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Fatigue assessment on butt welded splices in plates of different thicknesses

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ABSTRACT

Fatigue performance of butt welded splices in plates of different thicknesses (hereafter referred to as BWSPDT) was investigated in this paper. Fatigue tests were conducted on 26 specimens. Experimental S-N curve of 95% survival probability for BWSPDT was established based on 21 effective fatigue test data involving 7 stress levels. Both analytical and numerical fatigue crack propagation analysis were fulfilled. It was found that the numerical approach would provide a lower stress intensity factor (SIF) level than that obtained through the analytical approach, as the numerical approach can better reflect the relationship between the local crack development and the variation of the stress distribution of the whole structural details. The influences on fatigue life due to the variation of the size, shape and location of the initial crack were investigated. The calculation formula for the fatigue crack propagation life in terms of arbitrary initial crack between 0.075 mm and 0.4 mm was derived. For the fatigue crack propagation analysis for BWSPDT, a semi-circular crack with 0.075 mm initial depth locating at the center of the specimen was recommended to be adopted as the initial crack input when no detailed inspection information on initial flaws available.

1. Introduction

Butt welded splices have been widely used for connecting steel plates with different thicknesses in practical bridge engineering projects [1], as shown in Fig. 1. Due to the cyclic nature of the loads to which bridges are subjected, fatigue deterioration has been a great concern and the key fatigue prone structural details require special attention [2–4]. In terms of the normal butt welds connecting two steel plates of the same thickness, there have been numerous fatigue tests and analytical analysis. The related design S-N curves, including the nominal S-N curve and the hot spot stress S-N curve [5], were proposed and adopted in various design codes such as Eurocode3 [6], AASHTO [7], BS5400 [8], and so on. Nevertheless, there are very few tests and comments for butt welds connecting the steel plates of different thicknesses (especially those fabricated in China), whose fatigue performance may be various due to possible local stress concentration and bending effect caused by misalignment, although the weld quality for butt welds is always guaranteed. The corresponding design S-N curve keeps in line with those for normal butt welds connecting two steel plates of the same thickness [6], which may lead to an unsafe fatigue design or assessment.

In addition to the nominal stress approach or hot spot stress approach, which is based on the S-N curve of the structural detail, the linearly elastic fracture mechanics (LEFM) has been widely used for fatigue assessment [9]. From the view of the Fracture Mechanics based approach, the fatigue failure is the process of the fatigue crack initiation and propagation. Due to the inevitable defects in welds, the propagation life can be regarded as the total fatigue life for welded splices, which will lead to a conservative prediction on the fatigue performance of the structural details. Accordingly, LEFM can be adopted for the fatigue evaluation of BWSPDT. However, LEFM approach was mostly performed based on the analytical analysis which requires pre-assumptions and ignores the variation of the stress distribution with the fatigue crack development [10,11]. As a result, more accurate fatigue crack propagation analysis based on LEFM should be conducted to investigate the fatigue performance of BWSPDT.

In this paper, fatigue tests on BWSPDT specimens were conducted at first. Refined analytical and numerical fatigue crack propagation analysis based on LEFM was fulfilled afterwards. The experimental S-N curve of 95% survival probability for BWSPDT was established, which could replenish the public fatigue database in China. The effectiveness and advantages of the numerical fatigue crack propagation analysis were verified in comparison with the analytical approach. Suitable initial crack assumption was recommended and the influence of the

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Fig. 1. Typical application of BWSPDT [1].

location and the shape of the initial crack were discussed, which would provide a comprehensive evaluation for BWSPDT.

2. Fatigue test

2.1. Specimen preparation

Fig. 2 shows the designed geometric profile of the specimens for the fatigue test. The butt welds were designed to connect Q345qD grade steel plates of 12 mm and 8 mm thickness, with a 1/4 transition slope. The butt welds were produced by MCAW with 240 ± 20 A welding current and 30 ± 2 V welding voltage. The connections were as-welded and not to be ground flush. The steel plates used in the tests are in the exactly same batch with those tested in reference [12], which were fabricated in ZiJingGuan Bridge Plant in China. The external dimensions shown in Fig. 3 for all the specimens were measured. The average value of the geometric dimensions was recorded in Table 1, which will be adopted in the following FE modeling and analysis.

2.2. Experimental program

The fatigue test was conducted using a constant amplitude loading regime of which the stress ratio was 0.1. The loading equipment is PLG-200C fatigue test machine of ±10 t loading capacity. The end of the thicker plate was fixed and the end of the thinner plate was loaded by tensile force, as shown in Fig. 4. The maximum number of loading cycles for a specimen was set to be 5 million. The loading frequency depends on the stiffness of the specimens. If fatigue cracks occur in the specimens, the stiffness will decrease and so will be the loading frequency. The fatigue tests will stop when the loading frequency has a 10 Hz drop (about 10% reduction in terms of the initial loading frequency, after which the loading frequency decreases very quickly) or the loading cycles are up to 5 million. It should be called ‘run out’ instead of failure if the latter situation happened.

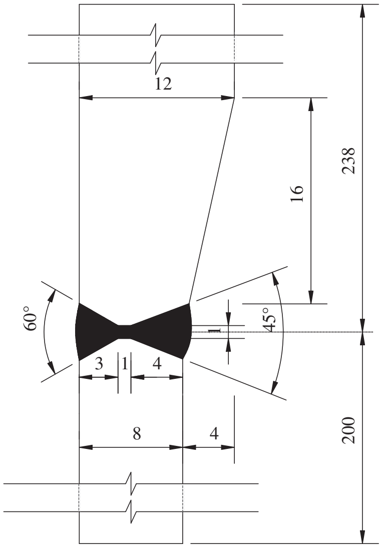

Fig. 2. Designed geometric profile.

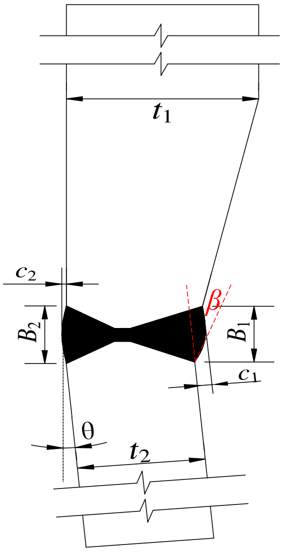

Fig. 3. Measurement scheme of the geometric profile.

To achieve a reliable S-N curve for the structural details, at least seven stress range levels should be involved and three repeated trails are required for each stress range level in the fatigue tests. For BWSPDT, the design S-N curve specified in Eurocode 3 is FAT 90, which refers to 90 MPa fatigue strength in terms of 2 million cycles' fatigue life [6]. Therefore, the fatigue test was started under the condition that the maximum stress is 100 MPa (refers to 90 MPa stress range when the stress ratio is 0.1) for the first specimen. If the specimen runs out instead of the appearance of the failure, the maximum stress will keep increasing at a 20 MPa interval until the first failed specimen occurs. The corresponding maximum stress will be determined as the first stress level and the following stress level will take a 10 MPa increment in terms of the maximum stress, until seven stress levels are involved. For this batch of specimens, the first failed specimen occurred when the maximum stress is 160 MPa. Therefore, the range of the maximum stress was determined as 160 MPa–220 MPa. The loading cases were noted by BW1 to BW7, accordingly.

2.3. Fatigue test results

26 specimens were tested in total and five of them run out at last. Accordingly, 21 effective fatigue test data were obtained. The detailed fatigue lives were recorded in Table 2 and plotted in Fig. 5. All the effective specimens failed at the butt weld toes in junction with the thinner plate. The testers chose three failed specimens and snapped them completely. It was found that the fatigue crack depth occupies half the thickness of the thinner plate, that was, about 4 mm. As for

Table 1
Measured average geometric dimensions.

Item	B_1/mm	c_1/mm	B_2/mm	c_2/mm	t_1/mm	t_2/mm	Θ_b/rad
Average value	12.29	2.60	10.55	0.84	11.75	7.52	0.0