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Retrofitting method against fatigue cracking of web gap plates

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ABSTRACT: Lots of fatigue crackings were reported at the upper end of vertical stiffeners connected to sway bracings and web gap plates under RC slab in steel highway girder bridges. In this study, we investigate fatigue cracking behavior, and propose a retrofitting method against fatigue cracking at the upper end of web gap plates under RC slab. In this method, TRS (Thread Rolling Screw) is used to attach angle steel to upper flange, and HTB (High Tension Bolt) is used to connect angle steels to web gap plate. The effectiveness of the method is investigated through fatigue tests using a beam specimen with the web gap detail of the same size as the actual bridge under alternative loading using two actuators. As a result, the method can reduce the local stress concentration at crack initiation points to about 50~60 %, and can extend fatigue crack initiation life more than 2~6 times and fatigue crack propagation life more than 100 times after grinding away fatigue cracks.

1 INTORODUCTION

Lots of fatigue crackings were reported at the upper end of vertical stiffeners connected to sway bracings and web gap plates under RC slab 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. Whereas, the semicircular cutting method for web gap plate to reduce stress concentration at the weldment were proposed, but cracks may be propagated when short cracks have been already initiated. In this study, we investigate fatigue cracking behavior, and propose a retrofitting method against fatigue cracking at the upper end of web gap plates under RC slab. In this method, TRS is used to attach angle steel to upper flange, and HTB is used to connect angle steels to web gap plate.

The effectiveness of the method is investigated through fatigue tests using a beam specimen with the web gap detail of the same size as the actual bridge 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 (Ichinose 2017), because of capacity of fatigue testing facility. But upper flange and web gap plates 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, B: No retrofitting method; 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.

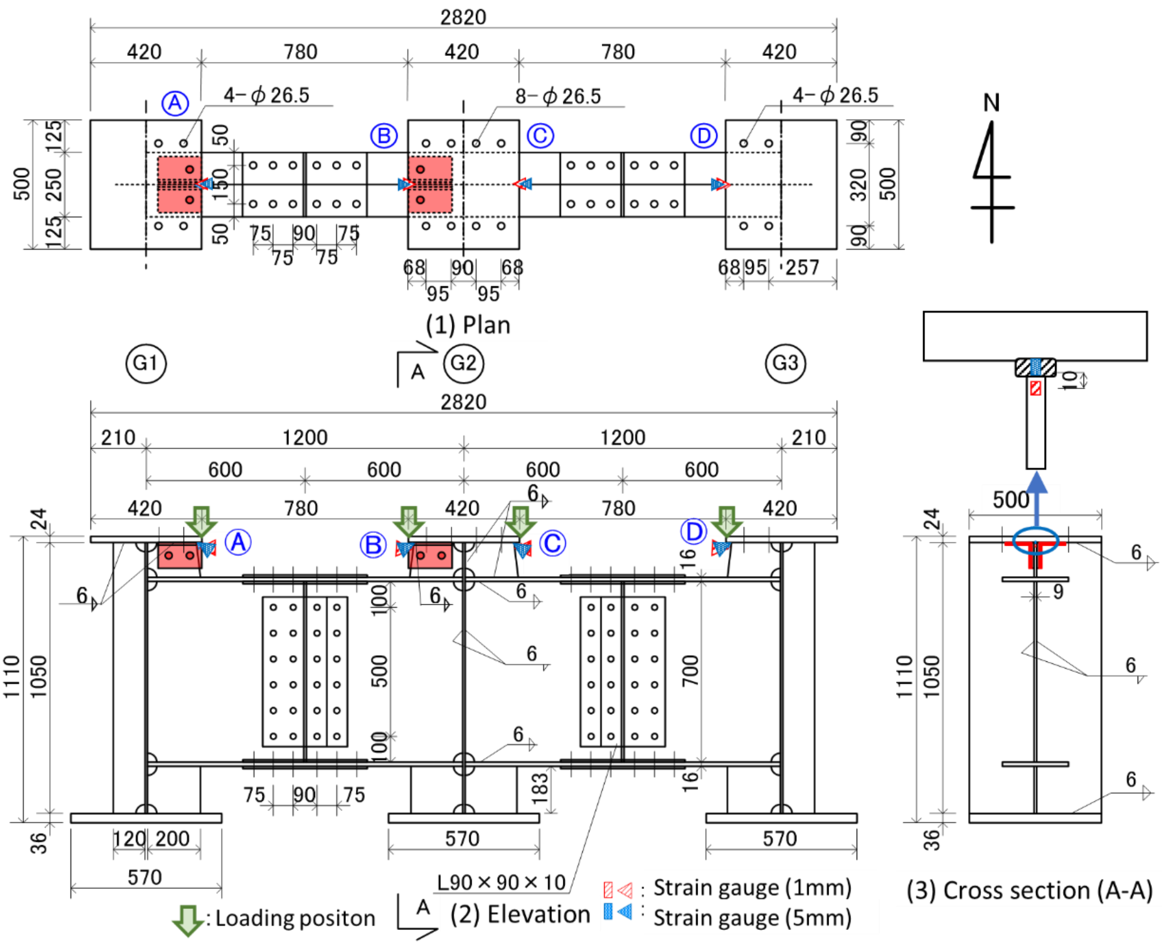


Figure 1. Configurations and dimensions of specimen

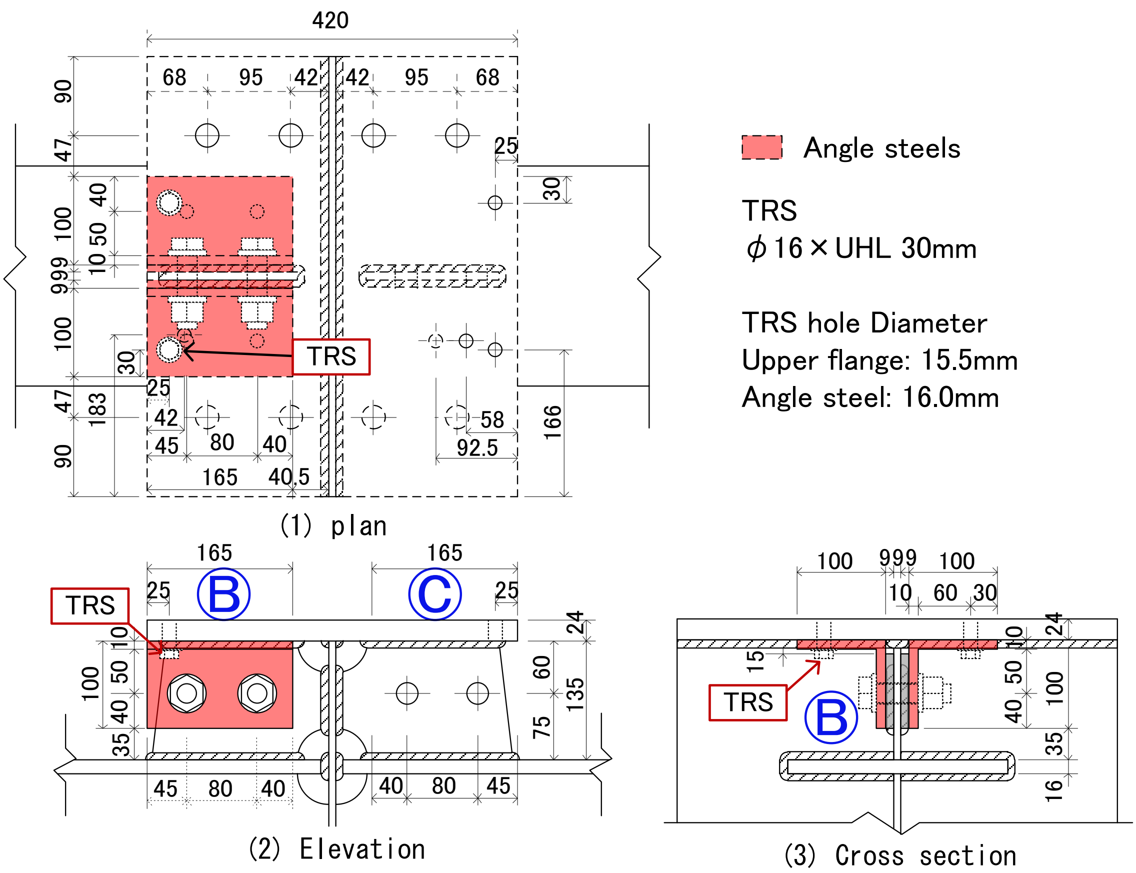
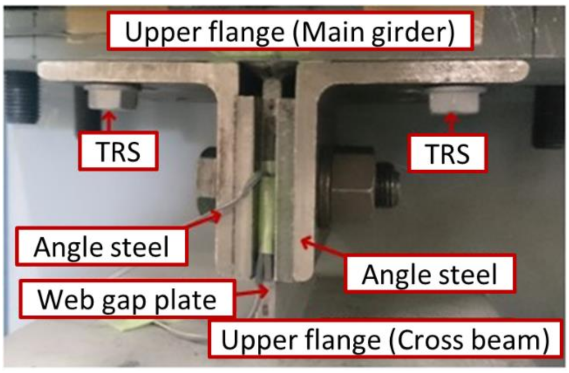
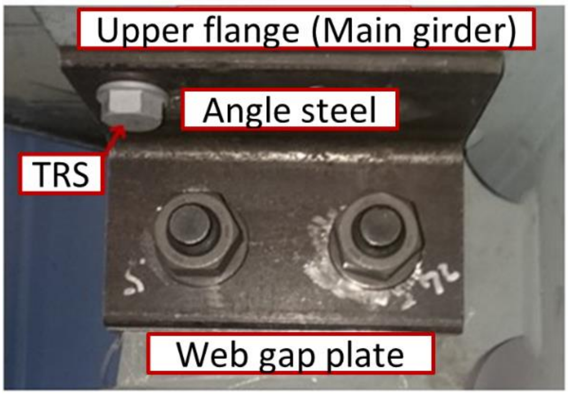


Figure 2. Retrofitting Details



(a) Cross section



(b) Elevation

Figure 3. Angle steel method using TRS

2.2 *Retrofitting method*

Figure 2 shows retrofitting details, and Figure 3 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*

Figure 4 shows the loading method and Figure 5 shows loading wave form. 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 120kN (Pmax=140kN, Pmin=20kN).

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 5mm long strain gages were pasted on the bead surface, in order to monitor initiation and propagation behavior of root cracks.

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.

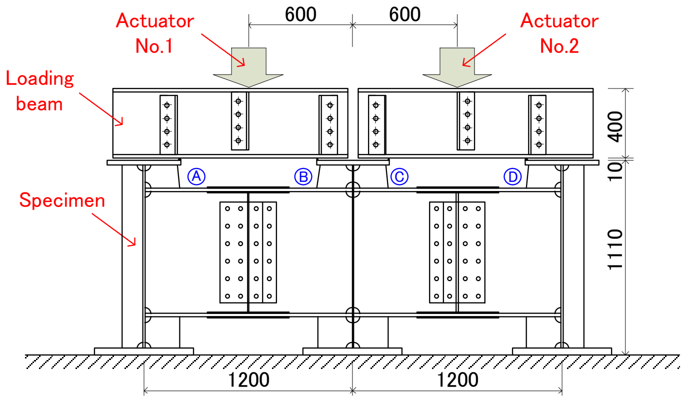


Figure 4. Loading Method

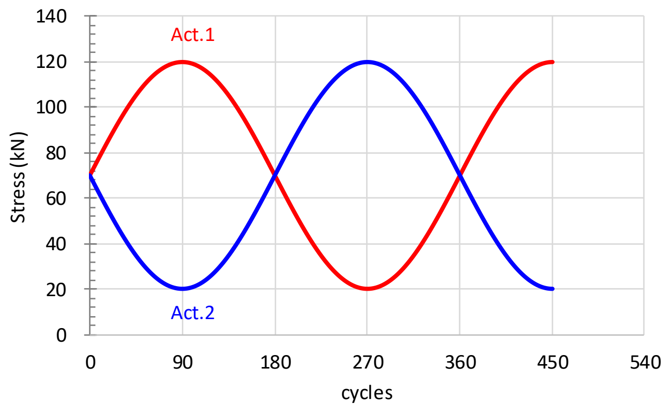


Figure 5. Loading wave form

Table 1. Fatigue test steps

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

Table 1 gives fatigue test steps.

(1) Step1: In the test part A and B, purpose is to investigate the effectiveness of angle steel reinforcement using TRS. In the test parts C and D, purpose is to recreate cracks without measure.

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

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.

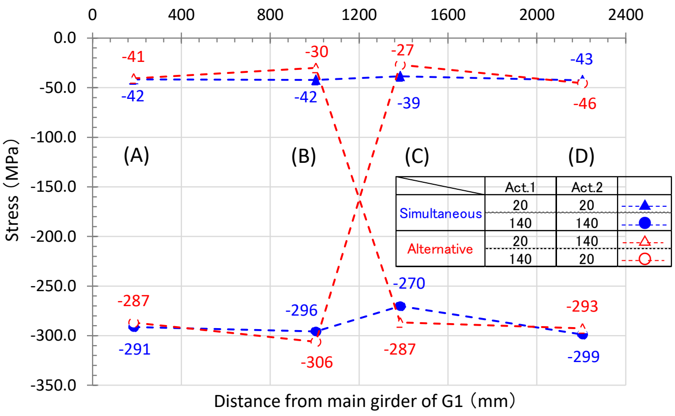


Figure 6. Stress Distributions under
Simultaneous Loading and Alternative Loading

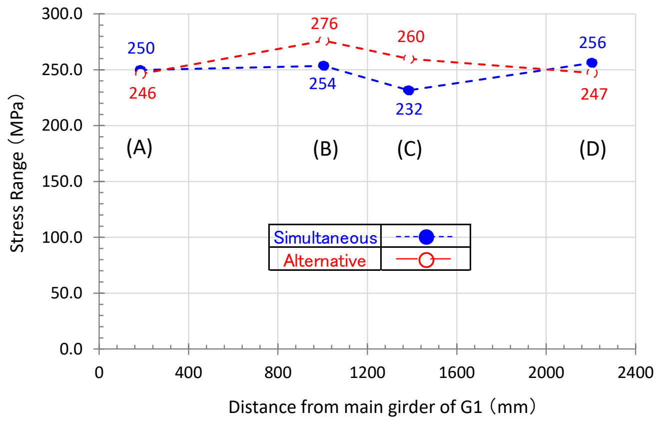


Figure 7. Stress Rage Distributions under
Simultaneous Loading and Alternative Loading

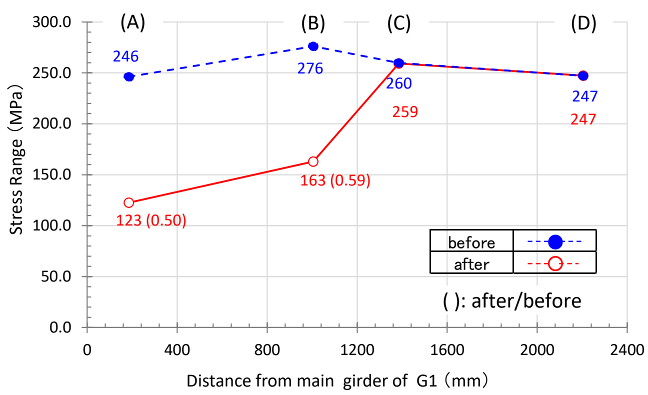


Figure 8. Stress Range Distributions
Before and After Retrofitting

3 EXPERIMENTAL RESULTS

3.1 *Static loading test results*

Figures 6 and 7 shows the stress and stress range distributions under simultaneous loading and alternative loading. The stress range in middle girder (B and C) under alternative loading method increases about 10% of that under simultaneous loading. Alternative loading can reproduce the alternative stress at the upper end of web gap plates in the middle girder when vehicles run on the driving lane and passing lane alternatively.

Table 2. Fatigue test results

test part	measure	fatigue life (Mcycles)			crack length (mm)	
		Ns	Nd (R)	Nd (T)	initiate	last
A	preventive	>500	>500	>500	–	–
	none	80	540	110	8 (8)	13 (64)
B	preventive	>500	>500	>500	–	–
	none	>750	–	140	4	8
C	none	110	290	190	13 (4)	20 (155)
	post cracking	>750	>750	>750	–	20 (157)
D	none	>500	–	230	7	12
	post cracking	>750	>750	>750	–	2

toe (root)

Figure 8 shows the stress range distributions before and after retrofitting. Angle steel reinforcement using TRS can reduce the local stress concentration to about 50-60% of that before reinforcement.

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.

Figure 9 shows the relationship between strain and the number of loading cycles and Figure 10 shows the relationship between crack length and the number of loading cycles. Table 3 shows retrofit effectiveness

(1) Step1

a) Recreating crack (Test Part C, D)

In test part C, strain changes irreversibly after N=1.1Mcycles loading without retrofitting method. Therefore Ns can be estimated at 1.1Mcycles. When N=1.9Mcycles, toe cracks detected (Nd(T)=1.9Mcycles), and N=2.9Mcycles, root crack appeared on the bead surface (Nd(R)=2.9Mcycles) as shown in Figure 11. As shown Figure 10, toe crack is hardly propagated, but root crack propagated rapidly after it appeared on the bead surface.

In test part D, When N=2.3Mcycles, toe cracks detected as shown in Figure 12 (Nd(T)=2.3Mcycles).

b) Preventive measure (Test Parts A, B)

In test parts A, B, strain changes very little comparing with test parts C, D, and no fatigue cracks were detected after 5.0Mcycles loading. Angle steel reinforcement using TRS can prevent fatigue cracking and extend fatigue crack initiation life more than 2.2 (5.0Mcycles / 2.3Mcycles) ~ 4.5 (5.0Mcycles / 1.1Mcycles) times as shown Table 3.

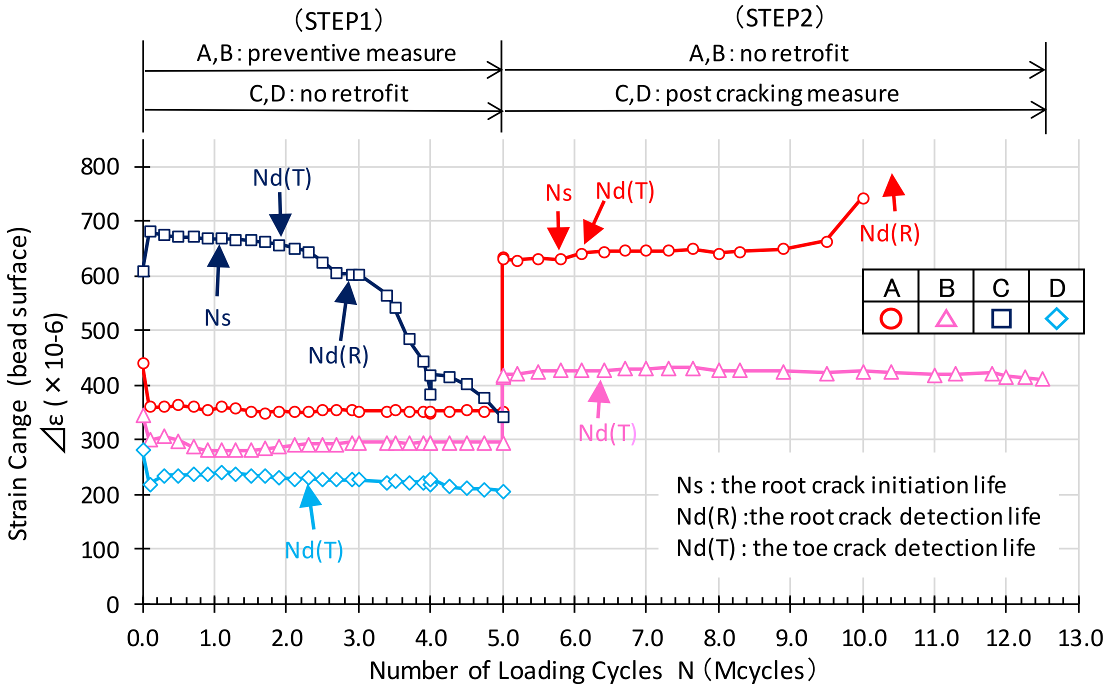


Figure 9. Relationship between strain and the number of loading cycles

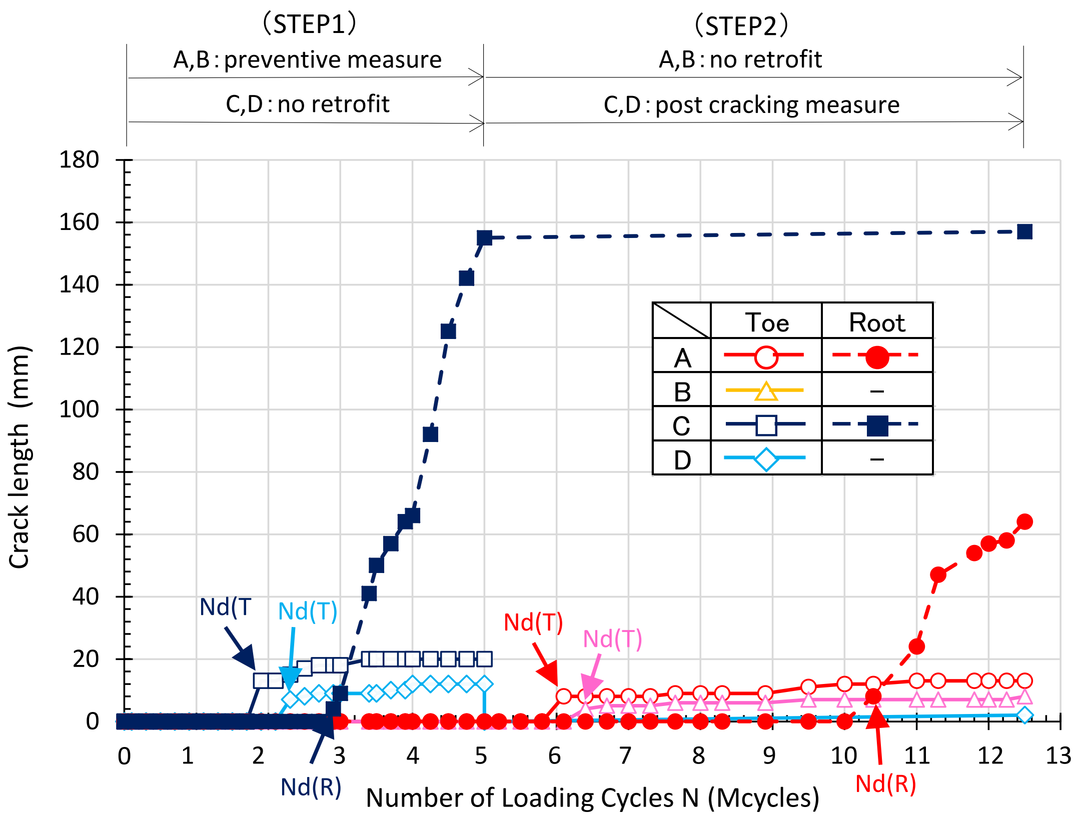
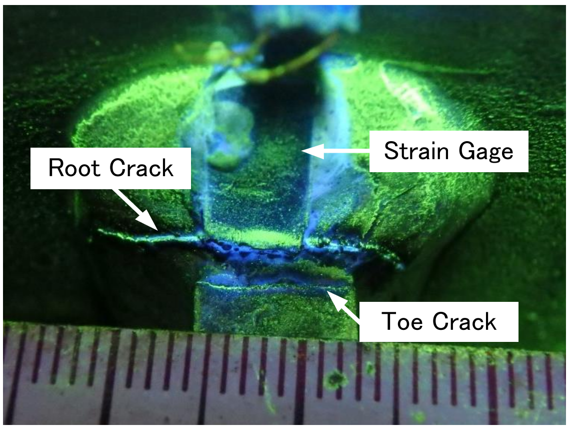


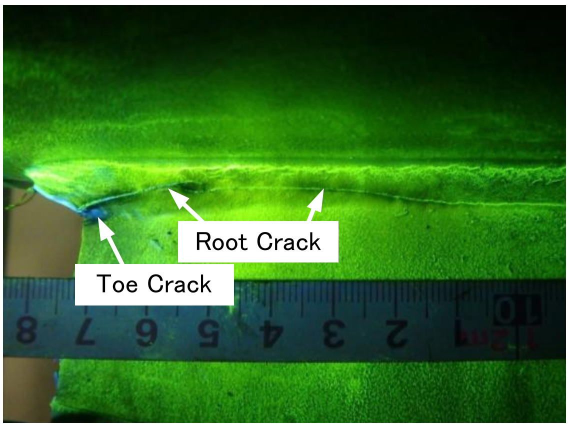
Figure 10. Relationship between crack length and the number of loading cycles

Table 3. Retrofit Effectiveness

test part	fatigue life		fatigue crack initiation life		crack growth rate		crack propagation life
	STEP1	STEP2	AB/C,D(①)	①/②	STEP1	STEP2	①/②
A	>500	80	−	>6.3times	−	−	−
B		140	−	>3.6times	−	−	−
C	110	>750	>4.5times	−	13mm/ 25Mcycles	2mm/ 750Mcycles	200times
D	230		>2.2times	−	7mm/ 20Mcycles	2mm/ 750Mcycles	130times



(a) Side view



(b) Face view

Figure 11. Propagated Toe Crack and Root Crack, Test Part C, N=5.0Mcycles

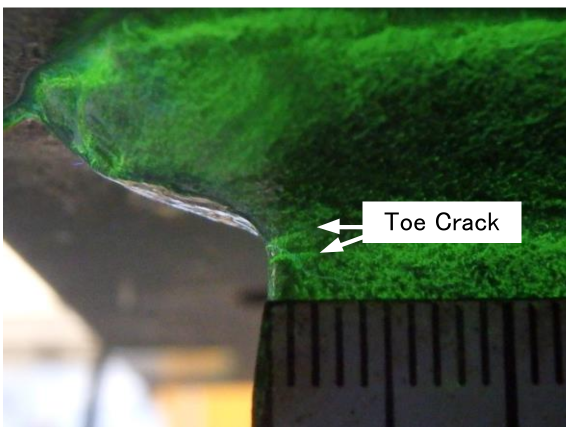


Figure 12. Propagated Toe Crack, Test Part D, N=5.0Mcycles

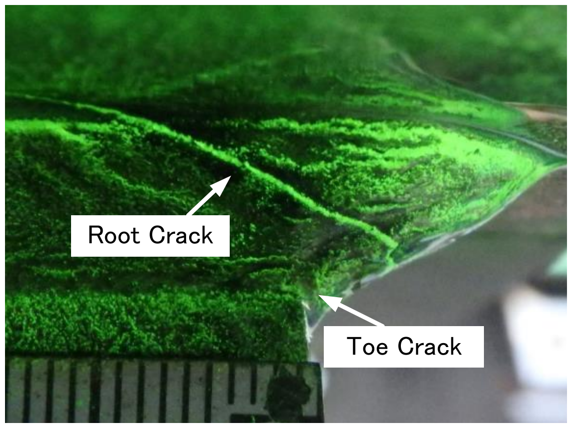


Figure 13. Propagated Toe Crack, Test Part A, N=7.5Mcycles

(2) Step2

a) Recreating crack (Test Parts A, B)

In test part A, strain changes after 0.8Mcycles loading. Therefore Ns can be estimated at 0.8Mcycles. When N=1.1Mcycles, toe cracks detected (Nd(T)=1.1Mcycles) and, when N=5.4Mcycles, root cracks appeared on the bead surface as shown in Figure 13 (Nd(R)=5.4Mcycles).

In test part D, when N=1.4Mcycles, root cracks appeared on the bead surface as shown in Figure 14 (Nd(R)=1.4Mcycles).

Angle steel reinforcement using TRS can prevent fatigue cracking and extend fatigue crack initiation life more than 3.6 (5.0Mcycles / 1.4Mcycles) ~ 6.3 (5.0Mcycles / 0.8Mcycles) times as shown Table 3.

b) Post cracking measure (Test Part C, D)

In test part C, crack tips were ground away by a bar grinder as shown Figure 15. After 7.5Mcycle loading, new root cracks with the length of 2mm was initiated from root tips as shown Figure 16. The retrofitting method can extend fatigue crack propagation life more than 200 (2mm/7.5Mcycles / 13mm/2.5Mcycles) times.

In test part D, crack tips were ground away by a bar grinder as shown Figure 17. After 7.5Mcycle loading, new toe crack with the length of 2mm was initiated as shown in Figure 18. The retrofitting method can extend fatigue crack propagation life more than 130 (2mm/7.5Mcycles / 7mm/20Mcycles) times.

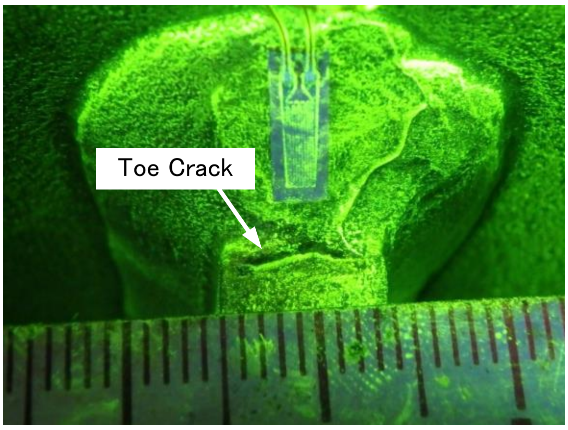


Figure 14. Propagated Toe Crack,
Test Part B, N=7.5Mcycles

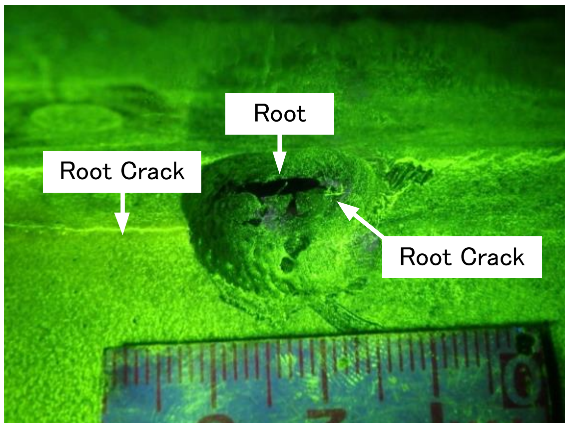


Figure 16. After post cracking measure,
Test Part C, N=7.5Mcycles

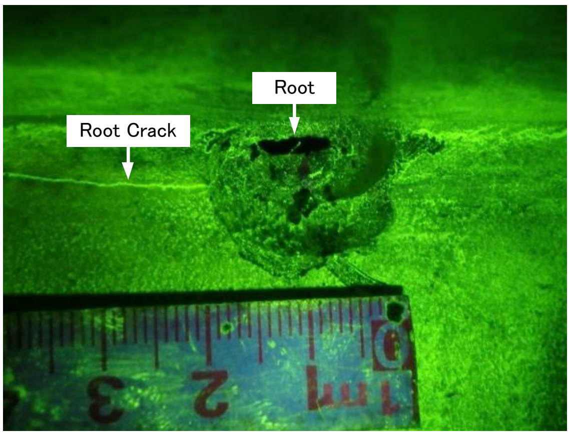


Figure 15. Grinding away crack tips,
Test Part C, N=5.0Mcycles

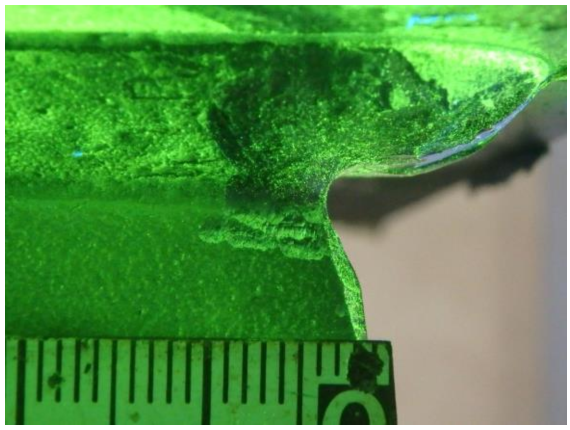


Figure 17. Grinding away crack tips,
Test Part D, N=5.0Mcycles

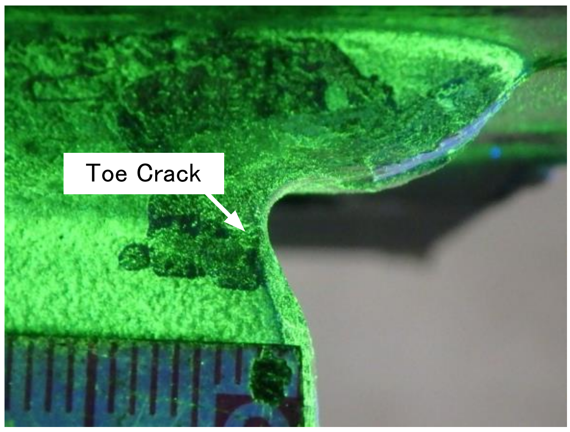


Figure 18. After post cracking measure,
Test Part D, N=7.5Mcycles

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 web gap plate in the middle girder when vehicles run on the driving lane and passing lane alternatively.

(2) Angle steel reinforcement using TRS, can reduce the local stress concentration at the crack initiation point to about 50~60% of that before reinforcement.

(3) Without the retrofitting method, root crack is initiated after 0.8 to 1.1Mcycles loading and toe cracks are detected after 1.1 to 2.3Mcycles loading.

(4) As a preventive measure, the method can prevent fatigue cracking and extend fatigue crack initiation life more than 2.2~6.3 times.

(5) As a post cracking measure, angle steel reinforcement using TRS after grinding away crack tips can extend fatigue crack propagation life more than 100 times of that without the reinforcement.

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