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Fatigue performance and evaluation of welded joints in steel truss bridges

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A B S T R A C T

While welded joints are extensively used in the connections of steel truss bridges, service life of the bridges is largely dependent on the fatigue resistance of the welded joints. Stress concentration and weld residual stress are two primary causes of fatigue damage in the welded joints. In this study, corner-fillet profile (CFP) and ultrasonic impact treatment (UIT) are used to improve the fatigue performance of the welded joints through relieving stress concentration and weld residual stresses, respectively. The fatigue resistance of welded joints is evaluated through experimentation. The results indicate that the use of CFP and/or UIT can alter the initiation location of fatigue crack. The fatigue resistance of welded joints was increased by 24% and 36% by using the CFP and UIT, respectively. The fatigue performance of welded joints was evaluated using three different methods, including the nominal stress method, effective notch stress method, and peak stress method. The peak stress method with a single fatigue resistance curve demonstrated the highest applicability and accuracy.

1. Introduction

Steel trusses have been extensively used in railway bridges and hybrid highway-railway bridges. Steel truss bridges are typically constructed by assembling prefabricated truss components on site. Fig. 1 (a) and (b) show a representative cross section of a main girder in a hybrid highway-railway bridge. The girder is assembled using different truss components, including the chords, vertical posts, diagonal elements, etc. The components are connected through welding and/or using high-strength bolts. Integrated welded joints (Fig. 1(b)) are usually prefabricated in factory to ensure high welding quality. The welded joints between the flange and gusset plates are subjected to varying tensile stresses and other adverse effects on fatigue resistance, and thus susceptible to fatigue damages. In general, the adverse effects include stress concentration, weld defects and residual stresses at welded joints [1–4]. Under cyclic loading, cracks tend to initiate at the welded joints (Fig. 1(b)) and compromise the long-term durability of the truss bridge.

The effects of stress concentration, weld defect and residual stresses on fatigue resistance of welded joints have been investigated [1–9]. The stress concentration of steel truss joints has been studied through finite element analysis [1] and experimentation [2–9]. The geometry of weld joints was optimized, and a corner-filleted profile (CFP) at weld of cruciform joints was recommended to reduce stress concentration [5]. Effects of weld residual stresses on fatigue resistance of welded joints were evaluated [2]. The ultrasonic impact treatment (UIT), which is a metallurgical processing technique, was utilized to study the effects of residual stresses on fatigue resistance [6–8].

Different methods for evaluating fatigue resistance of welded joints have been proposed [10–12], with consideration of stress concentration and weld residual stress. Nominal stress method is recommended by several design specifications for steel structures, such as Eurocode 3 [10], IIW recommendation [11], AASHTO specifications [12], etc. Hot spot based methods have been applied to evaluate the fatigue performance of weld toe or weld root in different types of welded joints [3, 13–15]. Other methods with a single *S-N* curve have been presented for fatigue evaluation of specific weld details, such as the weld toe or weld root, including the effective notch stress method [16–19], and peak stress method [20–23]. The effective notch stress method was used to analyze the fatigue resistance of welded joints where fatigue cracks initiated at the weld toe or weld root using the maximum principal stress [16–19]. The peak stress method was developed based on the notch stress intensity and local strain energy [20–23]. The fillet welded joint is approximated as a V-shaped notch that has a notch-tip radius of zero. To date, there is still lack of research on using the effective notch stress method and peak stress method to investigate the fatigue resistance of welded joints and effect of CFP and UIT in steel truss structures.

This study aims to investigate the fatigue resistance of welded joints in steel truss bridges. To this end, 16 specimens were tested under cyclic loading. The effects of stress concentration and weld residual stress on fatigue resistance were considered in the experimental investigation.

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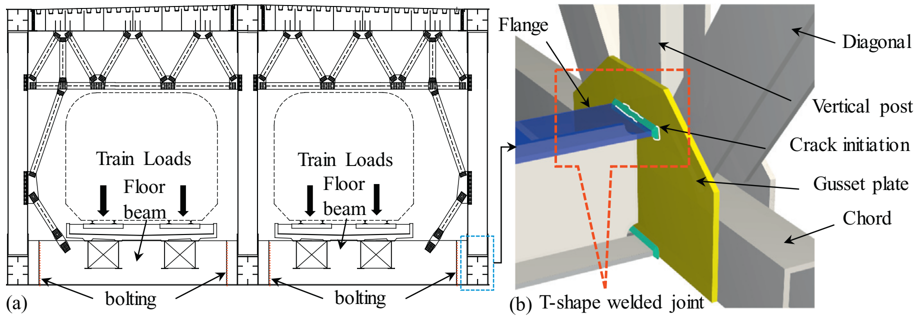

Fig. 1. Sketch of welded joint: (a) the cross-section; (b) the truss joint.

CFP and UIT were used to enhance the fatigue resistance of the welded joints. The nominal stress method, notch stress method and peak stress method are used to evaluate the fatigue resistance of the welded joints.

2. Experimental program

2.1. Specimens

Fatigue cracks often initiate at T-shape welded joints between the flange and the gusset plates, as shown in Fig. 1(b). To investigate the fatigue performance of T-shape welded joints, symmetrical cruciform welded specimens were used, as illustrated in Fig. 2(a) and (b). The two-pass gas metal arc welding is used in this study. The thicknesses of specimens were the same as those of the T-shape welded joints (Fig. 1(b)). CFP was employed to diminish the effect of the stress concentration, as shown in Fig. 2(a). For comparison, the corresponding specimen that does not have the CFP was used as control and tested to evaluate the effect of CFP on the fatigue resistance of the welded joints, as shown in Fig. 2(b).

To enhance the fatigue resistance of welded joints, UIT was applied to diminish the effect of the weld residual stress. In this study, the ultrasonic frequency was 20 kHz, and the impact frequency was 120 Hz. The indenter diameter was 4 mm, and oscillating amplitude of the output end of the waveguide was 50 μm. The output power, excitation voltage, and bias current were 250 W, 220 V, and 1.2 A, respectively. The dimensions of manual tool were 470 mm × 85 mm × 80 mm. The treatment speed in manual mode was 0.5 m/min. The treated workpiece region was weld toe. UIT was applied through repeating high-rate multi-directional impacts to the specimen surface in combination with ultrasonic vibration. This process was repeated for 4 times at each weld toe. The equipment and a sketch of the UIT operation are shown in Fig. 3.

To evaluate the effect of CFP and UIT on fatigue resistance of welded joints, three types of specimens were investigated: (1) specimens without CFP and UIT (designated as NCU), (2) specimens with CFP (designated as CFP), and (3) specimens with CFP and UIT (designated as CU). Each specimen was composed of three steel plates, two plates that simulate the flange (Fig. 1(b)) and one plate that simulates the gusset plate (Fig. 1(b)). The three plates were welded through metal inert gas welding, the same as that in real bridges.

The material of the test specimens is the hot-rolled low alloy steel Q370qD, which is a special structural steel for bridges. Two thicknesses of steel plates were used. Table 1 lists the mechanical properties and chemical composition of the steel Q370qD from mill certs.

2.2. Test setup and loading protocol

Fig. 4(a) shows the setup for cyclic tensile testing. Fig. 4(b) shows a specimen without CFP. Fig. 4(c) shows a weld joint of the specimen with CFP and UIT. Fatigue tests were conducted using a universal loading machine with a load capacity of 1500 kN. A total of 16 specimens were tested. The amplitude of the cyclic loading was constant for each specimen; different amplitudes and loading frequencies were applied to different specimens, as listed in Table 2. The lower bound of the cyclic load was set at 10 kN; the upper bound was changed to obtain the target load ranges. The effect of small change of load ratio on fatigue resistance was neglected [24, 25].

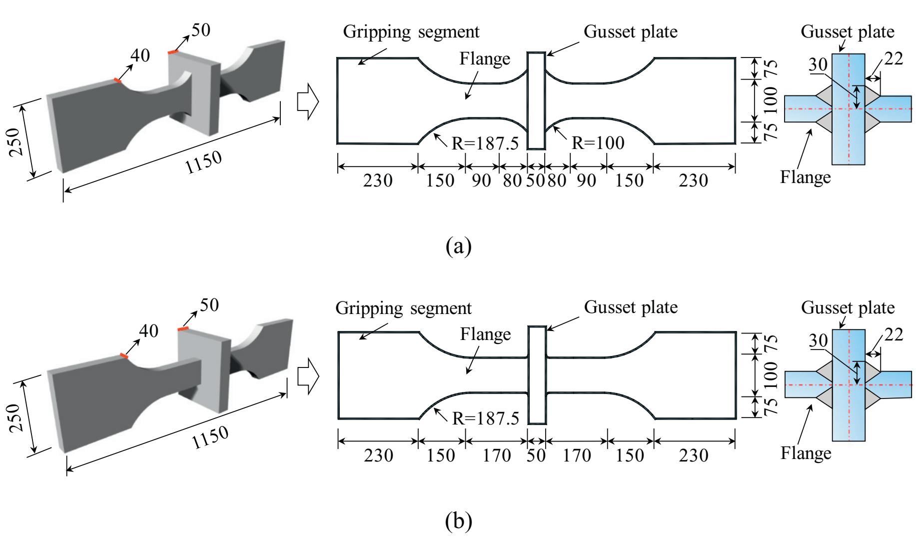

Fig. 2. Sketch of the specimens: (a) with CFP; (b) without CFP. (Unit: mm).