Experimental study on retrofitting method against fatigue cracking at the upper end of vertical stiffeners

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ABSTRACT

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 propose two types of retrofitting methods against fatigue cracking at the upper end of vertical stiffeners under RC slab. They are steel plate reinforcement using a jack-up jig, and angle steel reinforcement using thread rolling screw (TRS). The effectiveness of those two types of retrofitting methods are experimentally investigated through fatigue tests using a large specimen with three main girders under alternative loading using two actuators. As a result, both retrofitting methods can reduce the local stress concentration at the crack initiation point to about half of that before reinforcement, and can prevent fatigue cracking. Post cracking measure, i.e. angle steel reinforcement using TRS after grinding away crack tips can extend fatigue crack propagation life more than 10 times of that without the reinforcement.

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 [1, 2]. 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 [3-7]. But it has not been verified how effective in stress reduction and fatigue life extension. In this study, we propose two types of retrofitting methods against fatigue cracking at the upper end of vertical stiffeners under RC slab. They are steel plate reinforcement using a jack-up jig, and angle steel reinforcement using TRS [8].

The effectiveness of those two types of retrofitting methods are experimentally investigated through fatigue tests using a full-scale specimen with three main girders under alternative loading using two actuators.

2 EXPERIMENTAL PROCEDURES

2.1 Specimen

Fig.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 2mm gap by CO_2 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 TRS.

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

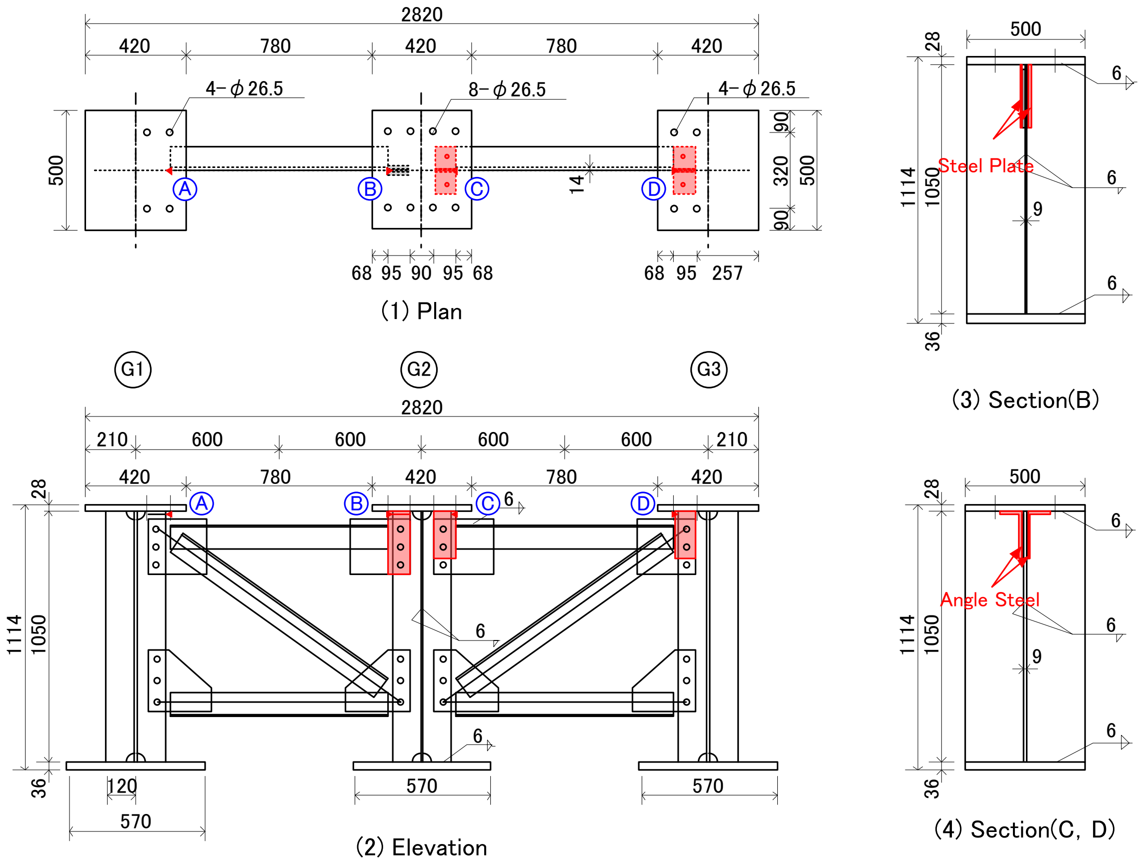


Fig.1 Configurations and Dimensions of the Specimen

2.2 Retrofitting Methods

(1) Steel plate retrofitting method using a jack-up jig

Figs.2 and 3 show appearance of steel plate reinforcement using a jack up jig. This method reduces the local stress concentration at the upper end of vertical stiffener by distributing the load to steel plates.

(2) Angle steel retrofitting method using TRS

Fig.4 shows appearance of angle steel reinforcement using TRS. 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

Fig.5 shows the loading method and Fig.6 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=120kN, Pmin=20kN).

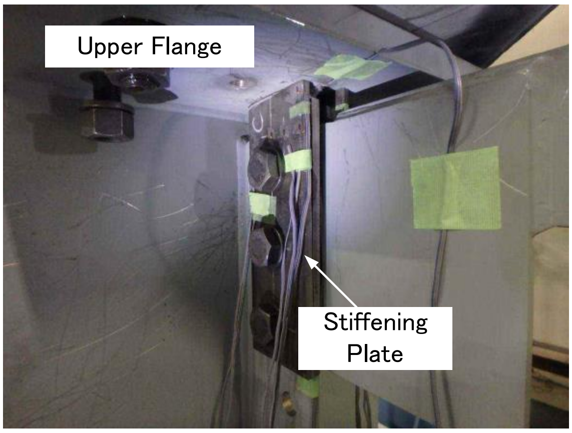


Fig.2 Stiffening Plate Retrofitting Method Using a Jack-up Jig

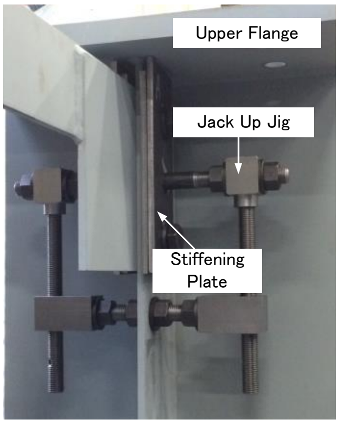


Fig.3 Stiffening Plate Retrofitting Method Using a Jack-up Jig

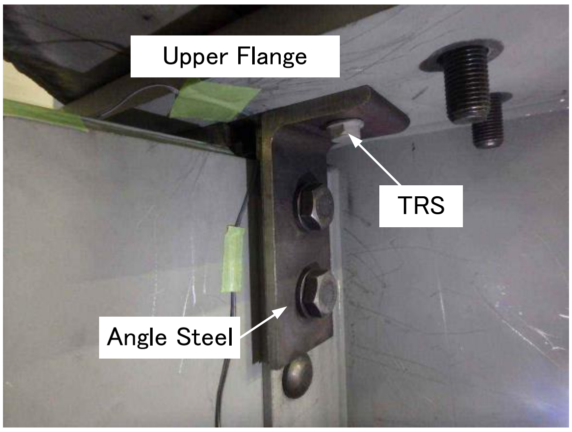


Fig.4 Angle Steel Retrofitting Method Using TRS

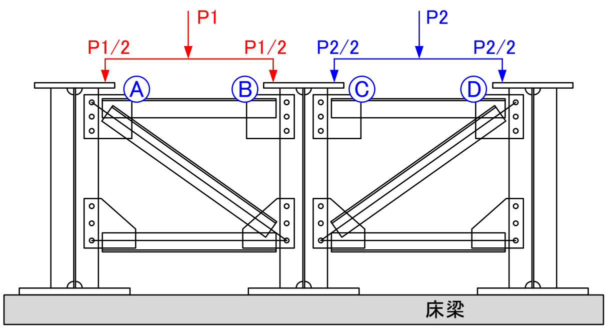


Fig.5 Loading Method

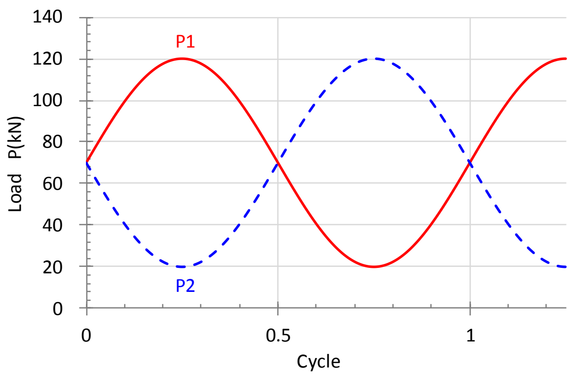


Fig.6 Loading Wave Forms

Fig.7 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 behaviour of root cracks.

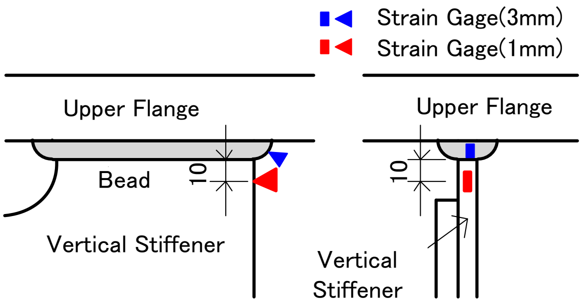


Fig.7 Location of Strain Gages

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.

Table 1 gives fatigue test steps.

(1) Step1: 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.

(2) Step2: In the test part A, purpose is to investigate the effectiveness of post cracking measure. Angle steel reinforcement using TRS was applied after grinding away crack tips. In the test parts B-D, purpose is recreating cracks without countermeasures.

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 behaviour of root cracks.

Table 1 Fatigue Test Step

Step	Test part	A	B	C	D
1	Purpose	Recreating crack	Preventive measure		
	Measure	None	Jack up	TRS	
2	Purpose	Post cracking measure	Recreating crack		
	Measure	Grainding crack tips + TRS	None		

3 EXPERIMENTAL RESULTS

3.1 Static loading test results

Fig.8 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.

Fig.9 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.

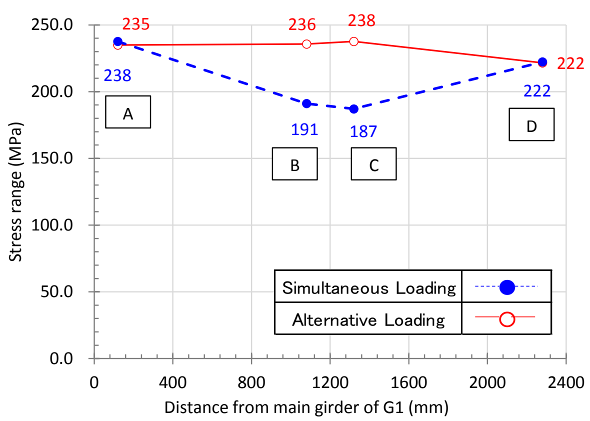


Fig.8 Stress Range Distributions under Simultaneous Loading and Alternative Loading

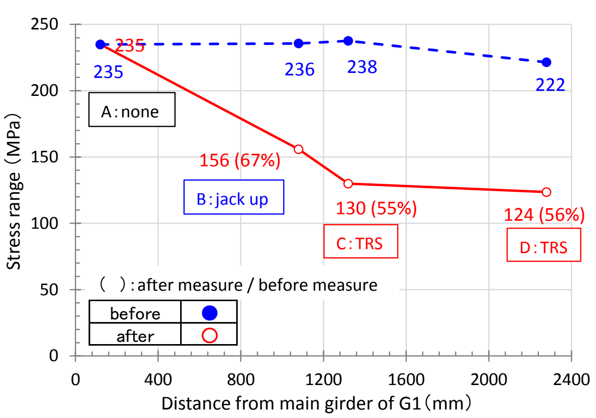


Fig.9 Stress Range Distributions Before and After Retrofitting

3.2 Fatigue test results

Table 2 gives 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 appears 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. Fig.10 shows the relationship between strain and the number of loading cycles. Fig.11 shows the relationship between crack length and the number of loading cycles.

Table 2 Fatigue Test Results

Test Part	Measure	Fatigue Life (Mcycles)			Crack Length (mm)	
		Ns	Nd,R	Nd,T	Initiation	Last
A	None	0.1	0.6	–	24	–
	TRS	–	–	–	–	46
B	Jack up	> 2.05	> 2.05	> 2.05	–	–
	None	2.55	3.75	1.6	3	22
C	TRS	> 2.05	> 2.05	> 2.05	–	–
	None	0.2	3.35	1.2	4	179
D	TRS	> 2.05	> 2.05	> 2.05	–	–
	None	1.4	1.6	–	12	49

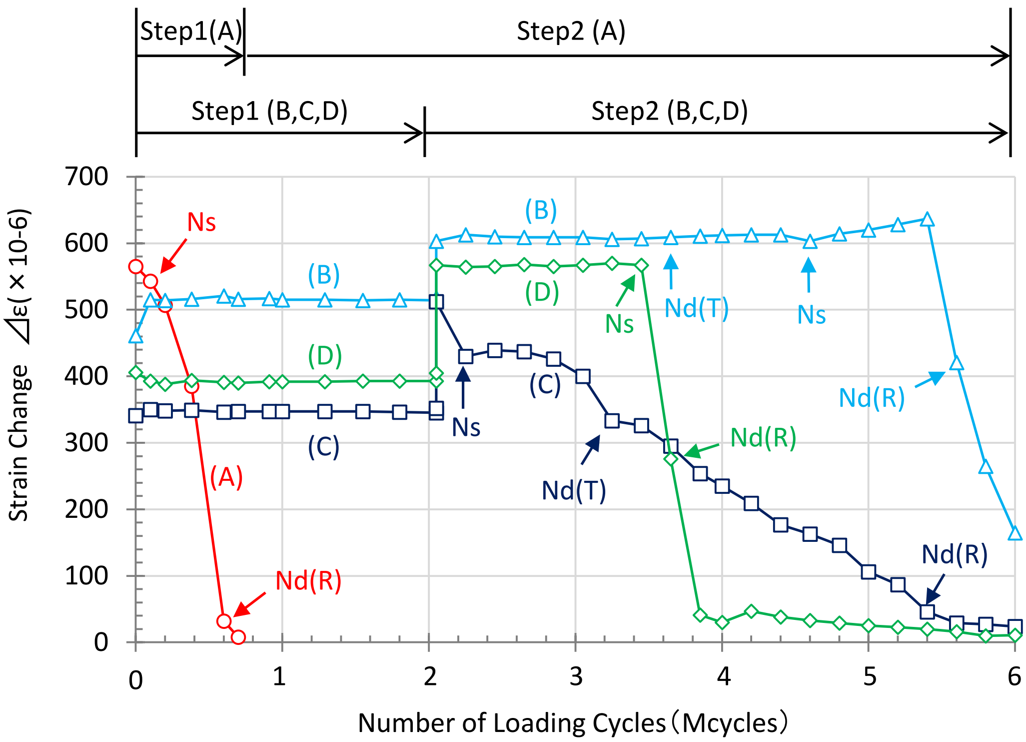


Fig.10 the Relationship between Strain Change and the Number of Loading Cycles

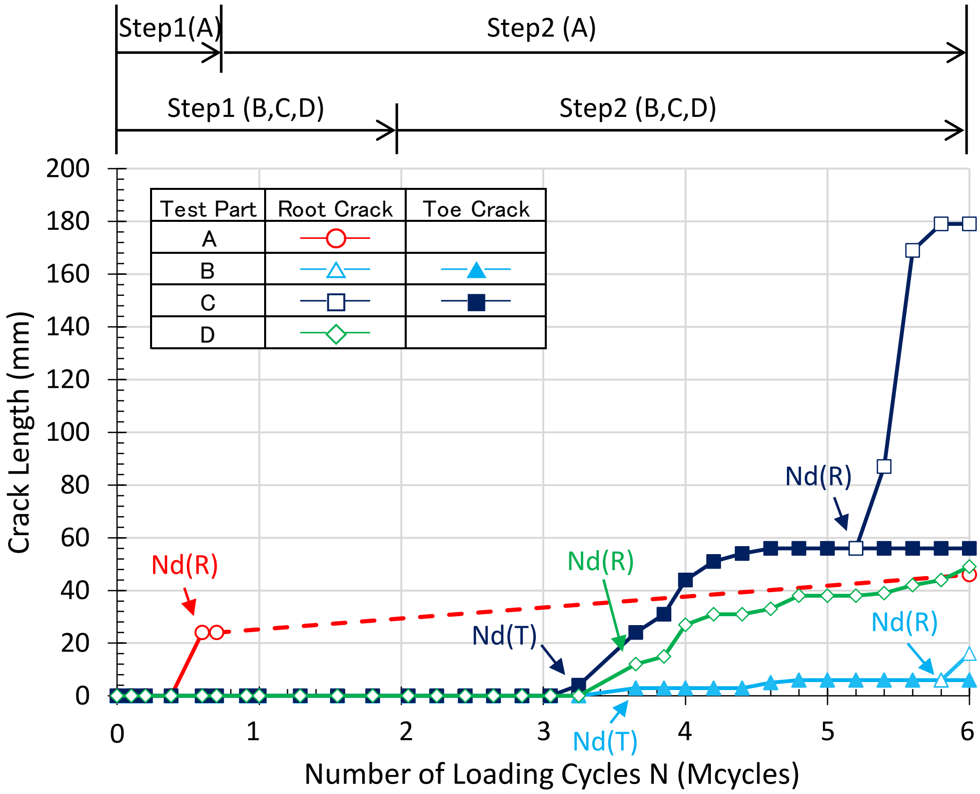


Fig.11 the Relationship between Crack Length and the Number of Loading Cycles

(1) Step1

a) Recreating crack (Test Part A)

As shown in Fig.10, strain changes rapidly after N=0.1Mcycles loading without retrofitting methods. Therefore Ns can be estimated at 0.1Mcycles. When N=0.6Mcycles, root cracks appeared on the bead surface as shown in Figs.11 and 12 (Nd(R)=0.6Mcycles).

b) Preventive measure (Test Parts B, C, D)

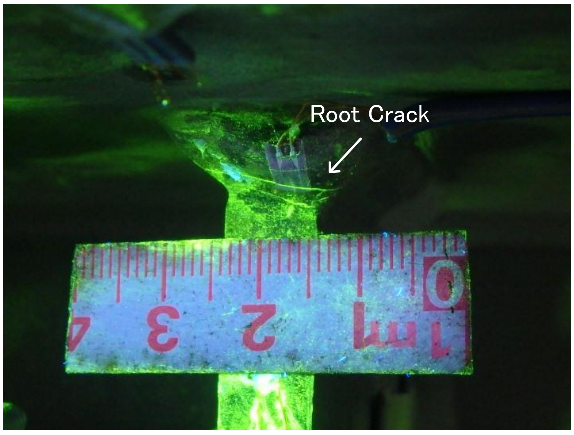
As shown in Fig.10, strain changes very little comparing with test part A, and no fatigue cracks were detected after 2.05Mcycles loading. Steel plate reinforcement using jack up jig (B) and angle steel reinforcement using TRS (C and D) can prevent fatigue cracking at the upper end of vertical stiffeners.

(2) Step2

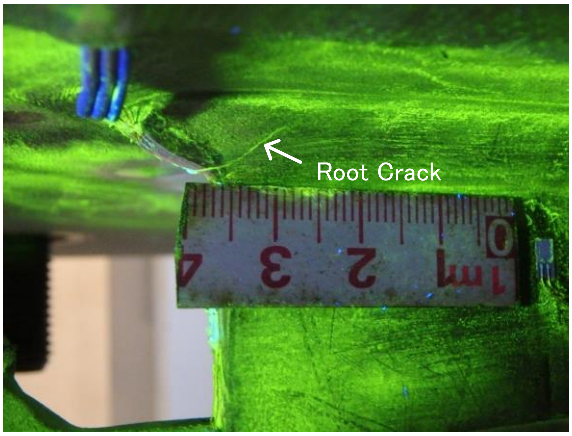
a) Recreating crack (Test Parts B, C, D)

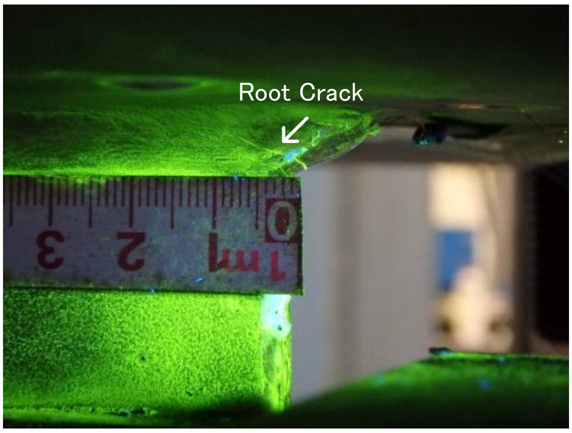
In test part C, as shown in Fig.10, strain changes irreversibly after 0.6Mcycles loading. Therefore Ns can be estimated at 0.6Mcycles. As shown in Figs.11 and 13, toe crack was detected at 1.2Mcycles (Nd(T)=1.2Mcycles). When N=3.35Mcycles, root cracks appeared on the bead surface as shown in Figs.11 and 14 (Nd(R)=3.35Mcycles). Eventually, when 3.75Mcycles loading, root cracks broke out the weld bead as shown in Figs.11 and 15.

In test part D, as shown in Fig.10, strain changes irreversibly after 1.2Mcycles loading. Therefore Ns can be estimated at 1.2Mcycles. When N=1.6Mcycles, root cracks appeared on the bead surface as shown in Figs.11 and 16 (Nd(R)=1.6Mcycles). And these cracks were propagated into the upper flange after 2.35Mcycles loading as shown in Fig.17.



(a) Side View





(b) Front View

(c) Back View

Fig.12 Appeared Root Crack, Test Part A, N=0.6Mcycles (Step1)

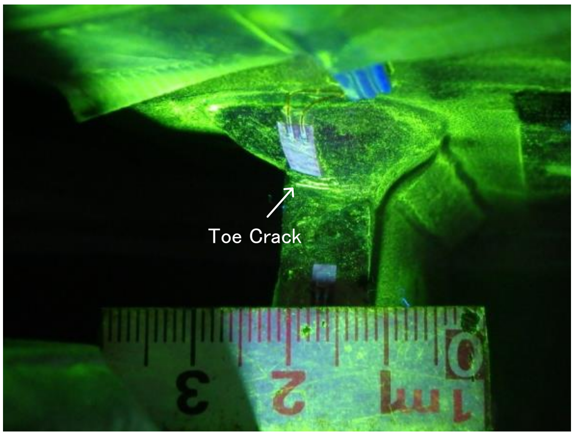


Fig.13 Detected Toe Crack, Test Part C, N=1.2Mcycles (Step2)

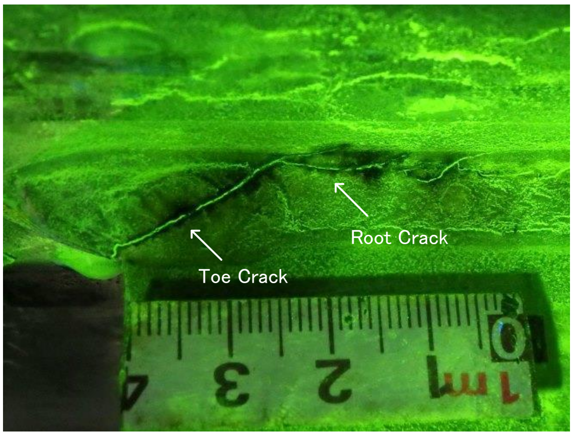


Fig.14 Propagated Toe Crack and Detected Root Crack Test Part C, N=3.35Mcycles (Step2)

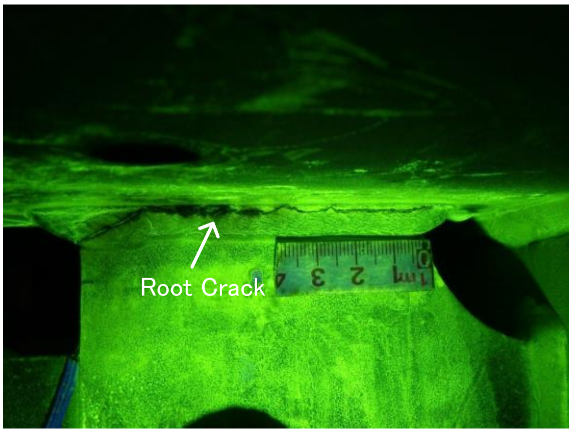


Fig.15 Root Crack breaking out the Weld Bead Test Part C, N=3.75Mcycles (Step2)

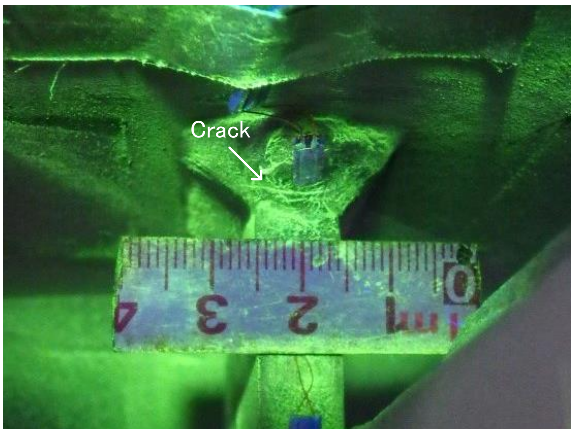


Fig.16 Appeared Root Crack, Test Part D
N=1.6Mcycles (Step2)

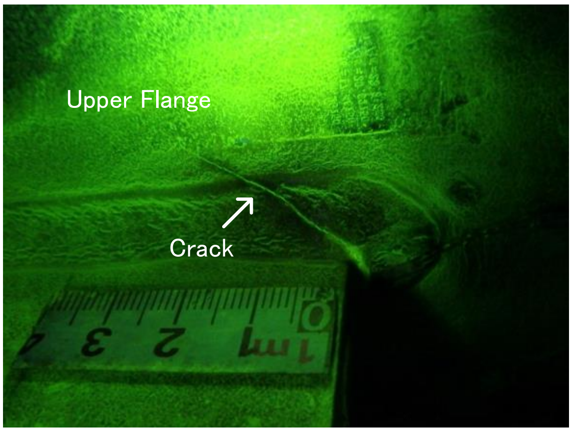


Fig.17 Root Crack propagated into the Upper Flange
Test Part D, N=3.95Mcycles (Step2)

In test part B, as shown in Fig.10, strain changes very little. But toe crack was detected at 1.6Mcycles as shown in Fig.18 (Nd(T)=1.6Mcycles). Thereafter, as shown in Fig.10, strain changes irreversibly after 2.55Mcycles loading. Therefore Ns can be estimated at 2.55Mcycles. When N=3.75Mcycles, root cracks appeared on the bead surface as shown in Figs.11 and 19 (Nd(R)=3.75Mcycles).

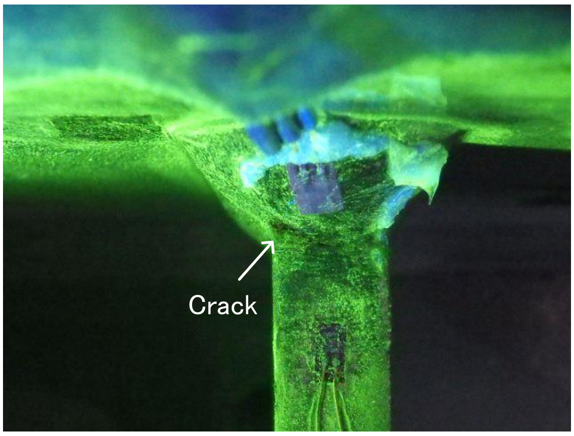


Fig.18 Detected Toe Crack, Test Part B
N=1.6Mcycles (Step2)

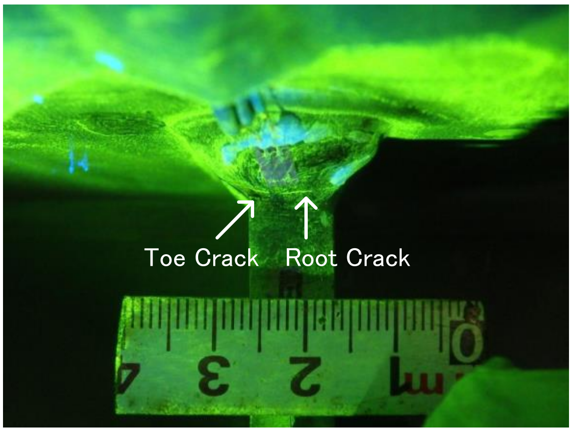


Fig.19 Propagated Toe Crack and Detected Root Crack
Test part B, N=3.75Mcycles (Step2)

b) Post cracking measure (Test Part A)

Crack tips were ground away by a bar grinder as shown Fig.20. After 5.3Mcycle loading, new root cracks with the length of 22mm on both sides were initiated and propagated from root tips as shown in Figs.11 and 21.

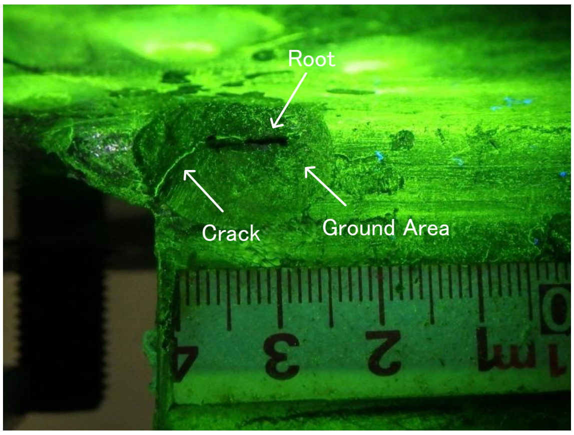


Fig.20 Ground Crack Tips
Test Part A, N=0.7Mcycles (Step1)

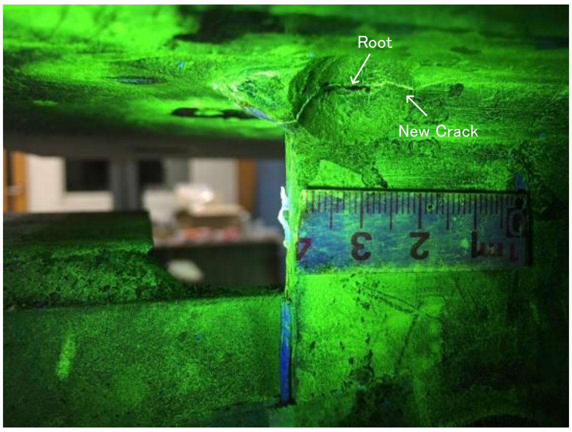


Fig.21 Initiated New Crack
Test Part A, N=5.3Mcycles (Step2)

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) 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.
(3) Without those retrofitting methods, root cracks are initiated after 0.1 to 2.75Mcycles loading and toe cracks after 1.2 to 1.6Mcycles loading.
(4) As a preventive countermeasure, both retrofitting methods can prevent fatigue cracking.
(5) As a post cracking countermeasure, angle steel reinforcement using TRS after grinding away crack tips can extend fatigue crack propagation life more than 10 times of that without the reinforcement.

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