Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-4-8

FATIGUE BEHAVIOR AT THE UPPER END OF VERTICAL STIFFENERS CONNECTED WITH SWAY BRACINGS

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Lots of fatigue crackings were reported at the upper end of vertical stiffeners connected to sway bracings in steel highway girder bridges. In this study, we investigate fatigue cracking behavior at the upper end of vertical stiffeners under RC slab, through fatigue tests using a large specimen with three main girders under alternative loading using two actuators. As a result, alternative loading can reproduce the alternative stress at the upper end of vertical stiffener in the middle girder when vehicles run on the driving lane and passing lane alternatively. Root cracks were initiated after 0.1 Mcycles loading and appeared on the bead surface when 0.6 Mcycles.

Keywords: Vertical stiffener, Fatigue test, Thread rolling screw, Jack up.

1 INTRODUCTION

Lots of fatigue crackings were reported at the upper end of vertical stiffeners connected to sway bracings in steel highway girder bridges (Japan Road Association 1997, Hanshin Expressway Technology Center 2012). Several countermeasures were proposed against those crackings, such as steel plate reinforcement between the upper flange and the vertical stiffener using high tension bolts after breaking RC slab, or re-welding. However, the work of breaking RC slab requires traffic lane closing, and re-welding may cause re-cracking. Then, some steel plate reinforcement methods using jack-up jigs were proposed, in which traffic lane closing should not be required (Koshiba *et al.* 2003, Harada *et al.* 2009, Kendo *et al.* 2008, Kawashima *et al.* 2008, Morino *et al.* 2010). But it has not been verified how effective in stress reduction and fatigue life extension.

In this study, we investigate fatigue cracking behavior at the upper end of vertical stiffeners under RC slab, through fatigue tests using a full-scale specimen with three main girders under alternative loading using two actuators.

2 EXPERIMENTAL PROCEDURES

2.1 Specimen

Figure 1 shows configurations and dimensions of the specimen, and location of strain gages. The depth and space of main girders are smaller than those of the actual bridge, because of capacity of fatigue testing facility. But upper flange, vertical stiffener and sway bracing are of the same size as the actual bridge. The specimen has three main girders, which reproduce the alternative stress in the top of the middle girder when vehicles run on driving lane and passing lane alternatively. The specimen is made of JIS-SM490YA, SM490YB and SM400 steels, which are of the same grade as the actual bridge. The upper flange and upper end of vertical stiffener are welded with a 2 mm gap by CO2 gas shield welding.

The specimen has 4 test parts with or without retrofitting methods as follows, A: No retrofitting method; B: Steel plate retrofitting method using jack-up jig; C, D: Angle steel retrofitting method using Thread Rolling Screw (TRS) (Suzuki 2015).

The effectiveness of these two types of retrofitting methods is investigated by comparing fatigue behavior of these 4 test parts.

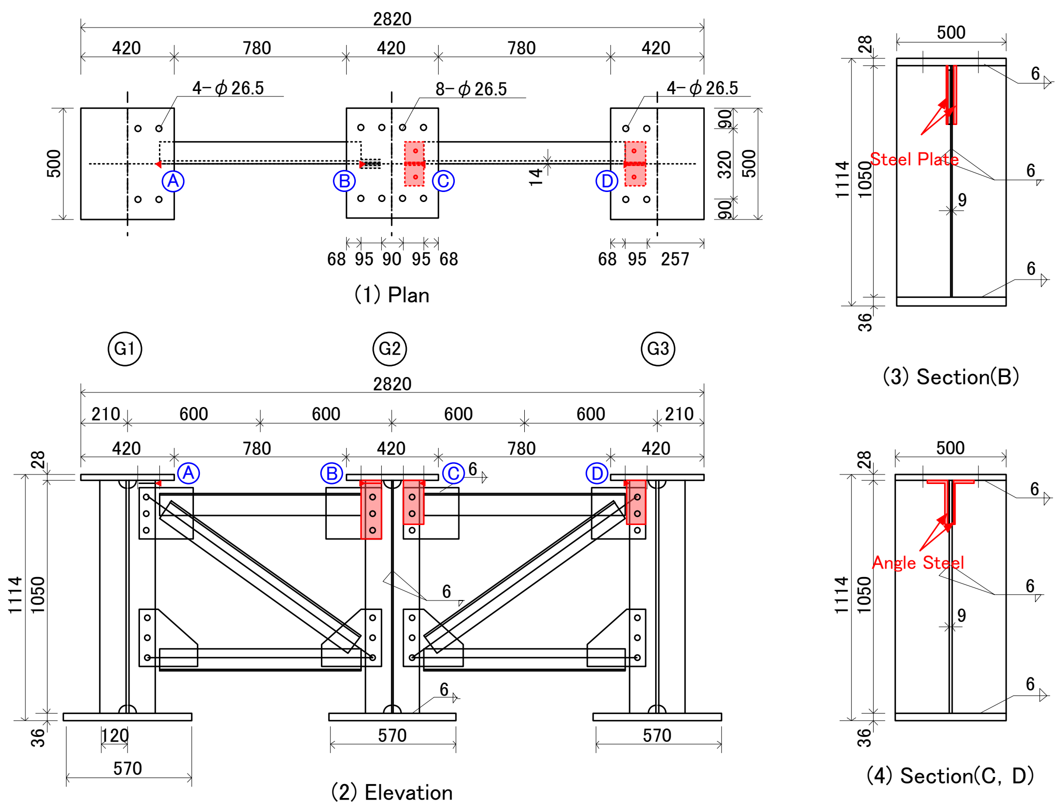


Figure 1. Configurations and dimensions of the specimen.

2.2 Retrofitting Methods

(1) <u>Steel plate retrofitting method using a jack-up jig:</u> This method reduces the local stress concentration at the upper end of vertical stiffener by distributing the load to steel plates.

(2) <u>Angle steel retrofitting method using TRS:</u> This method reduces the local stress concentration at the upper end of vertical stiffener by distributing the load to angle steel.

2.3 Static Loading Test Procedures

Figure 2 shows the loading method and Figure 3 shows loading wave forms. The static loading test was conducted using two actuators to reproduce the simultaneously and alternatively stress in the middle girder when vehicles pass on the driving lane and passing lane simultaneously and alternatively. Load range was 100kN (Pmax = 120 kN, Pmin = 20 kN). Figure 4 shows location of strain gages. In static loading test and fatigue test, two types of uniaxial strain gages were used. 1mm long strain gages were pasted on the plate side surface 10mm below the weld toe, in order to measure the local stress. Whereas 3mm long strain gages were pasted on the bead surface, in order to monitor initiation and propagation behavior of root cracks.

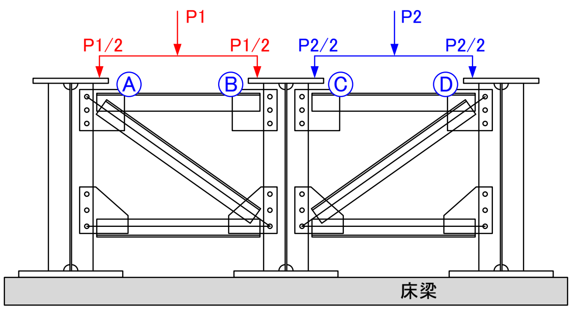


Figure 2. Loading method.

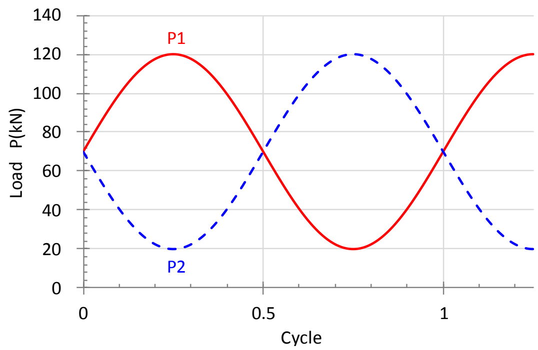


Figure 3. Loading wave forms.

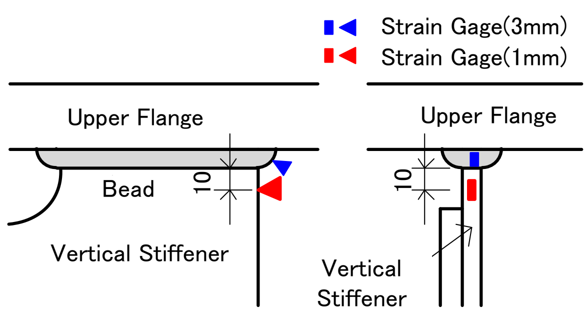


Figure 4. Location of strain gages.

2.4 Fatigue Test Procedures

The fatigue test was conducted using two actuators under alternative loading to reproduce the alternative stress in the middle girder when vehicles run on the driving lane and passing lane alternatively. Loading frequency was 3-4Hz.

In the test part A, purpose is to recreate cracks without countermeasure. In the test parts B-D, purpose is to investigate the effectiveness of preventive measures. Steel plate reinforcement using jack up jig was applied in the test part B, while angle steel reinforcement using TRS was applied in test parts C and D.

Magnetic Particle Testing (MT) was used to detect toe cracks and to measure the crack length. Strain gages pasted on the bead surface were used to monitor initiation and propagation behavior of root cracks.

3 EXPERIMENTAL RESULTS

3.1 Static Loading Test Results

Figure 5 shows the stress range distributions under simultaneous loading and alternative loading. The stress range in middle girder (B and C) under alternative loading increases about 20% of that under simultaneous loading. Alternative loading can reproduce the alternative stress at the upper end of vertical stiffener in the middle girder when vehicles run on the driving lane and passing lane alternatively.

Figure 6 shows the stress range distributions before and after retrofitting. The steel plate reinforcement using a jack-up jig can reduce the local stress concentration at the crack initiation point to about 60% of that before reinforcement. And, angle steel reinforcement using TRS can reduce the local stress concentration to about 50% of that before reinforcement.

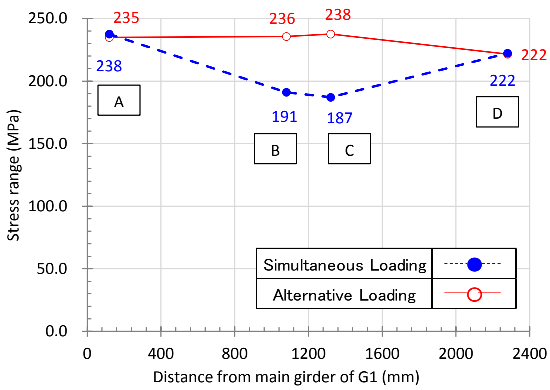


Figure 5. Stress range distributions under simultaneous loading and alternative loading.

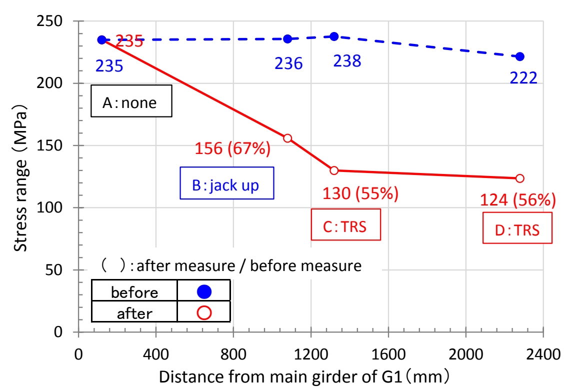


Figure 6. Stress range distributions before and after retrofitting.

3.2 Fatigue Test Results

Ns is the root crack initiation life defined as the number of loading cycles when the strain changes irreversibly. Nd(R) is the root crack detection life defined as the number of loading cycles when root cracks appear on the bead surface. Nd(T) is the toe crack detection life defined as the number of loading cycles when toe cracks are detected at the weld toe.

Figure 7 shows the relationship between strain and the number of loading cycles. Figure 8 shows the relationship between crack length and the number of loading cycles.

3.2.1 *Recreating crack (Test Part A)*

As shown in Figure 7, strain changes rapidly after N=0.1 Mcycles loading without retrofitting methods. Therefore, Ns can be estimated at 0.1 Mcycles. When N=0.6 Mcycles, root cracks appeared on the bead surface as shown in Figures 8 and 9 (Nd(R)=0.6 Mcycles).

3.2.2 *Preventive measure (Test Parts B, C, D)*

As shown in Figure 7, strain changes very little comparing with test part A, and no fatigue cracks were detected after 2.05 Mcycles loading. Steel plate reinforcement using jack up jig (B) and angle steel reinforcement using TRS (C and D) can prevent fatigue cracking at the upper end of vertical stiffeners.

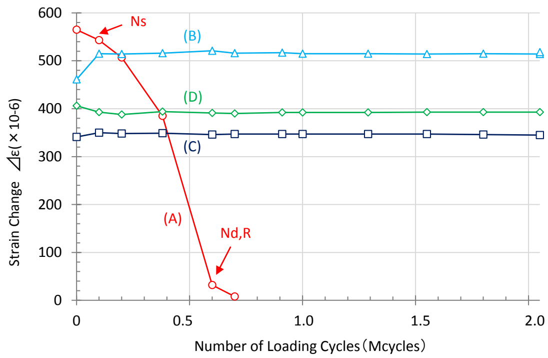


Figure 7. The relationship between strain change and the number of loading cycles.

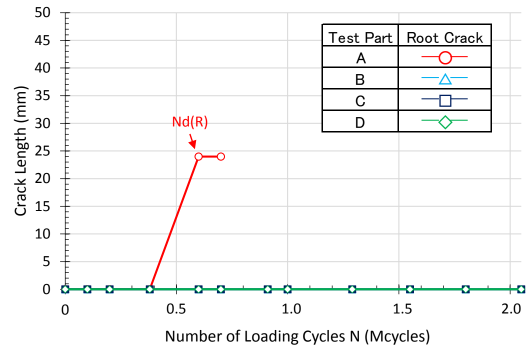
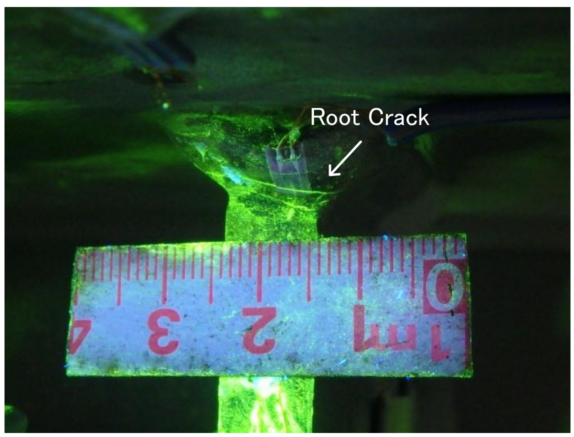
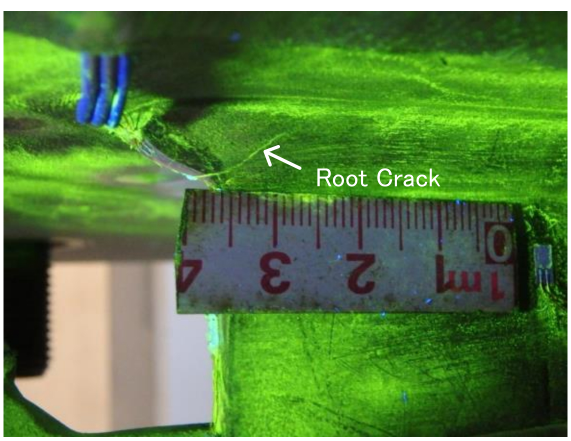


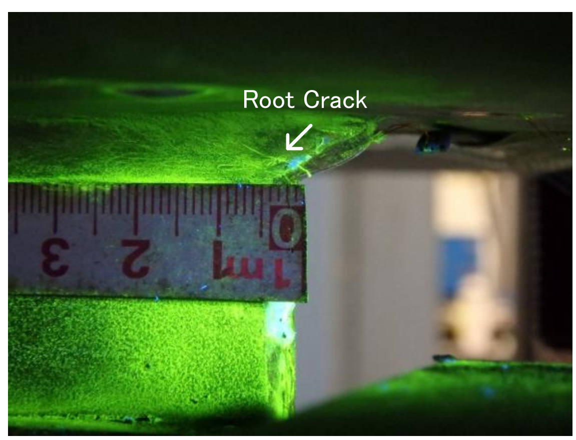
Figure 8. The relationship between crack length and the number of loading cycles.



(a) Side view



(b) Front view



(c) Back view

Figure 9. Appeared root crack, test part A, N=0.6 Mcycles.

4 SUMMARY

The main conclusions obtained through this study are as follows:

(1) Alternative loading can reproduce the alternative stress at the upper end of vertical stiffener in the middle girder when vehicles run on the driving lane and passing lane alternatively.

(2) Without retrofitting methods, root cracks were initiated after 0.1 Mcycles loading and appeared on the bead surface when 0.6 Mcycles.

(3) Both retrofitting methods, i.e. steel plate reinforcement using jack up jig and angle steel reinforcement using TRS, can reduce the local stress concentration at the crack initiation point to about half of that before reinforcement, and can prevent fatigue cracking.

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