

Analysis of Fatigue Performance of U-Rib to Deck Connections in Orthotropic Steel Bridge Structures

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Abstract. The stress condition of the transverse rib, bridge deck, and crossbeam in orthotropic steel bridge decks (OSBD) is complicated. Existing fatigue test specimens and the fatigue performance of components in OSBD differ significantly. In this paper, the numerical analysis method using traction structural stress is validated by the comparison with fatigue test results. The evaluation results of the fatigue behavior using the traction structural stress method are proven to be accurate. The comparative results give the fatigue performance of various types of typical test specimens in terms of the equivalent structural stress and initiation locations.

1 Introduction

With the advantages of light-weight characteristics and high bearing capacity, orthotropic steel bridge decks (OSBD) are widely used [1].

According to existing research studies, the percentage of the fatigue cracks which generate from the weld toe and weld root of the deck and U rib accounts for 18.9% [1]. Researchers carried out various fatigue specimen tests in OSBD [2].

Fatigue tests are mainly carried out using two main structural models, i.e., the single-span model without the crossbeam [3], the single-span model with the crossbeam, and doubled U-ribs [4], and multi-span model with doubled U ribs [5]. The loading force can be applied to the top of the bridge deck or the bottom of the U-rib [7].

The single-span model with the crossbeam is welded with the bridge deck, the crossbeam, and doubled U-shaped ribs. The model is supported at the bottom of the single crossbeam. The multi-span model with doubled U-ribs is constructed with bridge deck, doubled U-ribs, and multi-span crossbeams. The model specimen is supported at the bottom of the crossbeam and is applied to the top of the bridge deck [7-9].

Researchers adopted some conventional prediction methods, such as the nominal stress method, hot spot stress method, and notch stress method, to evaluate the fatigue mechanism performance of the connection.

The mesh-size insensitive traction structural stress method and master S-N curve were proposed [10-12] with the validation of various fatigue test data in the field of the fatigue performance evaluation of pressure vessels and orthotropic steel bridges.

In order to evaluate and compare fatigue performance differences of fatigue test specimens in the OSBD with the evaluation criterion, this study analyzes fatigue

properties of two types of typical fatigue test specimens using the traction structural stress method.

The comparison with test data validates the numerical analysis method using the traction structural stress. The traction structural stress is evaluated to obtain the fatigue fracture modes and fatigue performances of various types of typical test specimens.

2 Validation of the FEA method

2.1. Fatigue test and test results

The size of the OSBD is determined based on actual steel bridges, and the fatigue test model consists of a single U-shaped rib or doubled U-shaped ribs in paper [12]. In the fatigue test specimens, the connection joints of the bridge deck and U-rib were single-side welded joint (SS80 and DS80) and double-side welded joint (SD80 and DD80).

According to the OSBD standard Eurocode 3, the loading zone and constraint condition were determined. The fatigue load was applied to the loading block in the middle of the top side of the specimen with the actuator. Fig.1 shows the fatigue test equipment for the single and double U-rib specimens.

The initiation location of the fatigue crack of the specimen SS80 was weld toe of the U rib, and the crack propagated along with the web plate of the U rib. The fatigue crack of the specimen DS80 initiated at the weld root of the bridge deck and propagated along with the bridge deck thickness. The fatigue crack of the specimen DD80 initiated at the weld toe of the deck and propagated along the direction of deck thickness.

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2.2 Finite Element Analysis and Comparative Results

The finite element models of the fatigue test specimens were established (as Fig.1).

In order to simulate the actual constraint condition and load, the finite model was supported at the end of the bridge deck.

The connections of the bridge deck, U-rib, and crossbeam were single-side welded joint and double-side welded joint. Based on the finite element models, the equivalent structural stresses of the weld toe and weld root were obtained using the traction structural stress method.

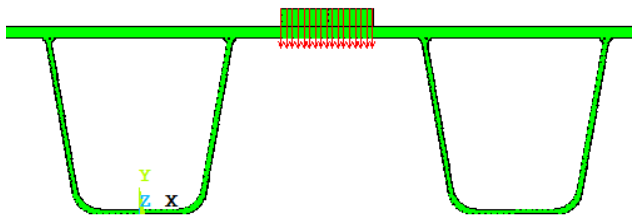


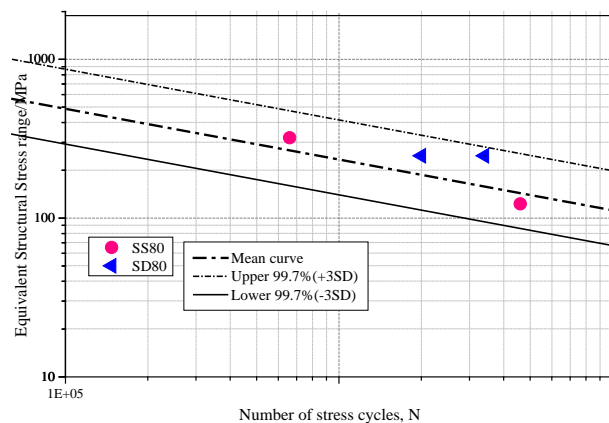
Fig. 1. Finite element model

The nominal stress was measured by a strain gauge, and fatigue life of the fatigue crack initiation was confirmed when the nominal stress declined sharply.

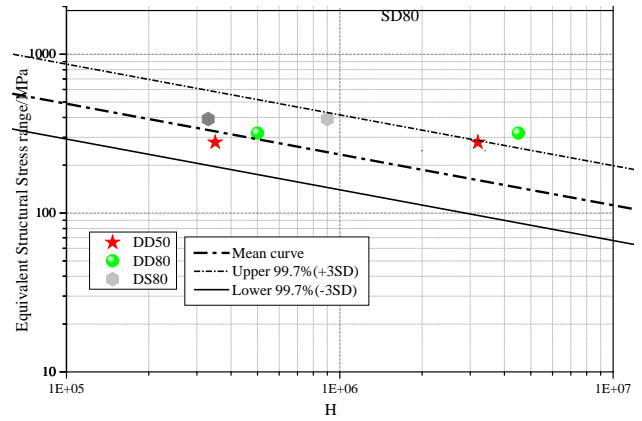
The stress extrapolation method was applied based on Eurocode 3, and the hot spot stress of the weld toe was achieved. Equivalent structural stresses of the weld root and toe were obtained using the traction structural stress method.

Traction structural stress versus the fatigue test life of test specimens is plotted in the contour of the master S-N curves (see Fig.2).

The master S-N curves are obtained based on the traction structural stress method. The traction structural stress and master S-N curves are validated [13-14].



(a) Single U rib specimens



(b) Double U ribs specimens

Fig.2. Fatigue cyclic life versus traction structural stress

3. Fatigue performance of fatigue test models

3.1 FEA models and loading mode

In order to obtain the fatigue performance of various types of fatigue models under specified loading mode based on the fatigue test specimens, various types of fatigue models of OSBD were investigated to determine the fatigue crack initiation locations and propagation direction.

Fatigue models were designed with the same components size, material properties, and constraint conditions.

The equivalent structural stress of the hypothetical fatigue cracks was studied, and the fatigue fracture modes were obtained based on traction structural stress.

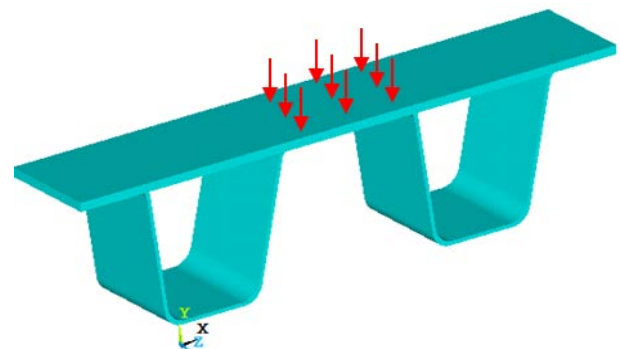
In this paper, two main models of fatigue test, including the single-span model without the crossbeam, and the single-span model with the crossbeam and doubled U-ribs, are investigated.

Fig.3. shows the finite element models of various specimens. The finite element of the software is Solid 185, and the material is Q345qD steel.

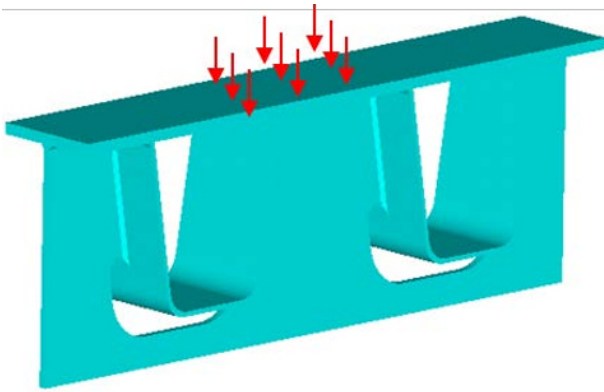
In this paper, a typical loading mode was applied to the fatigue model of the OSBD.

In the loading case, the model was applied to the middle of the top side of the overall specimen.

The loading width was 300 mm × 150 mm, and the load force was 10kN.



(a) Single-span model without a crossbeam



(b) Single-span model with a crossbeam

Fig.3. Two types of FEA models

3.2 Results and discussions

The structural stresses of the hypothetical fatigue crack are obtained using the traction structural stress method.

The number in the comparative contours is the base 10 *log* of the traction structural stress $\log S_s$, of the horizontal axis for more obvious comparison.

Also, the vertical axial represents the hypothetical locations of fatigue cracks.

Fig.4. shows the equivalent structural stress of these two types of specimen models under the loading case.

The location of the maximum equivalent structural stress of Model 1 is P1, i.e., the weld toe of the bridge deck.

The equivalent structural stresses of the locations of P1, R1, P3, R1', P1', and P3' in model 1 are 175.15 MPa, 155.06 MPa, 30.01 MPa, 126.54 MPa, and 140.84 MPa, and 49.1 MPa, respectively.

Compared with the model 1, the equivalent structural stress of all locations of P1, R1, P3, R1', P1', and P3' in model 2 are 0.08 MPa, 0.08 MPa, 0.05 MPa, 3.16 MPa, and 3.44 MPa, and 6.16 MPa, respectively.

It is found that the equivalent structural stress of model 1 is significantly different from that of model 2 under the specific loading case based on the orthotropic steel bridge deck standard, Eurocode 3.

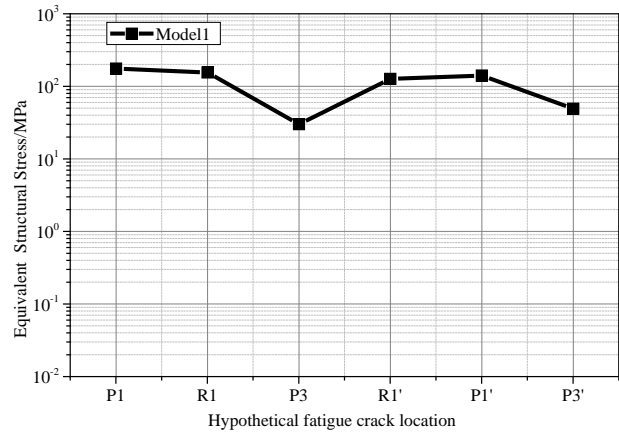
We can determine the fatigue cracks initiation positions based on the amount of the equivalent structural stress values.

Previous study shows that fatigue cracks are more likely other occur at the position with high structural stress value.

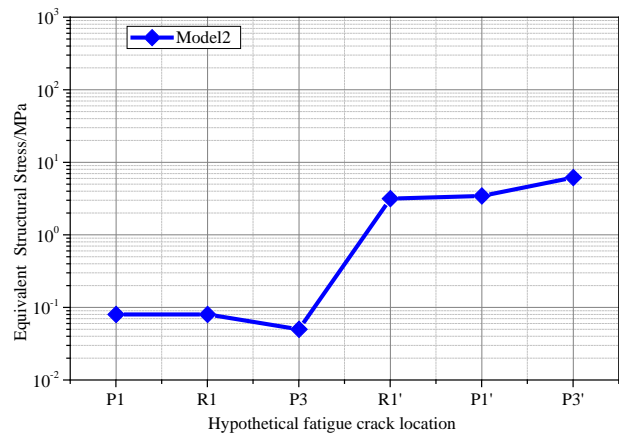
The comparative results indicate that the fatigue crack propagates along the direction of the bridge deck thickness.

The equivalent structural stresses of R1, R1', and P1' are high, and these locations are the hypothetical initiation locations.

The location of the maximum equivalent structural stress of Model 2 is P3' instead, at the weld toe of U-shaped rib, and some fatigue cracks propagate perpendicularly to U-rib.



(a) Equivalent structural stress of model 1



(b) Equivalent structural stress of model 2

Fig.4. Equivalent structural stress of various models

4. Conclusions

In this paper, the fatigue performances of two types of typical fatigue test specimens are analyzed using the traction structural stress method under the specified loading cases based on Eurocode 3.

The following conclusions can be drawn.

(1) The traction structural stress method and master S-N curve are validated.

The comparative results indicate that the employed method in this study can be applied for the evaluation of the fatigue behavior of weld root and weld toe in the orthotropic steel bridge decks.

(2) The equivalent structural stress of Model 1 under the specified loading case is the most significant based on the comparison of all locations.

The fatigue crack initiates at the weld toe of the bridge deck according to comparative results.

(3) The employed evaluation method used in this study can be extended for fatigue performance analysis of other connection structures in the orthotropic steel bridge decks.

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