBLs enlarged the degree of irregularity of load distribution and reduced the load ratio of bearing plate. Finally, the load ratio formula of PBLs and bearing plate under serviceability stage was derived. The calculated load ratios were in good agreement with the test and numerical results. It was proposed that the total row numbers of PBLs were no >4 or 6 for the joints with or without bearing plate.

1. Introduction

Arch bridges have been extensively applied in bridge construction due to the advantages of large span, high bearing capacity, low maintenance cost and elegant appearance. In the tied arch bridges (Fig. 1), suspenders transferring dead and live loads from girder to arch rib are one of the most significant components. Exposed or built-in anchors are currently used as suspender-girder anchorage structure. However, as shown in Fig. 2, traditional anchor structures often encounter the following problems in operation [1,2]: 1) local concrete crushing due to stress concentration (Fig. 2a); 2) protective facilities fracture caused by rigid connections between suspenders and girders (Fig. 2b); and 3) seeps and corrosion in anchor heads (Fig. 2c and d). It is inconvenient for the inspection, maintenance and replacement of suspenders owing to anchor heads located at the bottom or interior of girders.

The benefits of steel and concrete can be efficiently exerted by using suitable connectors in composite structures which apply to bridge constructions because of rational structural behavior, convenient construction and economical cost. Various shear connectors, such as welded headed studs [3], perfobond connectors [4–6], L-shaped connectors [7] and concrete dowels [8], are used to ensure that load can be effectively transferred between steel and concrete components in composite structures. Recently, perfobond connectors (PBLs) are increasingly employed resulting from the superior shear behavior and fatigue performance [9–12]. In comparison with traditional suspender-girder anchors, steel-concrete composite joints can avoid stress concentration through using groups of shear connectors. Easy construction and convenient maintenance could be achieved since the suspenders and joints are connected above the concrete slabs. Besides, open space for labor-operation is allowed which benefits suspender replacement.

Therefore, this paper proposed a new type of suspender-girder composite anchorage joint (Fig. 3), which consists of the pin holes, ear plate and connection system. The steel and concrete components were combined by PBLs and bearing plate. The joint was applied to a through CFST (Concrete Filled Steel Tube) tied arch bridge (Wenzhou Longgang Bridge), as shown in Fig. 1. The bridge with a parabolic arch axis has a main span of 100.0 m and a rise-span ratio of 1/5. The arch ribs were made of dumbbell-shaped CFSTs filled with C50 micro-expansion concrete. A total of 18 pairs of suspenders were set on the bridge with longitudinal space of 5.1 m. The tension amplitudes of suspenders are considerable under vehicles load during serviceability stage so that the anchorage joints may experience fatigue issues. Although construction

* Corresponding author.
E-mail address: yql@tongji.edu.cn (Y. Liu).

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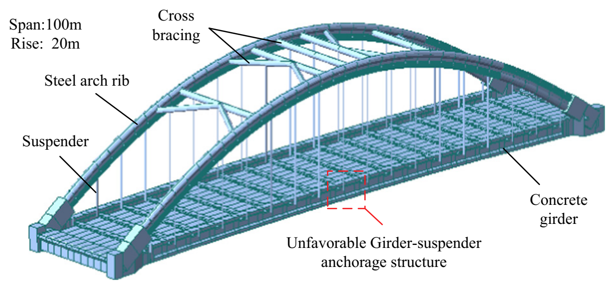

Fig. 1. Through steel-concrete composite arch bridge.

merits of the new anchorage joints are apparent, the static and fatigue behaviors are unclear.

With the development of composite structures and shear connectors, composite anchorage joints are gradually utilized in composite bridges, such as cable-tower anchorage zones, composite truss joints, hybrid girder joints [13–17], etc. Zheng et al. [13] revealed the loading mechanism of cable-tower composite anchorage zone by theoretical analysis and numerical simulation. The shear formula for connectors based on the method of continuous elastic interlayer was derived. Sato et al. [14] conducted static tests and finite element analysis to investigate the load transferring path and bearing capacity of composite truss joints. Fewer PBLs were required than welded headed studs for achieving the same connection strength. Liu et al. [15] carried out fatigue tests on composite truss joints including three specimens using welded headed studs, concrete dowels and PBLs as shear connectors respectively. Test results demonstrated the composite truss joints had adequate fatigue strength and the stiffness reduction in PBL type was less than that in the other two types. Kim et al. [16] analyzed bearing capacity of hybrid girder joints through three points bending tests. The joints using PBLs as shear connectors had a higher bearing capacity and stiffness than the joints using studs. Based on the large-scale field test, He et al. [17] studied the stress transfer mechanism of hybrid girder joints and concluded that the degree of stress concentration decreased due to the presence of bearing plate and PBLs. However, the load and boundary conditions of suspender-girder anchorage joints are different from other joints mentioned above. As a result, it is necessary to investigate the structural behavior of this innovative anchorage joint and propose effective calculation formula to analyze and design the composite anchorage joints in practice.

In this paper, to investigate the load transfer mechanism and fatigue performance of suspender-girder composite anchorage joint, static and fatigue tests of two specimens denoted as pure-shear (PS) and shear-compression (SC) were conducted. Based on the test results, load-slip curves, load ratios of the shear connectors and the bearing plate, stress of perforated rebar and vertical stress distributions of concrete were discussed. Furthermore, three-dimensional nonlinear finite element models were established and verified by the test results. The effects of PBL row number and bearing plate on the load transfer mechanism were analyzed by numerical parametric research. Finally, a load ratio formula of PBLs and bearing plate in serviceability stage was derived aiming to obtain shear force distribution without complex numerical simulation.

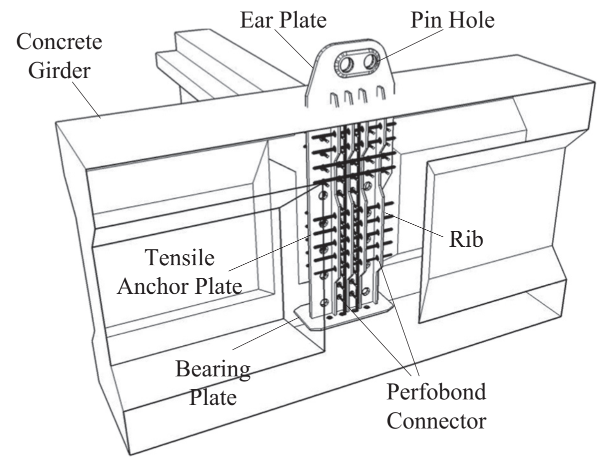

Fig. 3. Schematic diagram of composite anchorage joint.

2. Experimental program

2.1. Test specimens

According to the numerical results of the full bridge model in Fig. 1, the composite joint with the most significant suspender tension was selected as the test specimen. The geometric scale of specimens was designed as 1:2. The diameter of PBL circular hole and perforated rebar is 40 mm and 16 mm respectively. As shown in Fig. 4, depending on the presence of bearing plate, pure-shear (PS) and shear-compression (SC) specimens were fabricated. Several circular grooves with 2 mm depth and 20 mm diameter were set at the location of gauges on the steel plate to prevent the damage of strain gauges under fatigue loading.

2.2. Material properties

Concrete cubes with the dimension of 150 mm × 150 mm × 150 mm and prisms (150 mm × 150 mm × 300 mm) were produced during the casting of two joint specimens. The measured material parameters of concrete and steel are listed in Table 1 and Table 2, respectively. Longitudinal prestressing was made by 12 fining rolled steel rods passed through the PVC pipes reserved inside the specimens with 50 mm diameter. The normal yield strength, ultimate strength and Young's modulus of the fining rolled steel rods is 830 MPa, 1030 MPa and 200 GPa, respectively. Anchor plates and nuts matched the fining rolled steel rods were utilized as anchor devices.

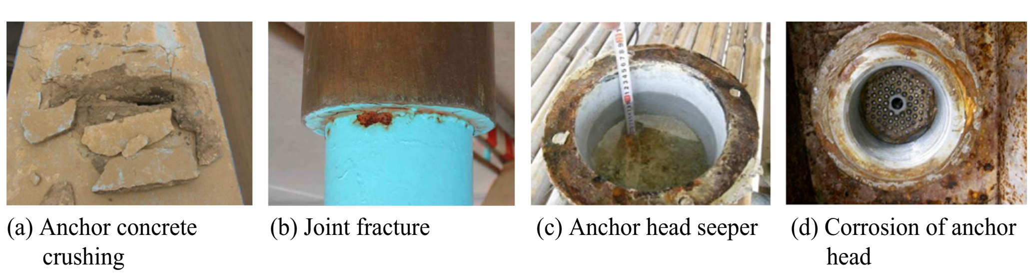

Fig. 2. Durability problems of anchorage structure during service [2].