Fatigue prevention retrofit for connections of main girder to transverse beam or sway bracing in steel bridges

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ABSTRACT

In recent years, a large number of fatigue damages in steel bridges has been successively reported in Japan and the numbers still show tendencies to increase with the progressive aging of the Japanese bridge stock. To assure the bridge safety and its adequate structural performance, appropriate fatigue counter-measures are required, not only to retrofit the weakened structural members, but also to avoid the further growth of the existing cracks and prevent the occurrence of new ones.

The present study focused on two different fatigue damage types, one occurring at the connection details of transverse beam flanges inserted through a slot in the intersecting girder web, and the other, occurring at the welding line between the upper end of vertical stiffeners and the girder upper flange. Preventive retrofitting measures were proposed for these details and applied to a bridge in service that had been constructed more than 40 years ago. Stress measurements under service load were carried out in situ, before and after the execution of fatigue preventive retrofitting works so as to verify the effectiveness of the proposed retrofit methods.

The results showed that, for the details of transverse beam lower flange inserted through an intersecting girder web, the stresses around the slot end area were considerably reduced after the execution of the proposed retrofits. As for the details of vertical stiffeners upper end, the stresses around the plate edge after the execution of the retrofitting works decreased significantly.

Based on the stress range obtained from field measurements, fatigue life for each location was evaluated. The results for the details of the transverse beam flange intersecting the girder web, lead to fatigue life values that were at least 4 to 6 times of their values before retrofitting and, with one exception, the results for vertical stiffener upper end detail retrofits presented fatigue life values that were more than 2 times the fatigue life of that of their original detail, confirming thus the effectiveness of the proposed retrofitting methods.

Keywords: fatigue retrofit, vertical stiffener, transverse beam, stress measurement

1 INTRODUCTION

A large number of fatigue damages in steel bridges have been successively reported in Japan in recent years and this amount shows a tendency to increase rapidly with the progressive aging of the structures. Unless adequate measures are not taken in due time, these cracks, depending on their nature and location, may lead to catastrophic consequences.

A great number of fatigue crack occurrences reported in plate girders 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 end of vertical stiffeners to the upper flange of the main girders at sway bracings intersections, also occur due to a similar mechanism and their number also represents a considerable amount among the accounted damages. Retrofitting measures, such as, replacing the damaged members or re-welding the web gap plate or the upper end of the vertical stiffeners [1], have been proposed for these locations in the past. However, the execution of weld in situ, under

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the effects of live loads, may cause inconveniences that could trigger problems in future. Thus, in the present study, two weldless retrofit methods, one, a jack-up method [2] applying a screw type jig and another, applying bolted connections using Thread Rolling Screw (TRS) fasteners were proposed.

Along with these damage patterns, critical damage patterns, such as, those that occur at the details of connections between the flanges of transverse beam and main girder web, where the flanges of the transverse beam is inserted through a slot in the main girder web and welded to the main girder web. As cracks originated in these locations, may propagate into the girder web to such an extent that may lead to structural collapse, urgent and adequate retrofits are required [1] as preventive measures. Past report 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, was not able to stop the crack initiation completely. To avoid difficulties from the constructional point of view, a method applying steel angles and after the complete removal of the weld was proposed [4].

In the present paper, the results obtained during the “Research Project for the Rationalization of Fatigue Crack Inspections in Steel Bridges” [5] (hereafter referred to as “the Research Project”), carried out at the Kinki Regional Bureau of the Japanese Ministry of Land Infrastructure Transportation and Tourism, are reported. 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 in a bridge in service and the results are reported in the lines below.

2 FIELD WORK

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

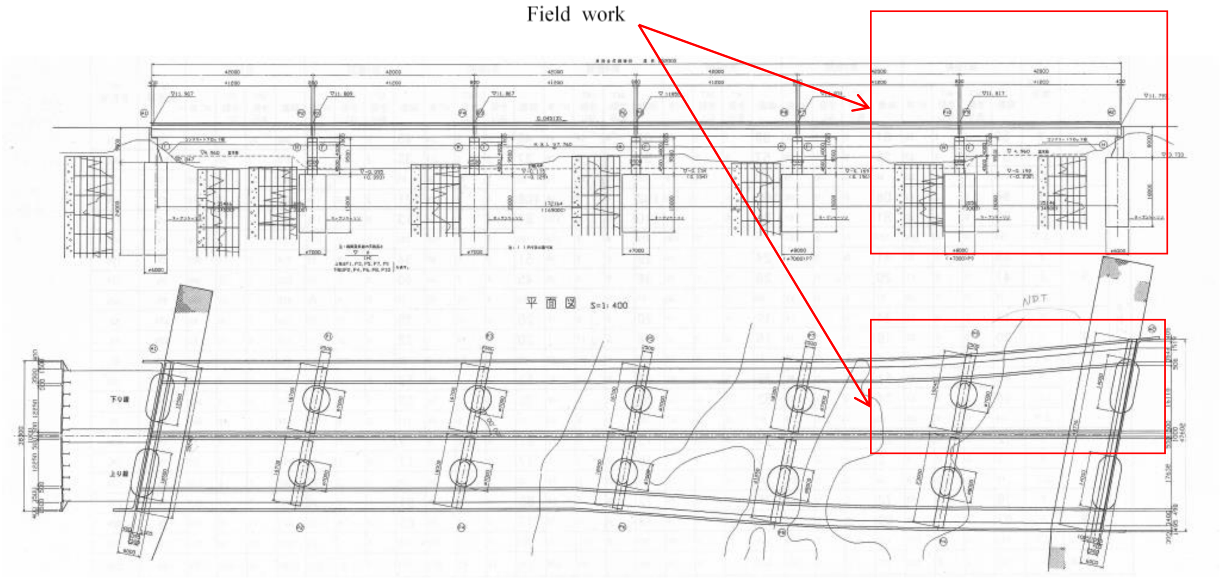

Fig. 1. Bridge selected for stress measurement

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 it is shown in the figure, the bridge is composed by 6 consecutive spans of simply supported composite steel girders, each of them having a span length of 41.2m and an average bridge width of 18.8m, accommodating a road with 6 traffic lanes, supported by 6 main girders. The bridge is located in one of the busiest routes in Japan and, according to a census carried out in 2010, the traffic volume that crosses the bridge is about 120,000 vehicles per day, 21.2% of which are considered to be heavy loaded vehicles.

Due to its easy accessibility the 6th span, shown in *Fig. 1*, was chosen for the execution of retrofit works and stress measurements.

2.2 Fatigue damages found in the bridge

Visual inspections carried out in 2012 revealed that more than 4000 locations presented cracks in their paint coating [6]. As fatigue cracks are often found underneath cracks in the coating, these cracks are considered to be potential fatigue cracks. Crack patterns found in the bridge are presented in *Fig. 2*, and their respective numbers are shown in *Table 1*. Among 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 occurrence among the crack patterns found in the bridge, is also one of the crack patterns with the highest occurrence in Japanese bridges. The latter is a crack pattern that may propagate into the main girder web and grow to an extent that can compromise the structural safety of the bridge, being, therefore, considered to be one of the most critical damage patterns found in Japanese bridges. [4, 7, 8]

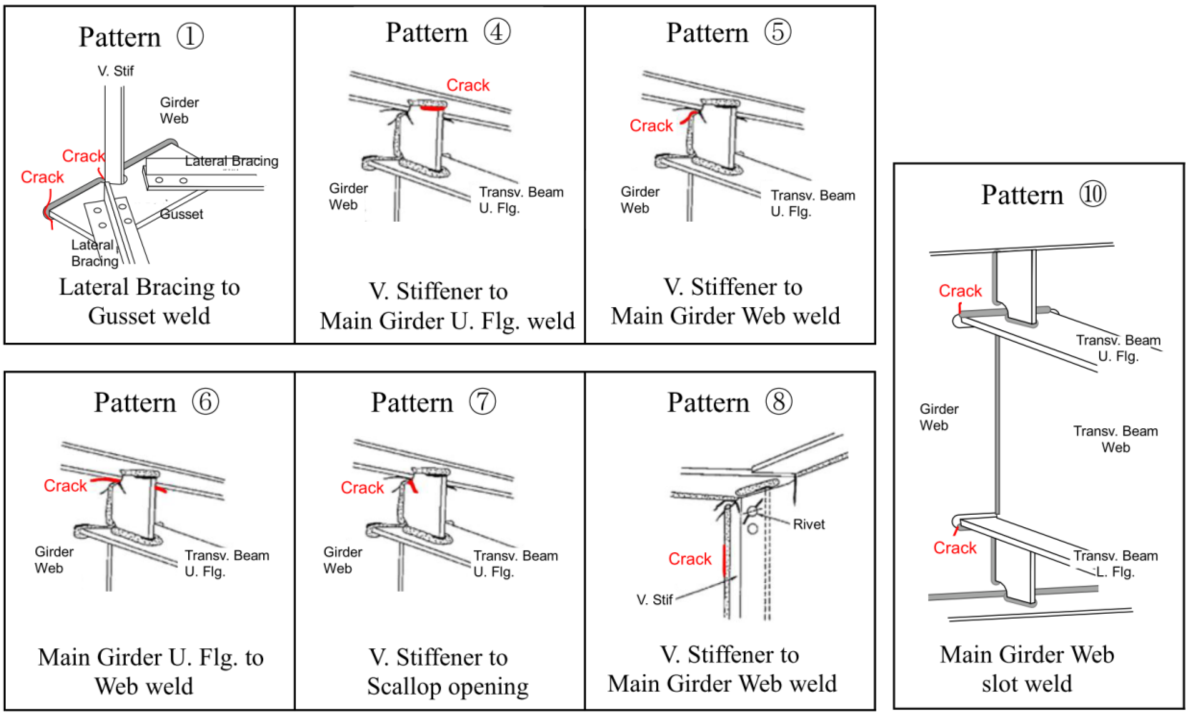

Fig. 2. Damage patterns found in the selected bridge

Table 1. Number of cracks in paint per damage pattern

Damage pattern	Outbound	Inbound	Total
Pattern ①	345	212	557
Pattern ④	631	560	1191
Pattern ⑤	214	208	422
Pattern ⑥	123	118	241
Pattern ⑦	304	274	578
Pattern ⑧	92	68	160
Pattern ⑩	456	421	877
Total	2165	1861	4026

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Retrofits were executed at the locations shown in *Fig. 3.* for the damage patterns ④ and ⑩, according to the proposed methods.

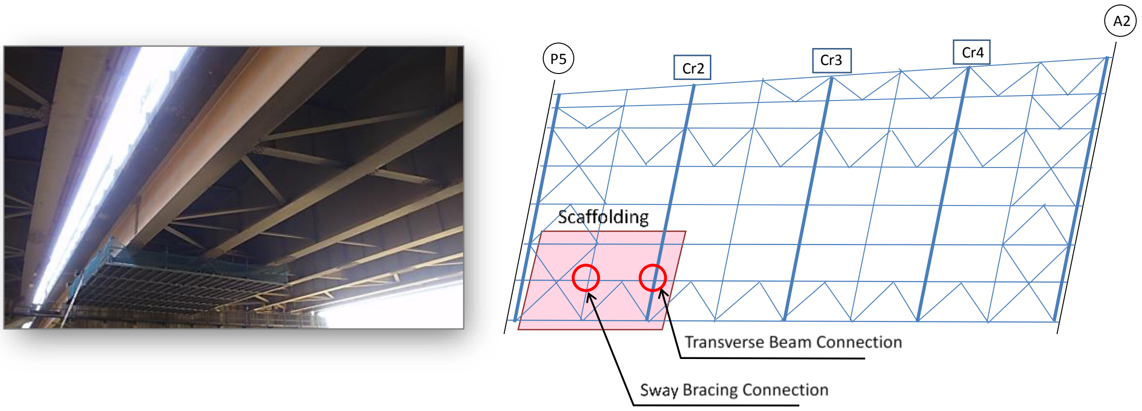

Fig. 3. Location of the retrofitting works

3 PREVENTIVE MEASURES

3.1 Retrofit for damage pattern ④

Two types of retrofit were applied for damage pattern ④ at 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 at both sides of the vertical stiffener using high tension bolts, which were fastened after jacking-up the reinforcing plates against the main girder upper flange. A screw type jig was applied to jack-up the reinforcing plates so that the part of the load transmitted to the vertical stiffener is transferred to the reinforcing plates, relieving the stress concentration at the upper end region of the vertical stiffener [2, 7].

The second method applied steel angles at 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) [7], which secured fastening to the upper flange, from its bottom side, without perforating the flange material into 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 it to the steel angles [7.8]. The TRS method was also applied to the web gap plate upper end at the transverse beam connection, as shown in *Fig. 7*.

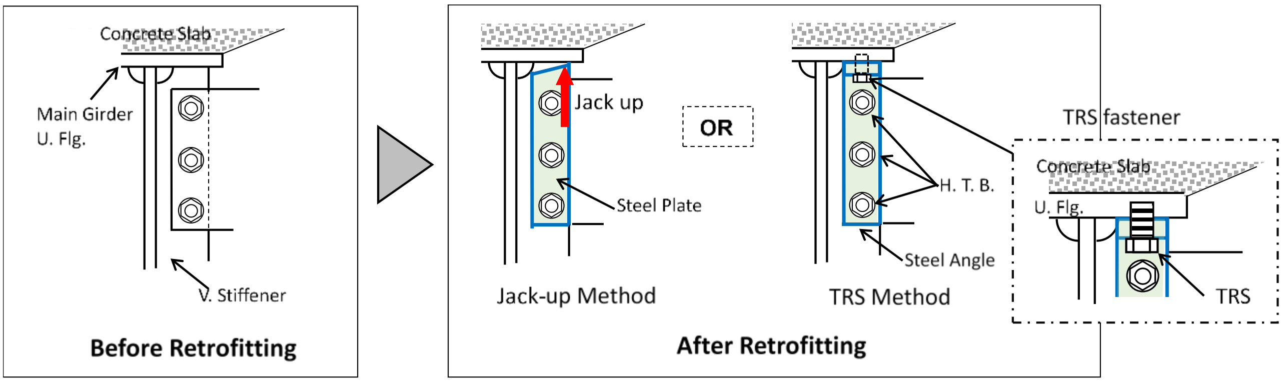

Fig. 4. Retrofit for damage pattern ④

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 equivalent resistance area, as shown in *Fig. 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 relieving the stresses around the slot edge area.

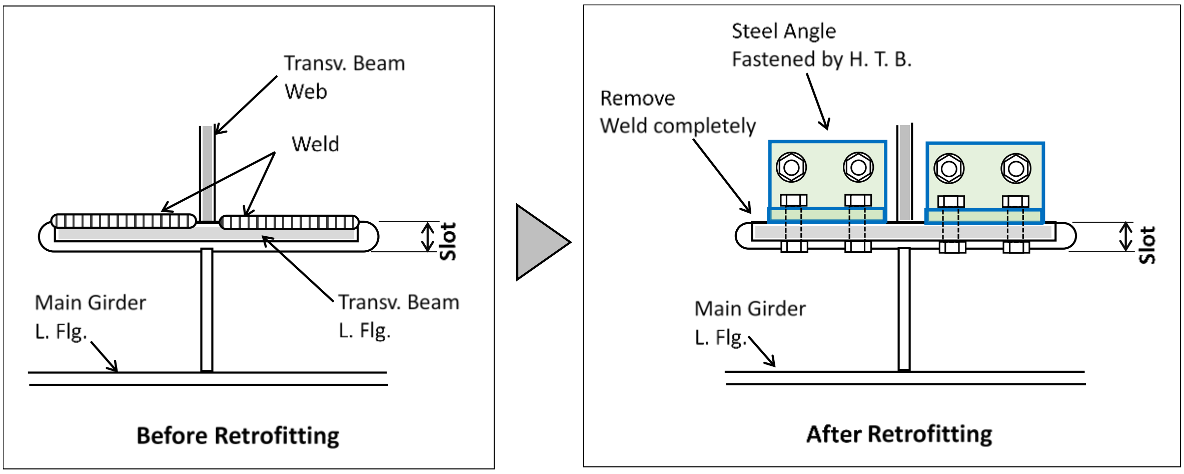

Fig. 5. Retrofit for damage pattern ⑩

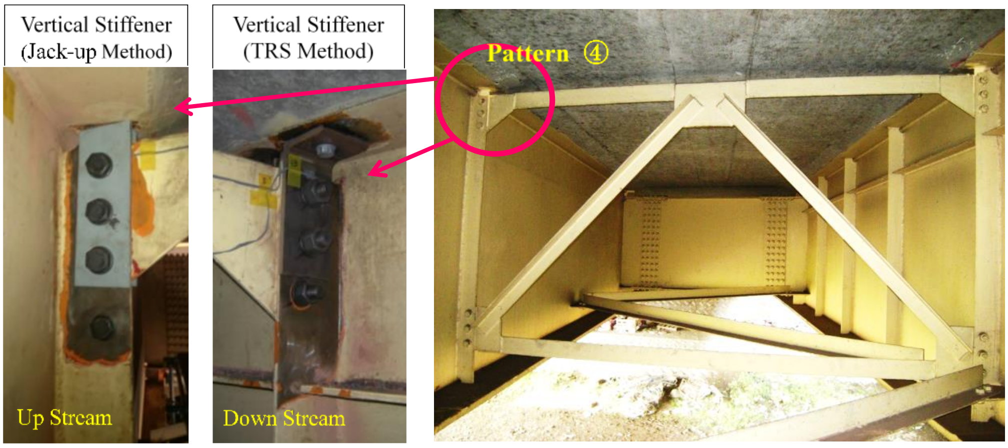

Fig. 6. Sway bracing connection retrofit

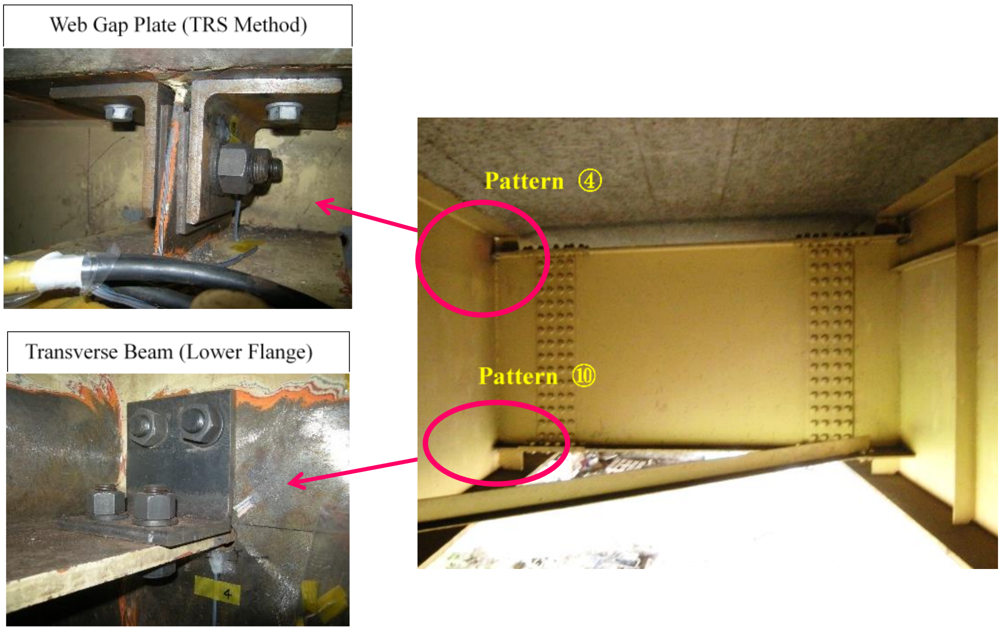

Fig. 7. Transverse beam connections retrofit

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4 STRESS MEASUREMENTS

In order to verify the effectiveness of the retrofits, stress measurements under service load were carried out for 72 hours (3 consecutive week days), before and after the execution of the retrofitting works.

Fig. 8 shows the strain gauge locations before the execution of the retrofits. The measurement points were selected focusing at 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 so as to monitor the stress redistribution after the retrofitting works.

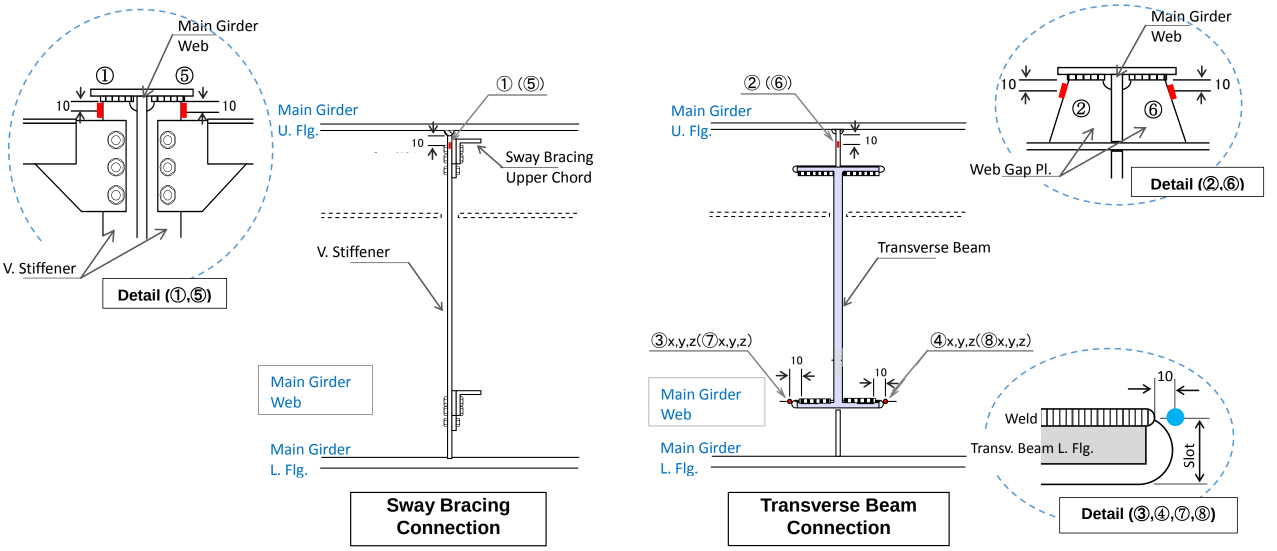

Fig. 8. Strain gauge location – Before retrofitting

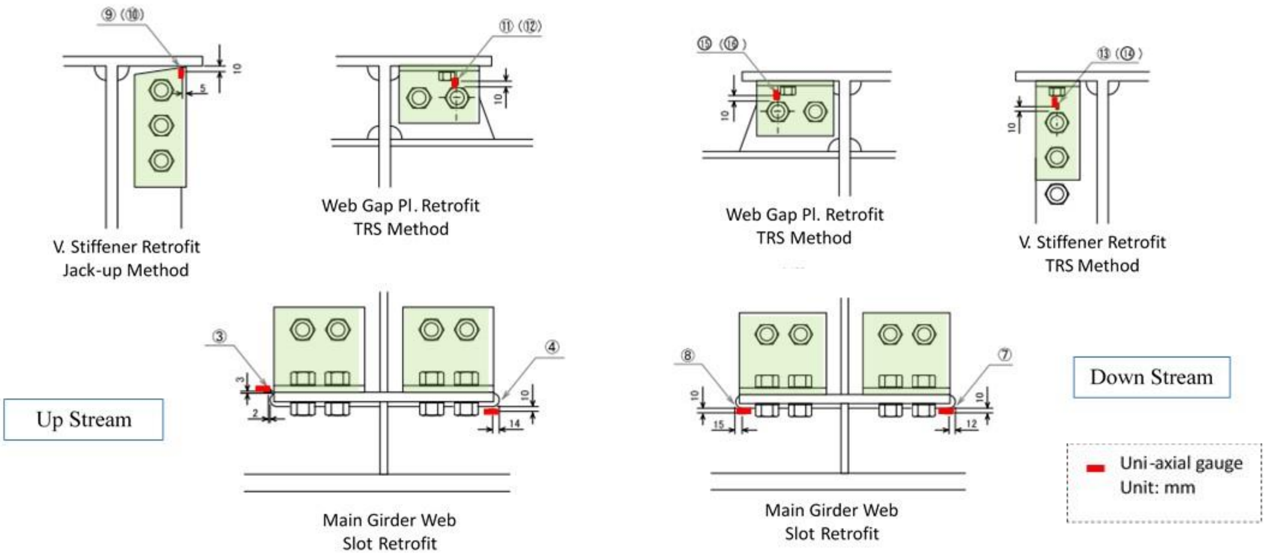

Fig. 9. Strain gauge location – After retrofitting

5 STRESS MEASUREMENT RESULTS AND COMMNETS

Measured stress range frequency histograms were obtained from the 3-days measurements data through rain-flow method and the stress frequency distribution for tension and compression stresses were obtained applying the peak-valley method.

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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 to the stresses occurring at the support side, higher tensile stresses occurred at the span centre side, tendency which were already confirmed in former laboratory tests [3].

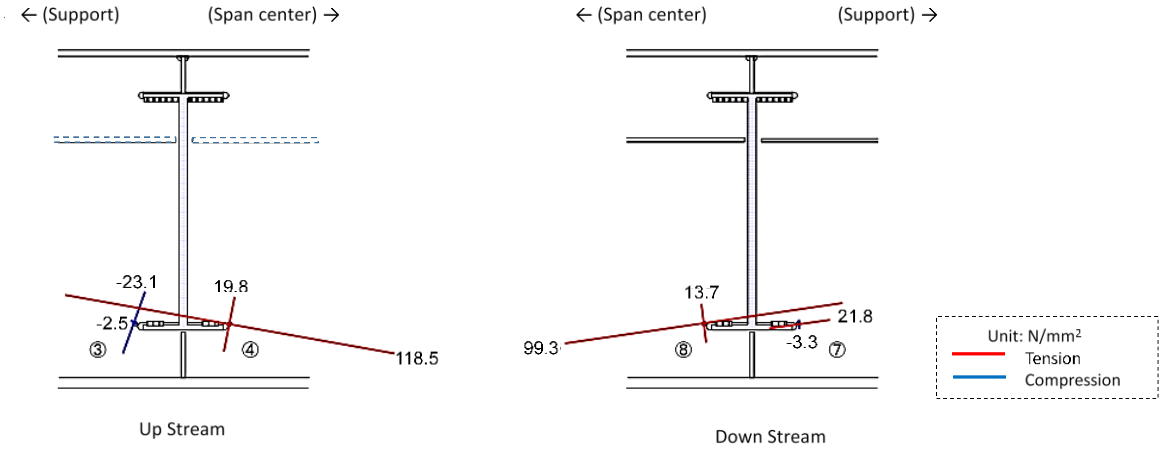

Fig. 10. Principal stresses at main girder web slot

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

5.1 Stress reduction effects

Maximum and minimum values of stress distribution obtained according to the peak-valley method is presented in *Fig. 11*. Tensile stresses at the slot edge in the main girder web (gauge no. 4x and 8x) decreased considerably after the execution of the retrofits, although the decrease was not so conspicuous at 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 present any considerable changes.

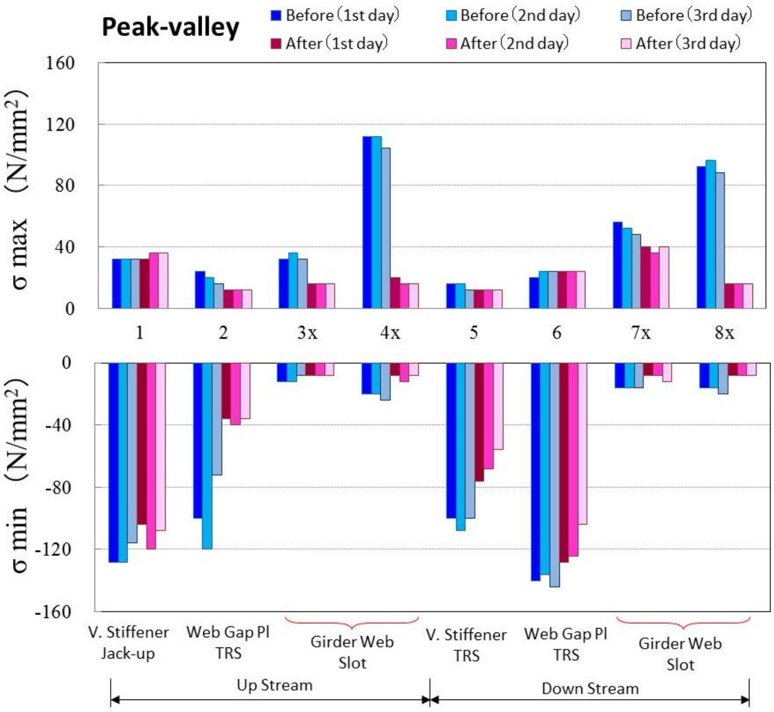

Fig. 11. Maximum and minimum stress before and after retrofitting (Peak-valley method)

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

For web gap plate, the TRS method presented a drastic reduction of 35% (from 140MPa to 52MPa) of the stress range at the up-stream side and a reduction to 88% (from 168MPa to 148MPa) of the stress range value before the retrofitting was observed at the down-stream side.

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

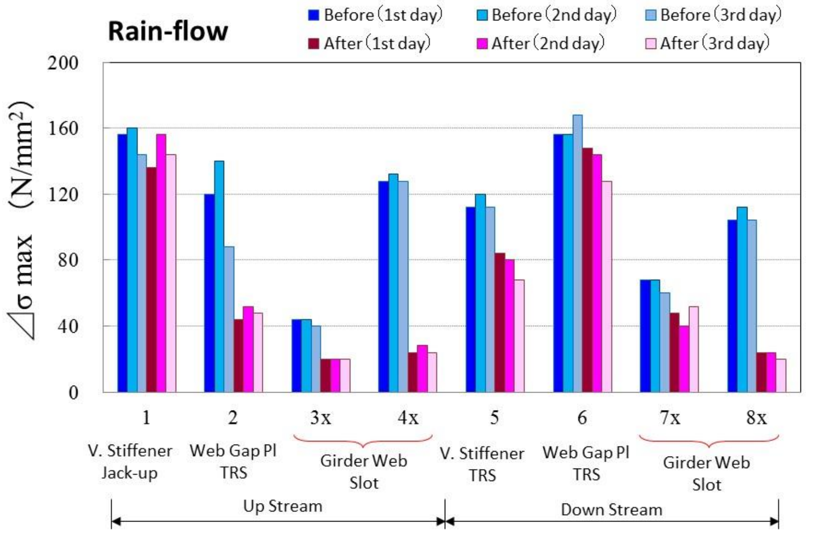

Fig. 12. Maximum stress range before and after retrofitting (Rain-flow method)

5.2 Improvement of fatigue life

Fatigue life for each location was evaluated for two cases, one, as category E according to the design recommendations of the Japanese Society of Steel Construction [9], which considers the hot spot stress influences, and the other, as category H’, whose accumulated damage is similar to that of a modified Minner’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*.

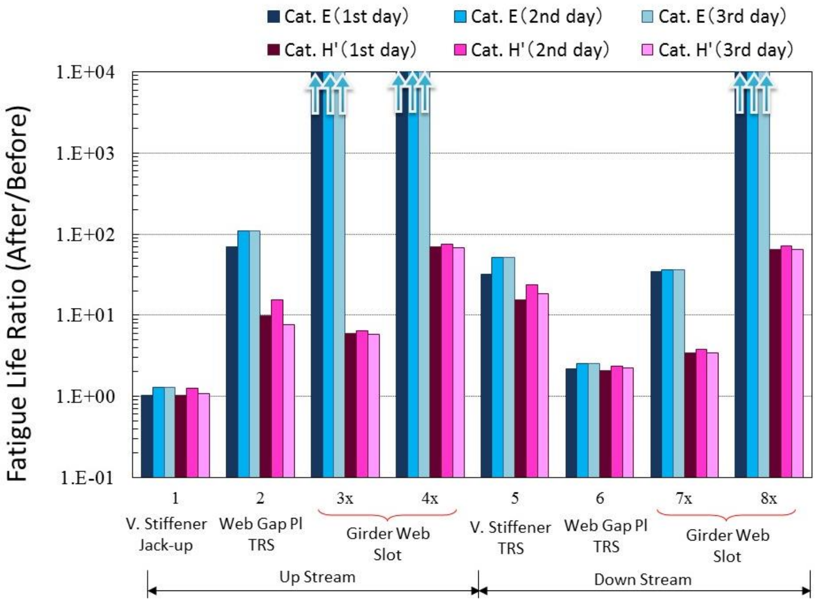

Fig. 13. Fatigue life ratio (after/before retrofitting)

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

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 of before retrofitting, improving remarkably.

5.3 Improvement of 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 observed that independent of the damage pattern and retrofit method, the fatigue life improved with the decrease of the maximum stress range.

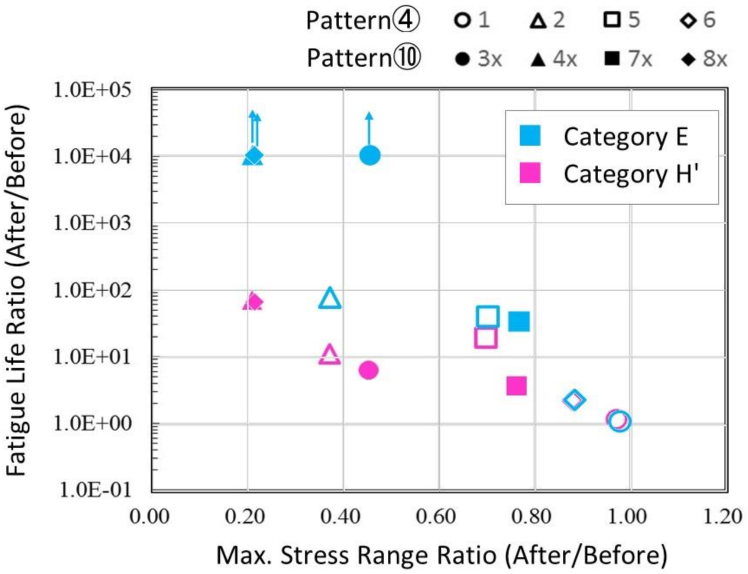

Fig. 14. Maximum stress range ratio and fatigue life ratio (after/before retrofitting)

It was clear from the figure that, in case the maximum stress range ratio is below 80%, that is, the reduction ratio is over 20%, the fatigue life improves by tens of times the original fatigue live, 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 measures for fatigue cracks, 3 new retrofit methods were proposed and executed in a bridge in service. The effectiveness of the proposed retrofitting methods were verified through stress measurements in field and results are as summarized as follows.

(1) Stress reduction effects was very small for the jack-up retrofit at the vertical stiffener upper end. However, for the TRS method, both vertical stiffener upper end and web gap plate retrofitted with steel angles, the stress was reduced by 60% at most. At the girder web slot edge, a reduction to 1/5 of the original stresses was observed after retrofitting.

(2) Excluding the case of the jack-up method, the fatigue life for the vertical stiffener upper end was considerably improved after the execution of retrofit works. It was verified that the fatigue life was improved by tens of times, in the case of TRS method and by a few times at the girder web slot area.

(3) From the relationship between the maximum stress range ratio and fatigue life ratio, it was made clear that if the reduction ratio of the maximum stress range is over 20%, the fatigue life of the respective details can be extend to a few times of that of before retrofitting.

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