

Effectiveness of fatigue retrofits to transverse beam and sway bracing connections in steel bridges

A great number of fatigue cracks have been found in the welded joints at the top end of web gap plates in the transverse beam connection, at the top end of vertical stiffeners in the sway bracing connection, and at the web penetrations with the transverse beam bottom flange.

The present paper is a report on the verification of the effectiveness of 3 new types of retrofit methods proposed against those fatigue crackings. Stress measurements were carried out before and after retrofit works in a 45 years old bridge located in one of the heaviest traffic routes in Japan. As a result, fatigue life was considerably improved after the retrofit works, except for the case of vertical stiffener upper end retrofitted by the jack-up method. Fatigue life was improved to more than a several times by the TRS method for the vertical stiffener upper end and web gap, and to more than tens of times at the girder web slot area after retrofitting.

1 Introduction

Many reports on fatigue damage in steel bridges have appeared in Japan in recent years and the numbers show a tendency to increase rapidly with the progressive ageing of the structures. Unless adequate measures are taken in time, these cracks – depending on their nature and location – could lead to catastrophic consequences.

Many occurrences of fatigue cracking in plate girder bridges were found in the welding line connecting the upper flange of the main girder to the web gap plate which connects the upper flange of the main girder to the upper flange of the transverse beam. Fatigue cracks in the weld connecting the upper ends of vertical stiffeners to the upper flange of the main girders at sway bracing intersections also occur due to a similar mechanism, and their number also accounts for a considerable proportion among the damage reports. Retrofitting measures, such as replacing the damaged members or rewelding the web gap plate or the upper ends of vertical stiffeners [1], have been proposed for these locations in the past. However, the execution of welding in situ, under the effects of live loads, can cause inconveniences that could trigger problems in future. Thus, the present study proposes two non-welded retrofitting methods: a jack-up method [2] employing a

screw-type jig and bolted connections using thread rolling screw (TRS) fasteners.

Together with these damage patterns, critical damage patterns also occur, such as those at the connection details between the flanges of transverse beam and main girder web, where the flanges of the transverse beam are inserted through a slot in the main girder web and welded to the main girder web. As cracks originating in these locations can propagate into the girder web to such an extent that structural collapse might result, urgent and adequate retrofits are required [1] as preventive measures. Past reports have considered attaching reinforcing plates and finishing the weld toes as preventive measures [3]; however, these measures, although improving the fatigue life of the detail to a certain extent, were not able to stop crack initiation completely. To avoid difficulties from the constructional point of view, a method was proposed which employs steel angles and complete removal of the weld [4].

The present paper outlines the results obtained during the “Research Project for the Rationalization of Fatigue Crack Inspections in Steel Bridges” [5] (hereinafter referred to as the “Research Project”) carried out at the Kinki Regional Bureau of the Japanese Ministry of Land Infrastructure Transportation and Tourism. The effectiveness of the preventive measures proposed in the Research Project were verified through stress measurements carried out before and after the execution of the retrofit works on a bridge in service and the results are reported below.

2 Field work

Field work was carried out on a 45-year-old bridge located on one of the busiest traffic routes in Japan. Preventive retrofit methods proposed in the Research Project were executed in a trial project and stress measurements were carried out before and after the execution of retrofitting works to evaluate the fatigue life of the locations of the retrofits and verify the effectiveness of the proposed methods.

2.1 Characteristics of the bridge

The bridge selected for field work was completed in 1972 and its plan view is presented in Fig. 1. As shown in the figure, the bridge is composed of six consecutive spans of

* Corresponding author:
L-Ichinose@jit-osaka.co.jp

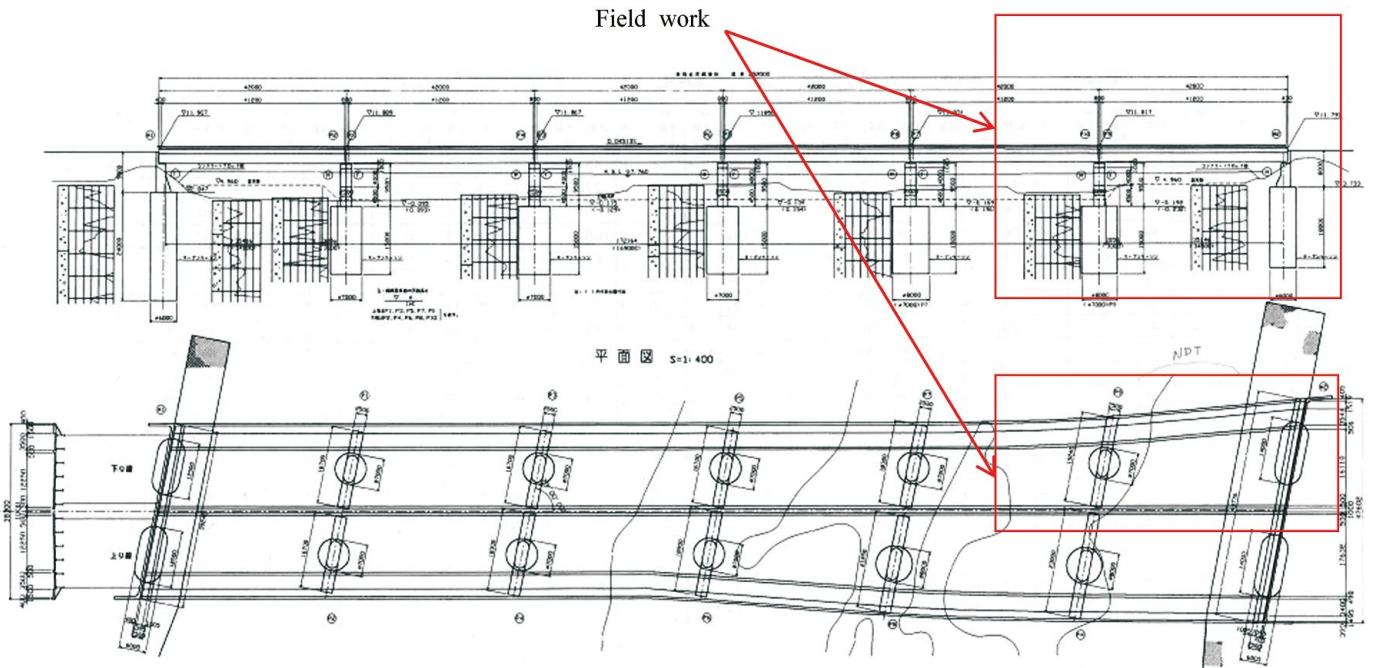


Fig. 1. Bridge selected for stress measurements

simply supported composite steel girders, each of them having a span length of 41.2 m and an average bridge width of 18.8 m, accommodating a road with six traffic lanes, supported by six main girders. The bridge is located on one of the busiest routes in Japan and according to a census carried out in 2010, the traffic volume crossing the bridge is about 120 000 vehicles per day, 21.2% of which are considered to be heavy goods vehicles.

Owing to its easy accessibility, the sixth span, shown in Fig. 1, was chosen for the execution of retrofitting works and stress measurements.

2.2 Fatigue damage found on the bridge

Visual inspections carried out in 2012 revealed cracks in the paint coating at more than 4000 locations [6]. As fatigue cracks are often found underneath cracks in the coating, these cracks were considered to be potential fatigue cracks. Crack patterns found on the bridge are presented in Fig. 2, and their respective numbers are shown in Table 1. Of the various patterns of coating cracks found during the visual inspections, the present paper will focus on crack patterns ④ and ⑩. The former, presenting the highest

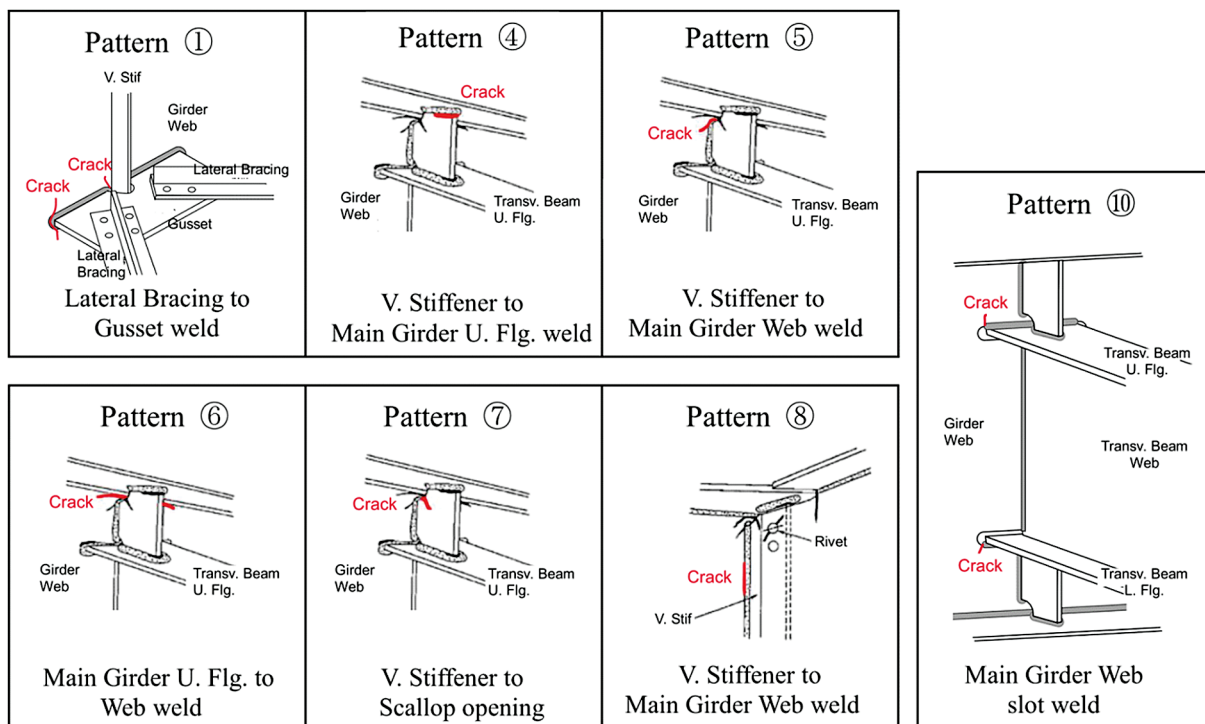


Fig. 2. Damage patterns found on the selected bridge

Table 1. Number of cracks in paint per damage pattern

Damage pattern	Outbound	Inbound	Total
Pattern ①	345	212	557
Pattern ②	631	560	1191
Pattern ③	214	208	422
Pattern ④	123	118	241
Pattern ⑤	304	274	578
Pattern ⑥	92	68	160
Pattern ⑦	456	421	877
Total	2165	1861	4026

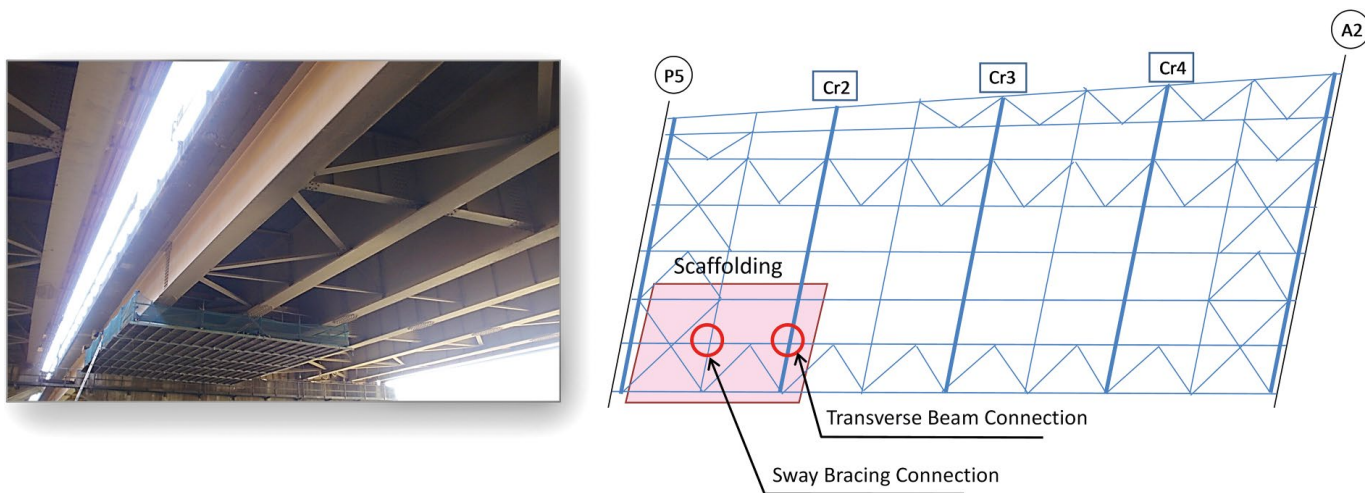


Fig. 3. Location of retrofitting works

occurrence among the crack patterns found on the bridge, is also one of the crack patterns with the highest occurrence on Japanese bridges. And pattern ⑦ is a crack pattern that can propagate into the main girder web and grow to an extent that can compromise the structural safety of the bridge. It is therefore considered to be one of the most critical damage patterns found on Japanese bridges [4], [7], [8].

Retrofits were executed at the locations shown in Fig. 3 for damage patterns ④ and ⑦ according to the proposed methods.

3 Preventive measures

3.1 Retrofit for damage pattern ④

Two types of retrofit were employed for damage pattern ④ at the connection between vertical stiffener and sway bracing connection, as shown in Fig. 4.

The first method reinforced the upper part of the vertical stiffener by attaching steel plates to both sides of the vertical stiffener with high tension bolts, which were fastened after jacking up the reinforcing plates against the main girder upper flange. A screw-type jig was used to jack

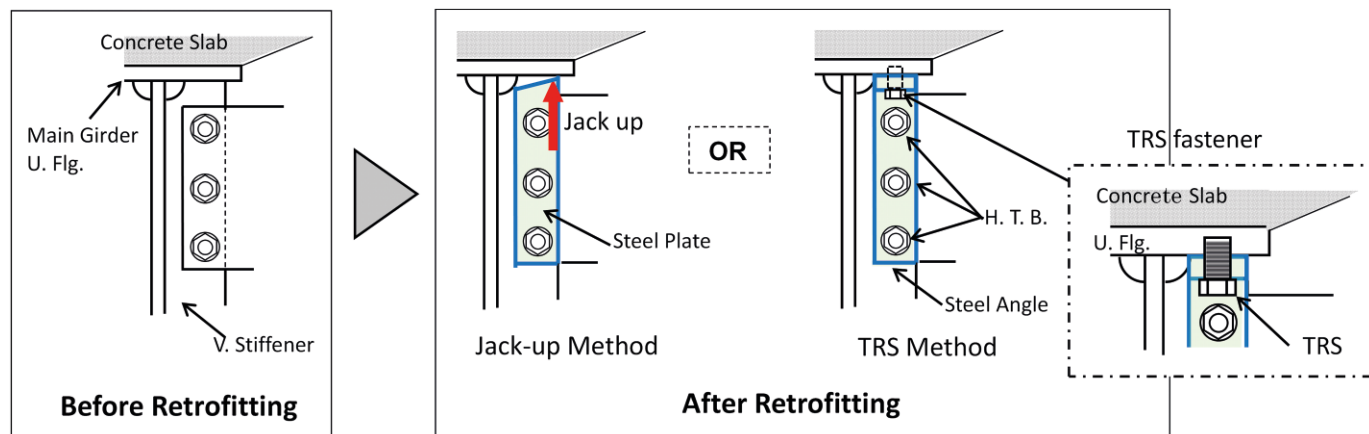


Fig. 4. Retrofit for damage pattern ④

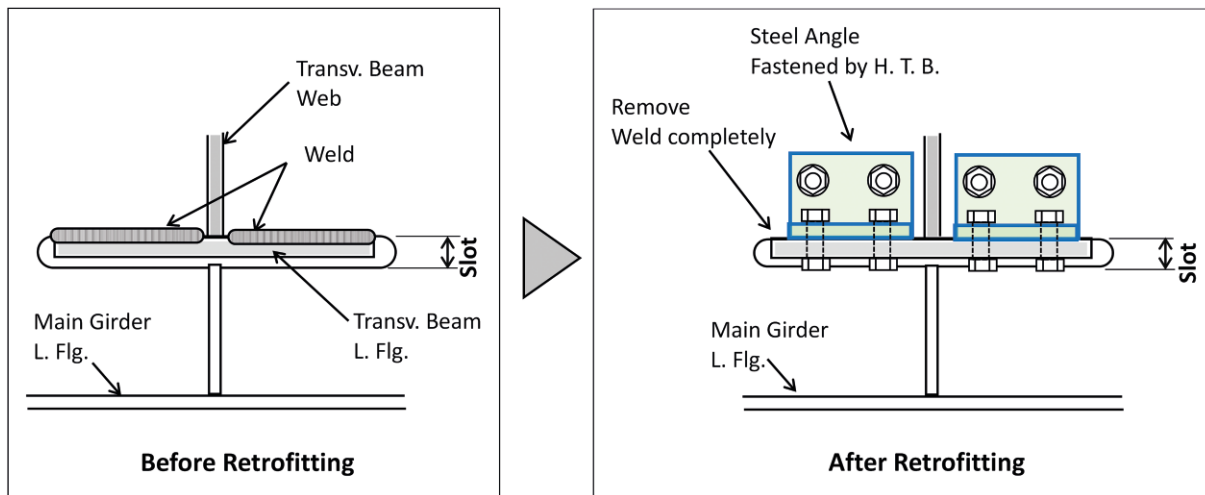


Fig. 5. Retrofit for damage pattern ④



Fig. 6. Sway bracing connection retrofit

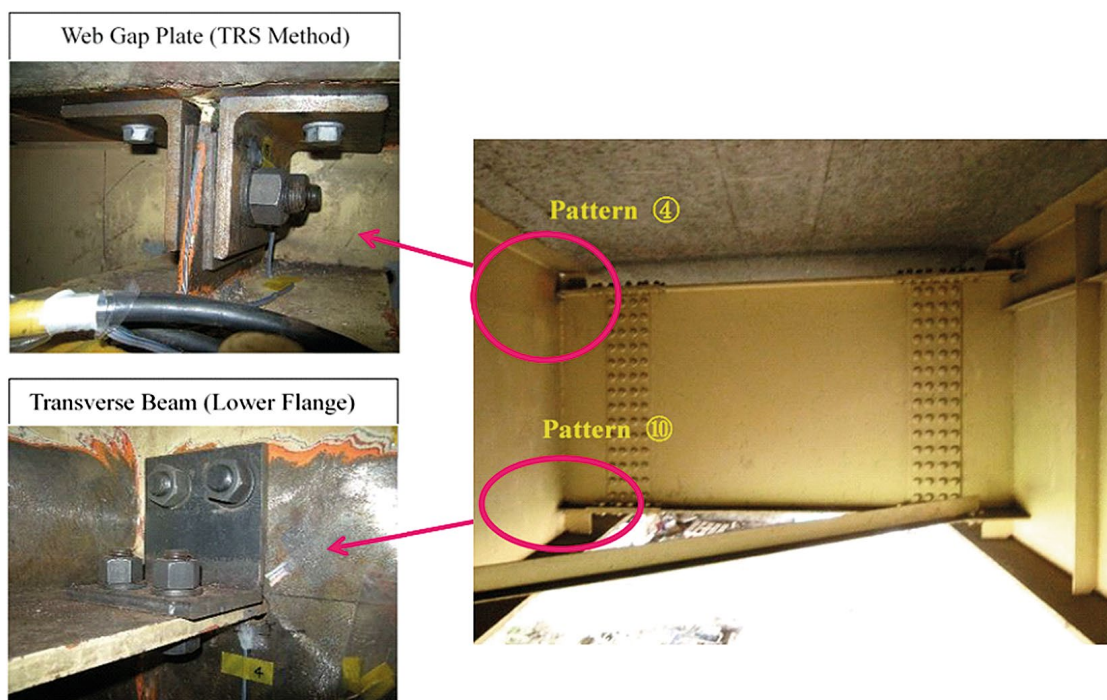


Fig. 7. Transverse beam connection retrofit

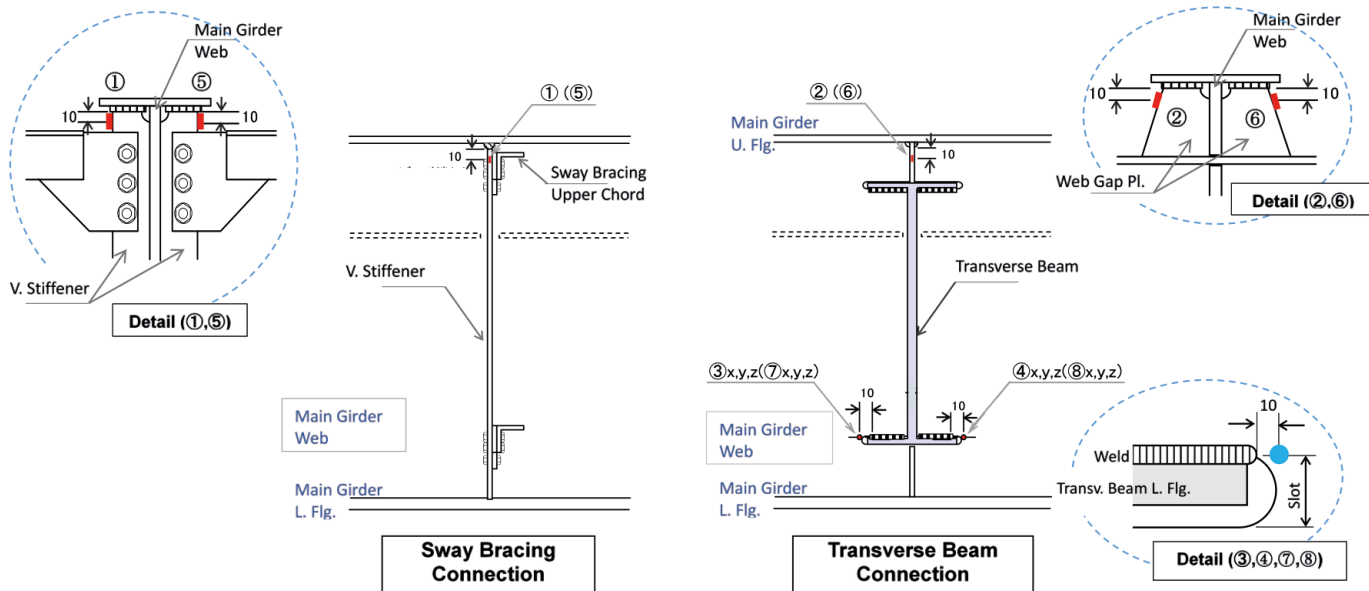


Fig. 8. Strain gauge locations – before retrofitting

up the reinforcing plates so that the part of the load transmitted to the vertical stiffener is transferred to the reinforcing plates, thus relieving the stress concentration in the upper end region of the vertical stiffener [2], [7].

The second method used steel angles on both sides of the upper part of the vertical stiffeners and fastened them to the main girder upper flange by means of thread rolling screw (TRS) fasteners [7], which provide a secure fastening to the upper flange from its underside without perforating the flange material and entering the concrete. The steel angle is fastened to the lower surface of the main girder upper flange so that the load transmitted to the vertical stiffener is relieved by transferring part of the load to the steel angles [7], [8]. The TRS method was also employed for the web gap plate upper end at the transverse beam connection, as shown in Fig. 7.

3.2 Retrofit for damage pattern ⑩

At the location with damage pattern ⑩, which occurs at the main girder web slot through which the transverse beam flange is inserted, the weld connecting the transverse beam to the main girder web was completely removed and replaced by steel angles having an equivalent resistance area, as shown in Figs. 5 and 7 [4]. In this retrofit method the weld bead along the slot in the girder web, considered to be one of the causes of stress concentration, is removed, thus relieving the stresses around the slot edge area.

4 Stress measurements

In order to verify the effectiveness of the retrofits, stress measurements under service load were carried out for 72 h (three consecutive weekdays) before and after the execution of the retrofitting works.

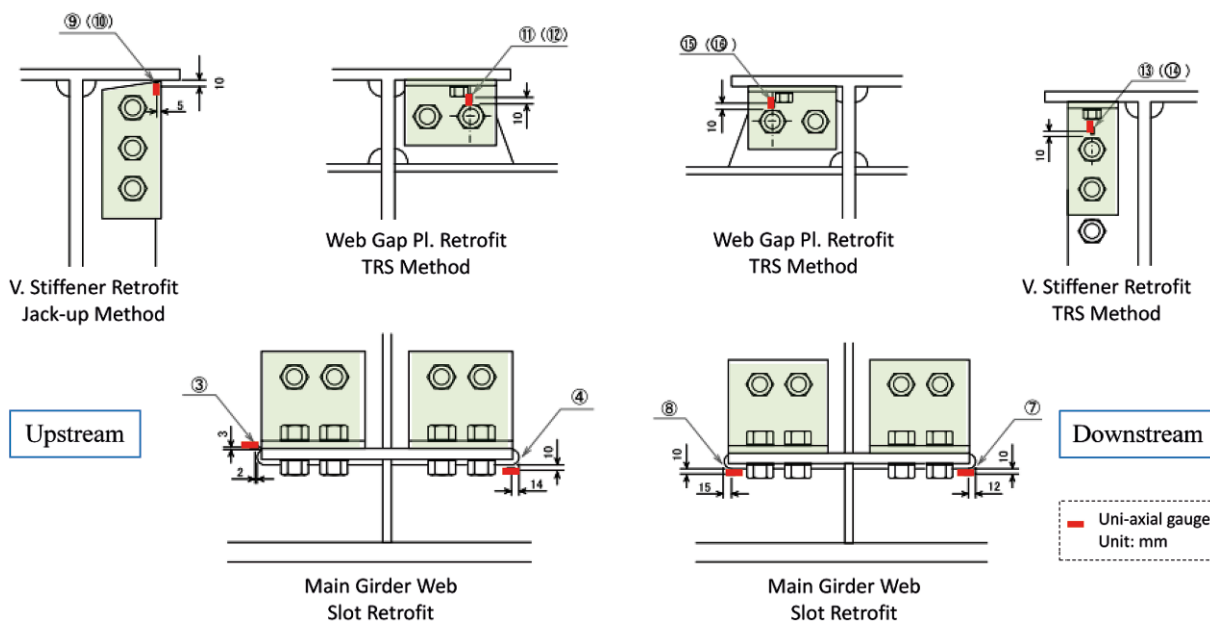


Fig. 9. Strain gauge locations – after retrofitting

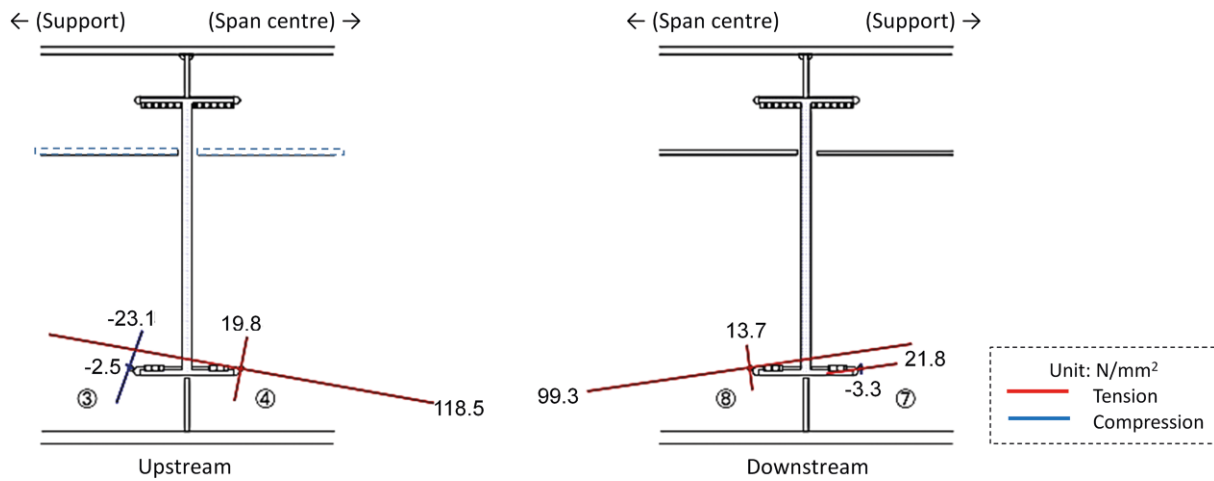


Fig. 10. Principal stresses at main girder web slot

Fig. 8 shows the strain gauge locations before the execution of the retrofits. The measurement points were selected focusing on stress concentration areas of the vertical stiffener and web gap plate upper end welds as well as the region around the slot edge in the main girder web.

The strain gauges for the measurements carried out after the execution of the retrofits are shown in Fig. 9. Additional gauges were placed on the reinforcing plates and steel angles in order to monitor the stress redistribution after the retrofiting works.

5 Stress measurement results and comments

Measured stress range frequency histograms were obtained from the data of the three days of measurements by using

the rain-flow method and the stress frequency distribution for tension and compression stresses was obtained with the peak-valley method.

Fig. 10 shows an example of the stress measurement results. The figure shows the maximum principal stress for the girder web at the slot edge area in the vicinity of the weld connecting the girder web to the transverse beam lower flange. It was observed that, compared with the stresses occurring on the support side, higher tensile stresses occurred on the span centre side – a tendency that had already been confirmed in previous laboratory tests [3].

After stresses due to live load on the bridge were measured before and after the retrofits, the data obtained were processed and the results are described below.

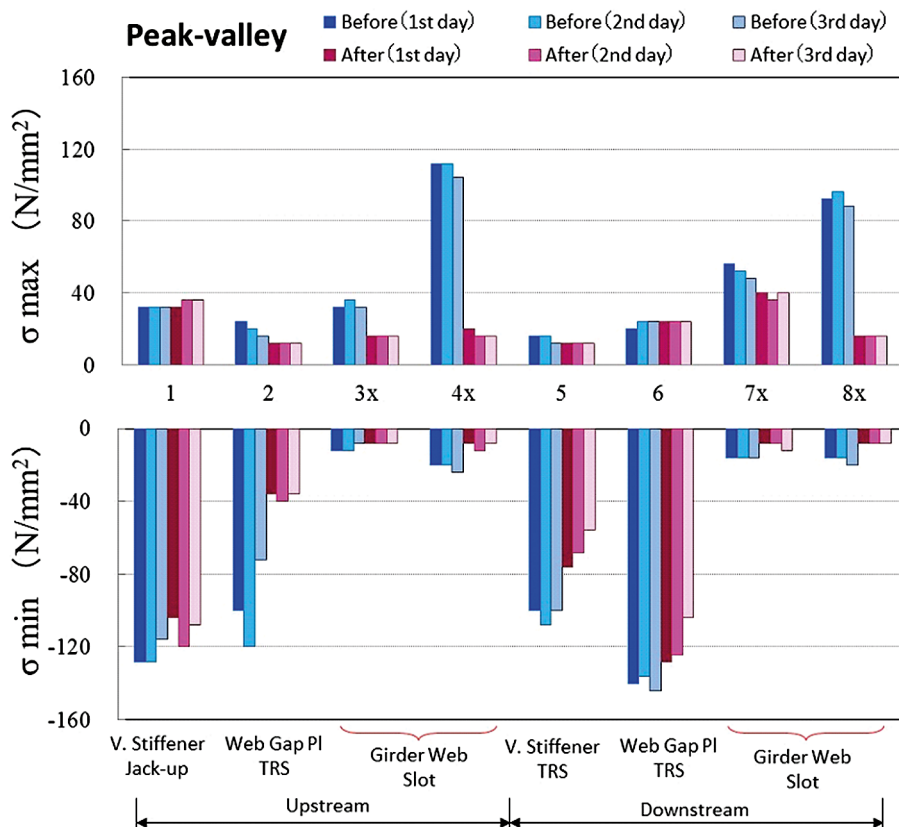


Fig. 11. Maximum and minimum stresses before and after retrofiting (peak-valley method)

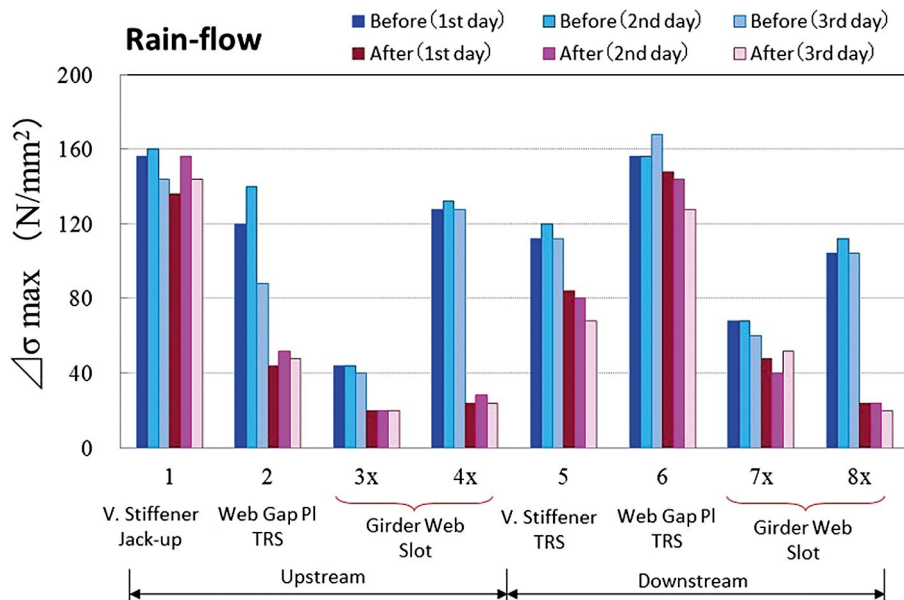


Fig. 12. Maximum stress range before and after retrofitting (rain-flow method)

5.1 Stress reduction effects

Maximum and minimum values of stress distribution obtained according to the peak-valley method are presented in Fig. 11. Tensile stresses at the slot edge in the main girder web (gauge Nos. 4x and 8x) decreased considerably after the execution of the retrofits, although the decrease was not so conspicuous on the compression side. The figure also shows that the compression stresses that were predominant at the vertical stiffeners and web gap plate upper end decreased to a certain extent, whereas the tensile stresses did not exhibit any significant changes.

As for the stress range, the maximum stress range values did not change significantly (98% of the values before retrofitting) for the vertical stiffener upper end retrofitted by the jack-up method (from 160 to 56 MPa); however, for the location retrofitted by the TRS method, the stresses after retrofitting decreased by 30% (from 120 to 4 MPa), as shown in Fig. 12.

For the web gap plate, the TRS method led to a drastic reduction of 35% (from 140 to 52 MPa) of the stress range on the upstream side and a reduction to 88% (from 168 to 148 MPa) of the stress range value before the retrofitting was observed on the downstream side.

The stress range around the slot edge locations, where a high stress concentration was observed on the span centre side, decreased to 1/5 of the values before retrofitting (from 132 to 28 MPa and from 12 to 4 MPa).

5.2 Improvement to fatigue life

Fatigue life for each location was evaluated for two cases: one as category E according to the design recommendations of the Japan Road Association [9], which considers the hotspot stress influences, and the other as category H', whose accumulated damage is similar to that of a modified Miner's rule-based curve. The results are presented as fatigue life ratio (fatigue life ratio = fatigue life after retrofitting/fatigue life before retrofitting) in Fig. 13.

At the vertical stiffener upper end, the fatigue life for the jack-up retrofit method presented values that were 1.1 times those before retrofitting for both categories E and H'. However, the TRS retrofit method presented values that were 41 times those before retrofitting for category E and 19 times for category H', which represent enormous improvements.

At the web gap plate upper end, the TRS method improved the fatigue life of the detail, when considered as category E, by 2 to 78 times the fatigue life before the execution of the retrofitting works, and by 2 to 11 times when considered as category H'.

For the girder web slot detail, the fatigue life was extended to almost infinity when considered as category E. Even when considered as category H', the fatigue life of the detail increased by 70 times the value before retrofitting – a remarkable improvement.

5.3 Improvement to fatigue life after retrofitting

The relationship between maximum stress range ratio and fatigue life ratio before and after retrofitting is shown in Fig. 14. In the figure it can be seen that, irrespective of the damage pattern and retrofit method, the fatigue life improved with the decrease in the maximum stress range.

It is clear from the figure that where the maximum stress range ratio is < 80%, i.e. the reduction ratio is > 20%, the fatigue life improves by tens of times the original fatigue life when evaluated as category E (plotted in blue) and by a few times when evaluated as category H' (plotted in magenta).

6 Conclusions

In considering preventive retrofits for fatigue cracks, 3 new types of retrofit methods were proposed and executed in a bridge in service. The effectiveness of the proposed retrofitting methods were verified through stress measurements carried out in field before and after the retrofitting works and results are summarized as follows.

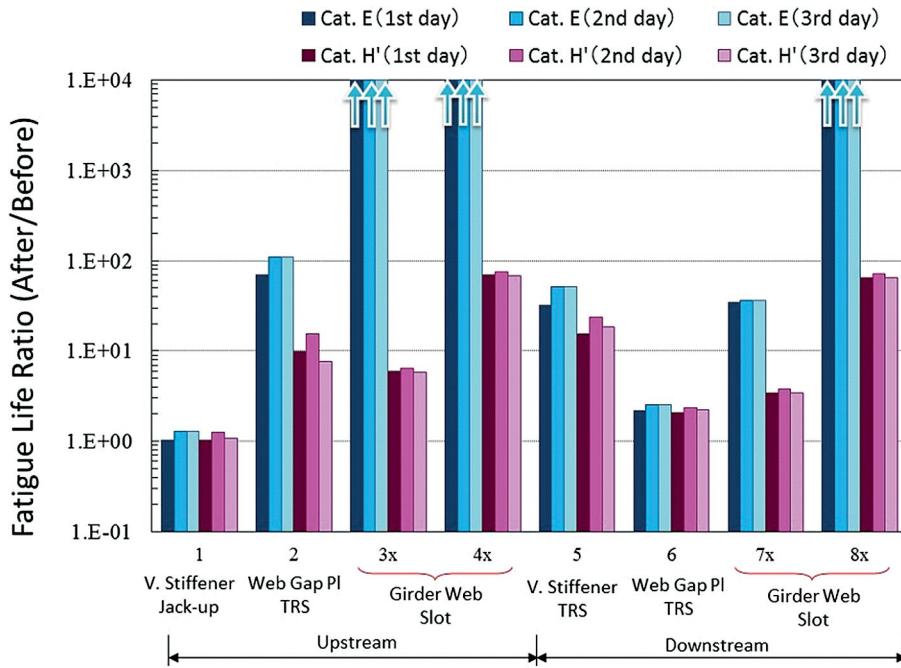


Fig. 13. Fatigue life ratio (after/before retrofitting)

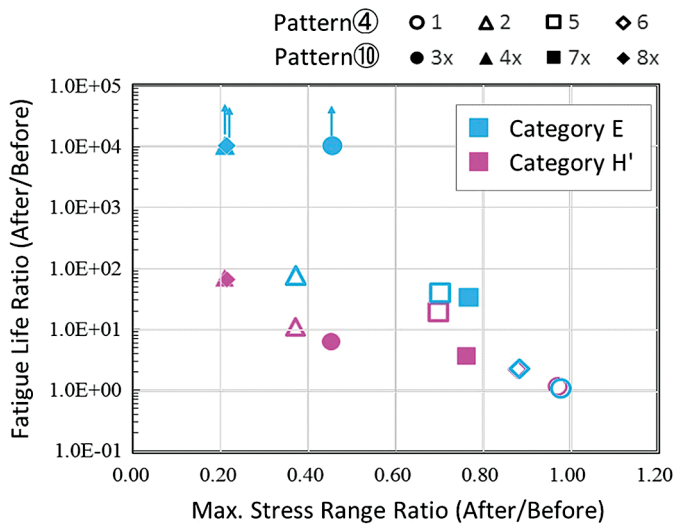


Fig. 14. Maximum stress range ratio and fatigue life ratio (after/before retrofitting)

- 1) Stress reduction effects was very small by the jack-up method at the vertical stiffener upper end. Whereas, by the TRS method, the stress was reduced to about 60% at most. At the web penetration, the stresses decreased to about 1/5 of the values before retrofitting, confirming a remarkable stress reduction effect.
- 2) Fatigue life was considerably improved after the retrofit works, except for the case of vertical stiffener upper end retrofitted by the jack-up method. It was verified that the fatigue life can be improved to more than several times by the TRS method for the vertical stiffener upper end and web gap, and to more than tens of times at the web penetration.
- 3) From the relationship between the maximum stress range ratio before and after retrofitting and fatigue life improvement effect ratio, it was clear that, when the reduction ratio of the maximum stress range is over

20%, the fatigue life can be improved to more than several times compared to that of before retrofitting.

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Authors

Luiza Hiroko Ichinose
Japanese Association for Non-destructive Testing Industry
Japan
L-Ichinose@jit-osaka.co.jp

Masahiro Koyama
Kinki Regional Development Bureau
Ministry of Land, Infrastructure Transport & Tourism
Japan
koyama-m86fd@kkr.mlit.go.jp

Masahiro Sakano
Department of Civil, Environmental & Applied System Engineering
Kansai University
Japan
peg03032@kansai-u.ac.jp