Study on cumulative fatigue analysis of a steel railway bridge

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1. INTRODUCTION

A cost comparison [1] of corrective maintenance (upgrading) and preventative maintenance (repair) towards a steel bridge (L=150m, 5 span girder) within 100 years showed a huge difference, with the cost at JPY3.1 billion and JPY800 million respectively. There were about 35,000 steel bridges (with span longer than 15m) constructed between 1966 and 1980 in Japan [2], the ageing problem of steel bridges is emerging as a critical issue. One of the main damages occurring with ageing is fatigue, which limits the load-carrying capacity and residual life of existing structures [3]. In this paper, cumulative fatigue analysis on a steel railway bridge was applied before and after replacing the bridge bearings. The results show that replacing the unfunctional bridge bearings significantly reduced the risk of fatigue failure.

2. MEASUREMENT

The measured bridge is a plate 2-girder bridge with span 36.1m constructed in 1970s. Cracks on lower flange near web at the location of the right side bearing were found during the general inspection. Plate reinforcement at where the cracks occurred was carried out as the emergency measure. The strain measured after completing the reinforcement still showed the occurrence of large stress, in addition, the measured displacement showed that the function of the bridge bearings were deteriorated as well. Then replacement of bridge bearings was proposed as a further measure.

24-hour strain measurements of 2 bridge bearings were conducted before and after the replacement separately. The setting of the strain gauge is shown in Figure 1, 23 strain gauges were installed with the same arrangement at 2 times measurement. The strain gauges were grouped into 3 sets: (a) on lower flange near reinforcement plate or near sole plate, (b) on lower flange near neither reinforcement plate nor sole plate, and (c) on web near lower flange. The data for channel 2-2, 2-6, and 2-8 were not properly recorded before the replacement, therefore which was discarded. The sampling rate was set at 100Hz.

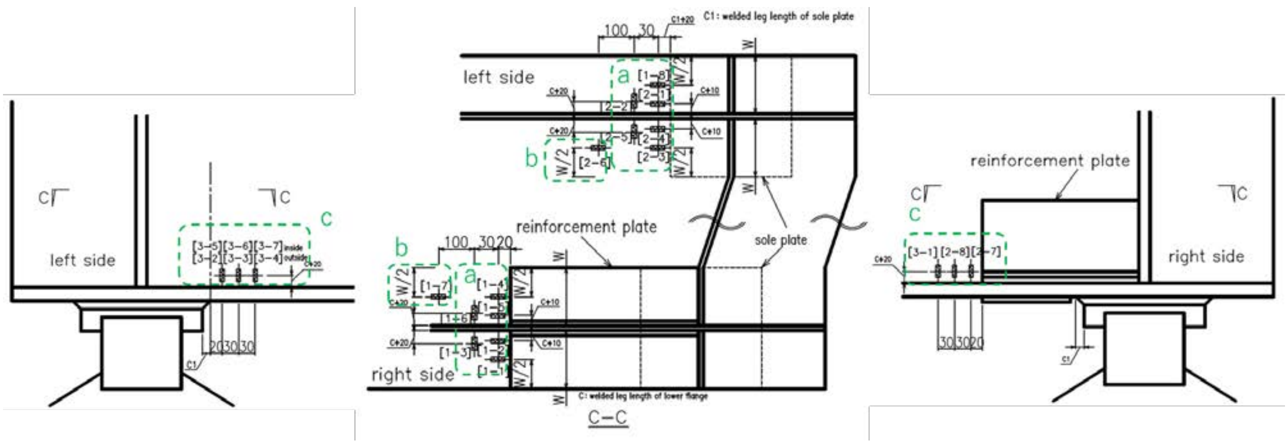

Figure 1. The setting of strain gauges.

3. CUMULATIVE FATIGUE ANALYSIS

The analysis in this paper followed the guidance for fatigue design of steel bridges issued by the Japan Bridge Association [4]. Overall, fatigue analyses of steel structures are based on the characteristics of S-N curves combined with the linear damage accumulation rule (also called Miner's Rule). The slope m of the S-N curve equals 3 since the stress type is direct stress. There are 2 stages for fatigue verifications when the stress range $\Delta\sigma$ is greater than the cut-off limit under variable amplitude loading $\Delta\sigma_{cv}$. In addition to $\Delta\sigma_{cv}$, there are 2 parameters specified according to the strength grade of the welded parts: the reference stress value under 2 million cycles $\Delta\sigma_f$ and the cut-off limit under constant amplitude loading $\Delta\sigma_{ce}$. The strength grade from D to H' were all considered to compare the effects of strength grade on fatigue damage.

The procedure of analysis is as follows:

1. Stress aggregation of time-history strain data by the rainflow counting method, the output of which are stress range and the corresponding cycle numbers.

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2. The effects of the average of stress range and the thickness of plates were not considered. Whether the maximum of stress range $\Delta\sigma_{max}$ was greater than $\Delta\sigma_{ce}$ was checked: if yes, step 3 was implemented; if not, the fatigue degree was considered 0.
3. For the verification yes in step 2, cumulative fatigue damage was calculated by Miner's Rule for the stress range greater than $\Delta\sigma_{cv}$.

4. RESULTS

The results of the damage degree (with 1 corresponding to fatigue failure) by 100 years for the same loading condition before the replacement are shown in Table 1.

Table 1. The summary of fatigue damage degree under various strength grade

No.	D	E	F	G	H	H'
1-1	0. 26	0. 64	1. 21	2. 66	5. 25	12. 67
1-2	0	0. 14	0. 40	0. 91	1. 80	4. 57
1-3	0	0	0	0	0	0
1-4	0	0. 21	0. 48	1. 08	2. 13	5. 14
1-5	0	0. 08	0. 28	0. 66	1. 30	3. 13
1-6	0	0	0	0	0	0
1-7	0	0	0. 09	0. 30	0. 63	1. 52
1-8	0	0	0	0	0. 02	0. 07
2-1	0	0	0	0. 02	0. 04	0. 17
2-3	0	0	0	0	0	0
2-4	0	0	0	0. 04	0. 09	0. 39
2-5	0	0	0	0	0	0
2-7	0	0	0	0. 24	0. 49	1. 17
3-1	0	0	0	0	0. 13	0. 37
3-2	0	0	0. 05	0. 13	0. 39	1. 29
3-3	0	0	0	0. 02	0. 03	0. 11
3-4	0	0	0	0	0	0
3-5	0	0	0. 03	0. 07	0. 19	0. 72
3-6	0	0	0	0	0	0. 02
3-7	0	0	0	0	0	0

For the results before the replacement, it shows the fatigue damage at the location of strain gauge 1-1 was severest, generally the fatigue damage on the lower flange in group (a) near where the cracks occurred (1-1, 1-2, 1-4, and 1-5) were relatively severe. The strength grade was D according to the inspection materials, under which the damage degree of 1-1 was 0.26. And the results of fatigue damage degree as of after the replacement were 0 but for 1-1 under H' grade was 0.12, which needs no worries for fatigue damage after the replacement. The replacement of the bridge bearings was assessed as proper measure when compare the results of fatigue analysis of two times. The measure was necessary when consider the uncertainty factor in the data and in the analysis. To understand the effects of various stress range and corresponding cycle times, the details for 1-1 under strength grade D are shown in Figure 2 and Figure 3. It illustrates the effects of various stress range on fatigue damage when comparing the occurrence times and the damage caused by the same stress range in two figures. Prevention of the occurrence of large stress, which has a greater factor causing fatigue damage, is the direction for steel bridge maintenance.

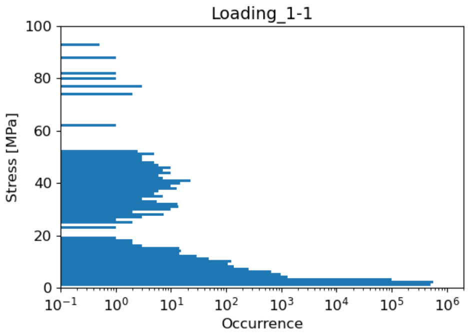

Figure 2. The results of rainflow counting.

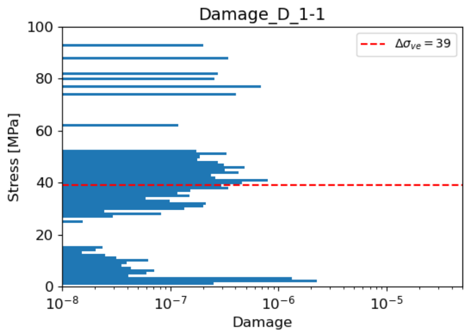

Figure 3. The fatigue damage among various stress range under the strength grade D in 24 hours

5. CONCLUSIONS

This study applied cumulative fatigue damage analysis on a steel railway bridge and compared the results before and after the replacement of the bridge bearings. Replacement of the unfunctional bridge bearings is considered an effective measure to release the risk of fatigue failure in steel bridges.

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