Reinforcement Method for Inhibiting Fatigue Cracks on Rivet Girder Supports

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Fatigue cracks initiate in the lower flange of rivet girder supports because of the stress caused by bridge member deterioration. There are cases where fatigue cracks cannot be immediately repaired because the procedure would be time consuming and costly. This research identifies some of the causes of the stress in the lower flange of rivet girder supports, having conducted loading tests on a rivet girder, and FEM analyses. On the basis these results, we began developing reinforcement methods for inhibiting fatigue crack growth in the lower flanges of rivet girder supports. Moreover, we are verifying the effect of these reinforcement methods through loading tests.

Keywords: rivet girder, fatigue crack, reinforcement method, loading test, FEM analysis

1. Introduction

A lot of plate girder bridges joined with steel plates and shaped steels with rivets, hereinafter referred to as “rivet girder” (Fig.1), have been used. Fatigue cracks, as shown in Fig.2, initiate in the lower flange of rivet girder supports, because of concentrated stress caused by bridge member deterioration [1]. There is a risk that the fatigue crack may break the lower-flange and negatively impact safety.

The method for repairing the fatigue crack involves replacing the lower flange with a temporary girder support [2]. This method would be time consuming and costly because of the need for preparing a temporary girder support jig and reinforcing girders. Consequently, fatigue cracks in the lower flanges of rivet girder supports are not only a burden on bridge maintenance, but in some cases cannot be repaired immediately.

This paper describes research that we have been carrying out to develop reinforcement methods for inhibiting fatigue crack growth without temporary girder supports. The reinforcement methods aim to level out labor needs and costs for repairing fatigue cracks by extending the serviceable life of rivet girders.

In the course of developing the reinforcement methods, we identified the relationship between the stress in the lower-flange and bridge member deterioration (girder support gaps and end stiffener defects, as shown in Fig.3) by conducting loading tests and FEM analyses. Girder support gaps are caused by damage in the shoe base mortar and wear of the sole plate, while end stiffener defects are caused by corrosion and wear. They are common types of deterioration found in rivet girders.

Based on these results, we designed two types of reinforcement method without using temporary girder supports. Furthermore, we examined the size of the reinforcing member through FEM analyses and verified the effect of the reinforcement methods by loading tests.

2. Loading tests and FEM analyses

We conducted loading tests on a full-size test body simulating a rivet girder for identifying the relationship between the girder support gap and the stress in the lower flange. In parallel, we conducted FEM analyses to identify the relationship between end stiffener defects and stress in the lower flange. Furthermore, we verified the effect of the reinforcement methods through loading tests and FEM analyses. Verification of the reinforcement methods is described later in section 4.
2.1 Loading tests

Figure 4 shows the shape of the test body that was used to simulate the end part of a rivet girder (tatsu No.94, span 9.8 m). The main girder of the test body consisted of part of an existing rivet girder. The other members (end stiffener, bracing and sole plate) were manufactured from steel plates and shaped steels (SS400). The gap (at 5 mm) simulating the end stiffener defect was formed between the end stiffener and the lower flange.

Girder support gaps were formed under the lower-flange end (Fig.3(a)) or the lower-flange center (Fig.3(b)) of the test body. Gaps under the lower-flange end were simulated by tilting the test body as shown in Fig. 5(a), whereas gaps under the lower-flange center were simulated by machining the top surface of the sole plate as shown in Fig.5(b). The test body was supported by rollers.

The test body was loaded through a loading beam as shown in Fig.6. The maximum load was 420 kN, which corresponds to the reaction force of the girder support under a train load (M-13) and an impact load (V = 130 km/h). The load was gradually increased in 10-20 kN increments.

2.2 FEM analyses

An FEM model was used to simulate the same rivet girder as the test body, constructed using solid hexahedron elements (Fig.7). The contact conditions were set on the boundary surface between the members on the support. The Young's modulus of the steel was 200 GPa, and the Poisson ratio 0.3.

3. Bridge member deterioration and lower flange stress

3.1 Girder support gap

Figure 8 shows the stress distribution in the lower flange with the girder support gap under a load of 420 kN in the loading test. When the girder support gap was under the lower flange end, the compression stress on one side of the flange was higher than when there was no girder support gap. When the girder support gap was under the lower flange center, the compression stress was high in both sides of the lower flange. It is assumed that the compression stress was caused by bending the lower flange as shown in Fig.9.

Figure 10 shows the relationship between the load and the lower flange stress when the girder support gap
was under the lower flange center. The lower flange stress increased as the load increased in the beginning, and then stabilized (gradually stopped increasing) from midway because the lower flange was in contact with the sole plate.

These results show that the stress is caused by bending deformation in the lower flange and stabilizes if the lower flange is displaced downward and comes into contacts with the soleplate.

### 3.2 End stiffener defect

This section compares the lower flange stress in cases with and without an end stiffener defect. Figure 11 shows the lower flange stress of the FEM model at a load of 420 kN when the girder support gap under the lower flange center was 2.5 mm.

The lower flange stress with the end stiffener defect was higher than without the end stiffener defect. Figure 12 shows the contour of the Mises stress in the FEM model. In the case where there was no end stiffener defect, the stress of the end stiffener bottom was high because of the contact with the lower flange. In this case, the lower flange stress did not increase much because the bending deformation of the lower flange was restrained.

These results demonstrate that the bending deformation of the lower flange is not restrained when there is the end stiffener defect and the fatigue crack are easily initiated by an increase in lower flange stress.

### 4. Reinforcement method for inhibiting fatigue crack growth

Chapter 3 demonstrated that lower flange stress is generated by the bending deformation of the lower flange because of the girder support gap and the end stiffener defect. On the basis of these results, it is expected that the lower flange stress decreases and the fatigue crack growth is inhibited if the girder support gap or the end stiffener defect is removed.

This chapter first describes two types of reinforcement method for inhibiting fatigue crack growth. Then the size of the reinforcement member was investigated by FEM analyses and the effect of the reinforcement method was verified through loading tests.
4.1 Concept of reinforcement method

4.1.1 Type A

In reinforcement ‘Type A’, shown in Fig.13, reinforcement members are joined to the defective end stiffener. The crack-tip stress at the lower flange is expected to decrease by restraining bending deformation of the lower flange, that is caused by the girder support gap. Although there used to be a conventional method with steel plates joined to the end stiffener, the steel plate was not in contact with the lower flange because of the unevenness due to corrosion and does not usually restrain bending deformation of the lower flange. A distinctive point of the reinforcement method A is that it enables the reinforcement member to come into contact with the lower flange by using filler resin and an L-shaped reinforcement member.

Epoxy resin containing metal powder was used as filler resin. A reinforcement member with a long, thick base (lower side) was used, to counter the possibility of the reinforcement member not restraining the bending deformation of the lower flange or the epoxy resin breaking due to excessive deformation. FEM analyses were used to investigate the appropriate size of the reinforcement member.

A reinforcement member, artificial cracks and stop hole were added to the FEM model (Fig.14). The maximum stress of the epoxy resin was compared with the compressive strength of the epoxy resin by using this FEM model.

Figure 15 shows that the stress of the epoxy resin was compressive strength of resin (118MPa).
A reinforcement member, artificial cracks and stop hole were added to the FEM model (Fig. 14). The maximum stress of the epoxy resin was compared with the compressive strength of the epoxy resin by using this FEM model.

Figure 15 shows that the stress of the epoxy resin was smaller than its compressive strength when the length $L$ and the thickness $T$ of the lower side of the reinforcement member were $L > 50$ mm, $T > 15$ mm. The size of the reinforcement member was designed on the basis of these results.

### 4.1.2 Type B

Figure 16 shows the concept of the other reinforcement method Type B. In this method, the lower flange displaces downward by tightening the lower flange and the sole plate by bolts when the girder support gap is under the lower flange center. According to the results in chapter 3, when the lower flange comes into contacts with the sole plate, fatigue crack growth should be inhibited because in this situation, the lower flange stress does not increase.

In the reinforcement Type B, the lower flange is tightened by bolts from above to sole plate. Bolting the L-shaped member tightly to the end stiffener and lower flange, pulls the center part of the lower flange with the fatigue crack down to fit snugly onto the sole plate.
4.2 Effect verification of reinforcement method

The effect of the reinforcement method was verified through loading tests. First, the fatigue crack growth from the slit machined in the lower flange grew by about 100 mm in length during the cyclic loading tests. A stop hole (φ=12 mm) was made at the crack-tip. Second, after applying reinforcement methods Type A and B, the stress at the stop hole of the lower flange during loading was compared with the stress before the reinforcement. The inhibition effect of reinforcement method Type A on crack growth was verified through cyclic loading tests. Figure 17 shows the test body after the stop hole was made and after the reinforcement.

Figure 18 shows the stress at the stop hole under a load of 420 kN when the girder support gap was under the lower flange center. The stress around the stop hole after the reinforcement decreased drastically.

After the reinforcement Type A, the cyclic loading test was conducted 3.7 million times. Figure 19 shows the length of the fatigue crack and the number of loads, where the fatigue crack does not grow after the reinforcement. The filler resin and the reinforcement member were not damaged after the cyclic loading. These results demonstrate that both reinforcement methods A and B can reduce the stress at the fatigue crack-tip dramatically, and also show that reinforcement method Type A is sufficiently durable.

5. Conclusions

We began developing reinforcement methods to inhibit fatigue crack growth in the lower flanges of rivet girders. During the development process, we made the following findings by conducting loading tests on a rivet girder and by carrying out FEM analyses.

1. The lower flange stress is caused by the bending deformation of the lower flange and does not increase if the lower flange is displaced downward and comes into contact with the soleplate.
2. The bending deformation of the lower flange is not restrained when there is the end stiffener defect and the fatigue crack are easily initiated by an increase in lower flange stress.

On the basis of these results, we began developing two reinforcement methods for inhibiting fatigue crack growth without the need to use temporary girder supports and verified the effect of these methods. We have demonstrated that both reinforcement methods can reduce the stress at the fatigue crack-tip and that Type A is sufficiently durable.

References

[1] Nishida, Kim, “Cause of fatigue crack initiated at lower flange of railway plate girder,” Proceedings of annual conference of the japan society of civil engineers, I-518, pp.1035-1036, 2011.
[2] Chigira, Tsukahara, Inoue, “Repair of steel railway bridge support and verification of effect by measuring,” Proceedings of annual conference of the japan society of civil engineers, VI-096, pp.191-192, 2014.

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