

## **Investigation of the fatigue damage in a half through steel Lohse bridge**

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### **ABSTRACT**

Many bridges in Japan were constructed during 1960s and 70s, the period of domestic high economic growth. The number of reports regarding functional deterioration tends to increase after around fifty years in service, recently. Fatigue cracks were observed around the sole plates in pier section of 17-years in service existing steel half through Lohse bridge. For determining the cause of fatigue damage, measurement and simulation for the objective bridge were conducted. A series of investigation and its results are shown in this paper.

### **1. INTRODUCTION**

Cracks were found in the four corners of welding area of the sole plates and stiffening-girder in the pier 1 of a half-through Lohse bridge in Nagasaki Prefecture. Generation of the bending moment accompanied by the restriction of rotating function of the support and eccentricity of neutral axis of stiffening girder and rotation center of support were estimated as the main cause of the crack generation. Also, cyclic change of the temperature of the bridge body was considered to be influence-factor. In this research, a series of loading test for the bridge were conducted to investigate the contribution of the cause. Furthermore, the authors conducted the numerical simulation for the investigation of the eccentricity. Generally, the eccentricity is considered in seismic design, whereas usual design for the plumb load such as dead load and live load is not considered. Therefore, the bending moment with the existence of the eccentricity was simulated, and the authors investigated the influence of rotating restriction in consideration of the deterioration of support.

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## 2. OBJECTIVE BRIDGE AND ESTIMATED CAUSE OF CRACK

### 2.1 Objective bridge

Objective bridge is the steel half through Lohse bridge with the length of main span of 135m and arch rise of 24m, which was opened for public in 1996(Fig. 1(a),(b)). The supports shoe consists of pin (P1 in Fig. 1(a)) and roller (the other side). The stiffening girder and arch rib are connected rigidly, and therefore, axial displacement of the arch rib is generated by the vertical loading. At the same time, axial force will be generated in stiffening girder depends on the position of the loading vehicle because the support P1 is fixed for lateral movement (Fig. 2(a),(b)).

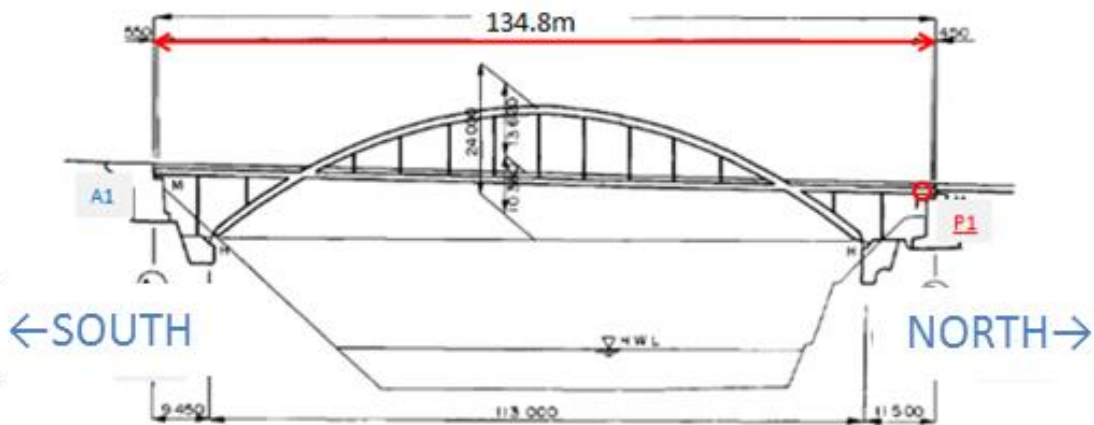


Fig. 1(a) Side view of the objective bridge

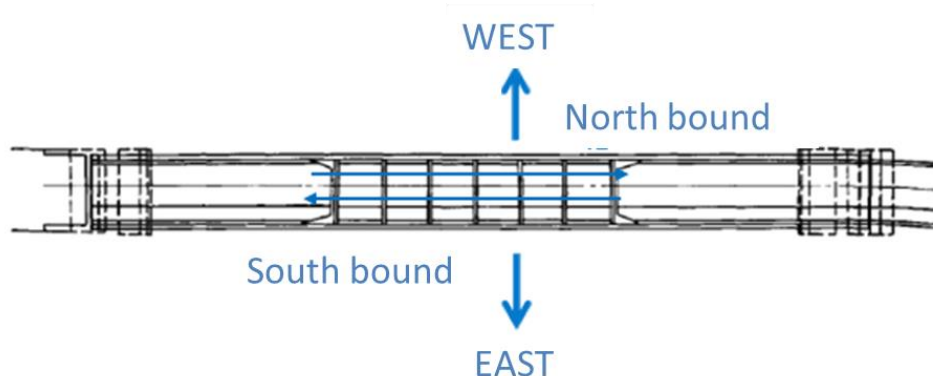


Fig. 1(b) Plan of the objective bridge

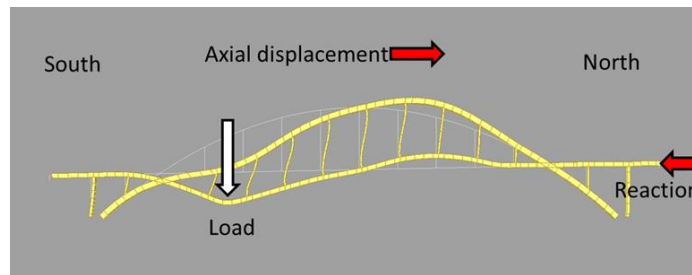


Fig. 2(a) Displacement of the arch rib and the girder with left side vertical loading

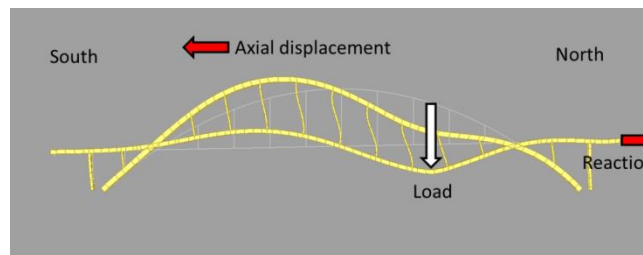


Fig. 2(b) Displacement of the arch rib and the girder with right side vertical loading

### *2.2 Fatigue crack and estimated cause*

Cracks were found in the four corners of welding area of the sole plates and stiffening-girder in the P1 supports area of the bridge during the periodic inspection (Fig. 3, 4). Most of the cracks were recognized penetrated through the flange of main stiffening girder by the following detail-inspection. Also, we confirmed that the thickness of the flange of the stiffening girder is relatively thinner than it of the soleplates and both were welded at above of the supports. The crack propagation can be caused by the facts that the difficulty of having the welding quality and/or the stress concentration to the cracks initiation. We assumed that the cracks were generated mainly by the effect of 1) rotational constraint of the supports by the functional deterioration for rotational movement; 2) generation of axial force of stiffening girder accompanied by the axial displacement of arch rib when eccentric active load are employed; and 3) temperature change of bridge body.



Fig. 3 The welding section crack-generations were recognized.

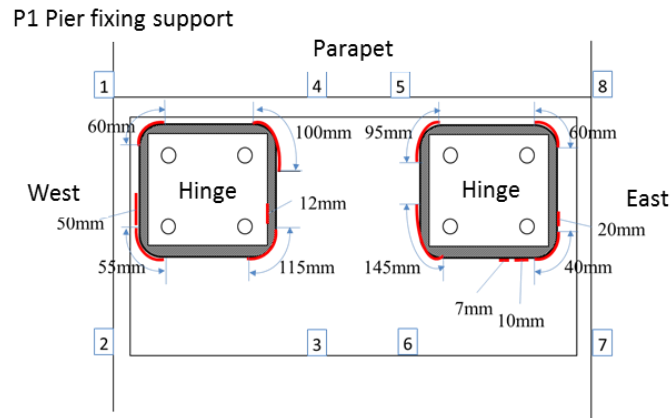


Fig. 4 Plan of the generated cracks with its length (mm)

### 3. ABSTRACT OF THE MEASUREMENT

The strain gauges were set to the tip of the propagated cracks (Fig. 5) and stiffening girder (Fig. 6) for the static/active measurements under the 200kN dump truck loading with 30km/h of velocity. With the measurement data, the bending moment generated by the rotational constraint and the one generated by the axial force of stiffening girder with the length of rotational center were calculated respectively. And each contribution for the damage was evaluated.

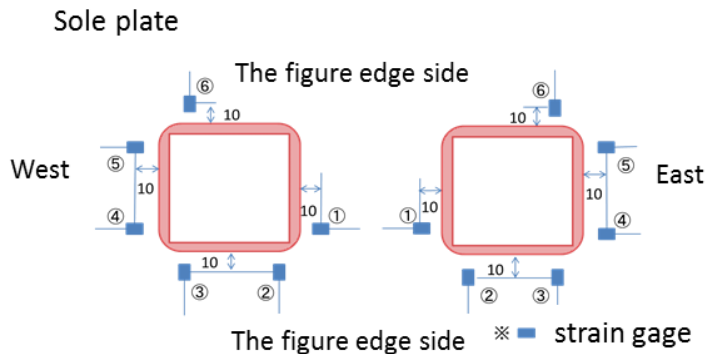


Fig. 5 Plan of the installed strain gauge near the fatigue cracks

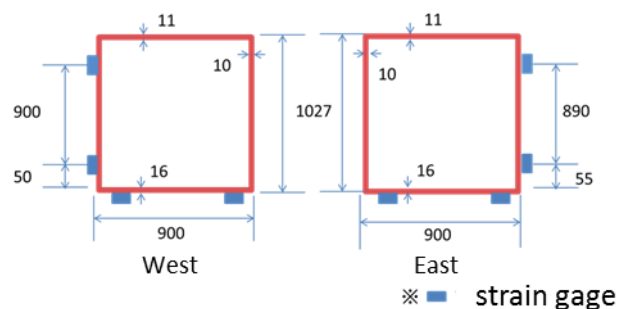


Fig. 6 Cross section of stiffening girder and the position of installed strain gauge

## 4. INVESTIGATION FOR THE CRACK GENERATION BY THE MEASUREMENT DATA

### 4.1 The fatigue strength class

The fillet welding was employed for uniting soleplate and bottom flange of stiffening girder. This means the strength class of the welding joint would be F class. However, F class is to be the lower limit level of the safer side, the actual value will be evaluated more strictly. Therefore, in this research, the fatigue strength was evaluated by using the E class.

### 4.2 The stain near the tip of cracks

The range of the stress using the maximum and minimum of the strain data near the tip of the cracks were showed in Fig. 7. In any measurement points, the stress range recorded over  $80\text{N/mm}^2$  which corresponds to 2million times-strength of E class. This means that these areas are under severe condition of stress concentration.

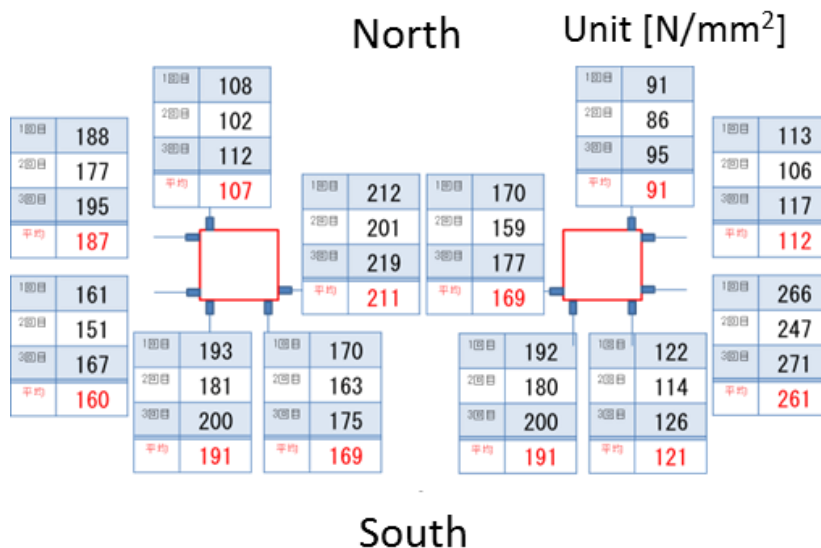


Fig. 7 Plan of stress range for each strain gauges

### 4.3 Calculation of the stress range frequency distribution

Stress range frequency distribution is calculated using by rain flow method for the obtained data (w/ ch.1 of west) of the continuous measurement in condition of the real traffic loading (Fig. 8). Estimated fatigue life using by modified minor rule was 3.3 years in E class as shown in Table 1. Since this measurement has carried out with cracks existing, the numerical value itself may overrate actual value. With an assumption of stress of 1.5 times are generated by cracks tentatively, the fatigue life will be 1.5 cubed, and the fatigue life of 11.1 years for the E class. In the view of the fact, it is revealed that there exists the possibility of occurrence of the fatigue cracks with 18 years in service.

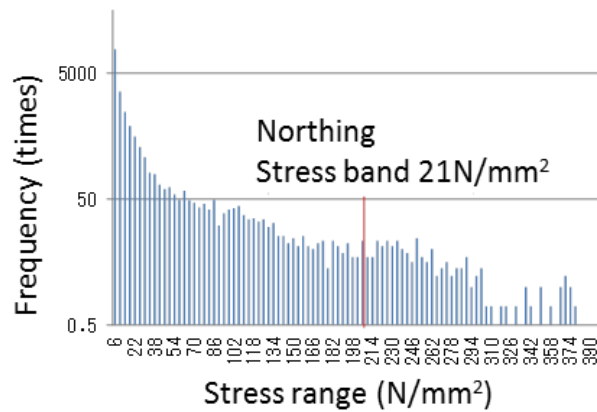


Fig. 8 Stress range frequency distribution

Table 1 Fatigue life

Strength class	E	F
Fatigue life	3.3 years	1.7 years

#### 4.4 Strain of stiffening girder

Fig 9 shows the stresses of the stiffening girder under the vehicle passing loading test (northbound). Fig 10 shows the stress distribution of the cross section using by the time when the minimum and maximum of stress occur, and the axial force and the bending moment on stiffening girders were calculated. The distance between neutral axis of stiffening girder and the center of the rotation is approximately 1m, therefore the numerical value of the bending moment by eccentricity will be the same number of the axial force as shown in Table 2. Bending moment by the eccentricity is around two times of the moment of the one by the rotation restriction of the supports, the influence of the bending moment by the axial force is bigger at the rate of two to one.

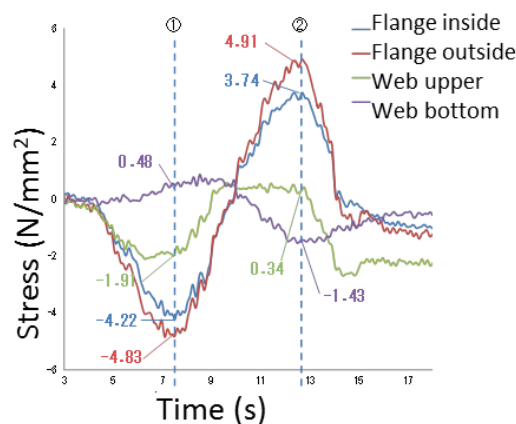


Fig. 9 Stress of the stiffening girder

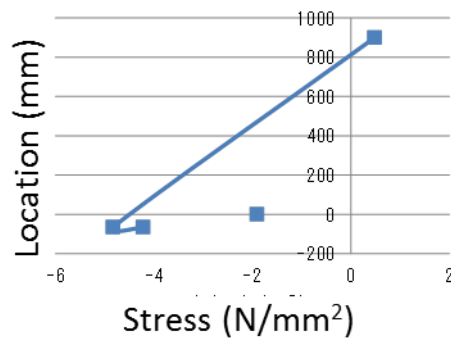


Fig. 10 Stress distribution chart

Table 2 Bending moment calculated by eccentricity and rotational restriction

Case	Moment by eccentricity	Moment by restriction
Northing	-94.8kN·m	54.4kN·m
Southing	88.0kNm	42.8kNm

## 5. NUMERICAL SIMULATION WITH FE ANALYSIS

### 5.1 Abstract of analysis

The objective bridge is modelled with 3D elastic beam element using by MIDAS Civil as shown in Fig. 11. The stiff beam element was added to the figure edge as shown in Fig. 12 to consider the distance of neutrality axis of the stiffening girder and the pivot point of the support. Also, the boundary condition was considered in the bottom end of the element. As for the rotation of the Y-dimension, the rotary spring was installed to consider aged deterioration of supports. The influence of rotational constraint for axial force of the stiffening girder and bending moment were evaluated under the condition of spring constant between 0 kN-m/[rad] as for the hinge and 1,000,000 kN-m/[rad] as for the totally fixed condition of the support for the simulation.

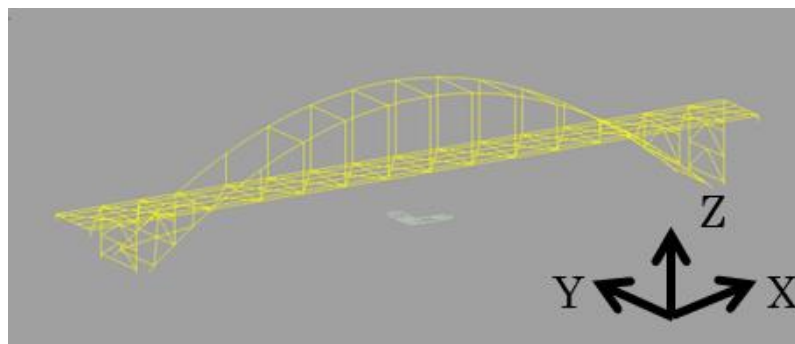


Fig. 11 3D FE model

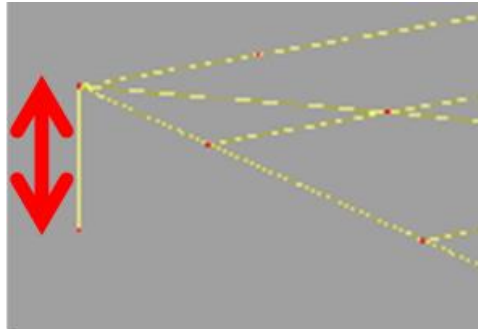


Fig. 12 Stiff component for considering the eccentricity

## 5.2 Results of the analysis

(1) Eccentric influence with the neutral axis of the stiffening girder and rotary center of the support

The bending moment and axial force at the center of the span are calculated. Fig. 13 shows the result with consideration of eccentric influence for the neutral axis of the stiffening girder and rotary center of the support, where Fig14 are without consideration. The axial force and the bending moment at the center of the span have no influence with the eccentricity by comparing the two cases.

On the other hand, the bending moment and the axial force are influenced by movement of the load in the end of the stiffening girder (Fig 15). The axial force is equivalent approximately 2 times, where the bending moment is almost same by comparing the value with the span center. When the support is installed on the neutrality axis position for the FE analysis, the bending moment of the edge of stiffening girder, which is equivalent to the one at the center span, are to be neglected. It is important to consider the eccentricity for live/dead load analysis for the type of the bridge with rigid connection between the stiffening girder and arch rib.

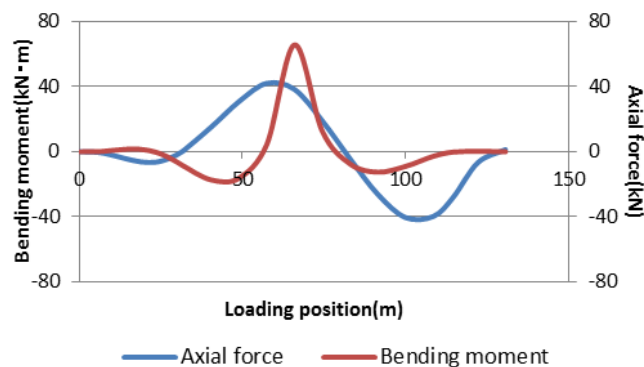


Fig. 13 With consideration to the eccentricity to support



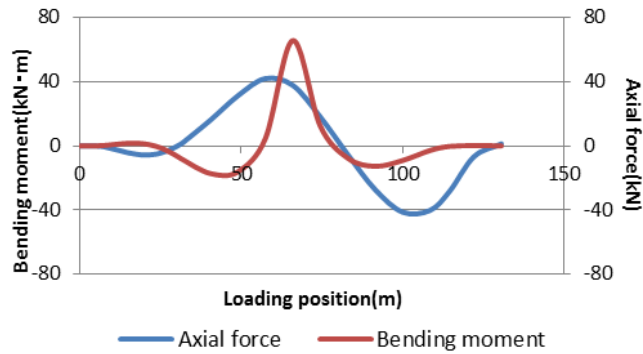


Fig. 14 Without consideration to the eccentricity to support

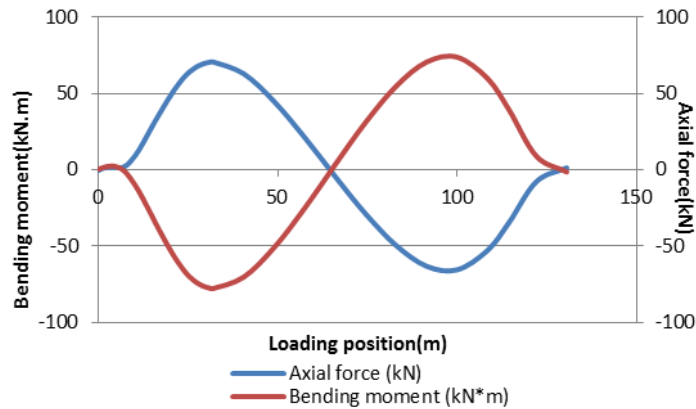


Fig. 15 Reaction of the end of the stiffening girder

(2) Influence of the intensity with rotation of the supports

Fig. 16 shows the axial force on the stiffening girder, bending moment on the neutral axis of stiffening girder and bending moment on the support. The figure shows that bending moment generates when restriction of support increases. In addition, the bending moment on the neutral axis decreases by its influence. When a restriction was small, the change of the bending moment and axial force are particularly big.

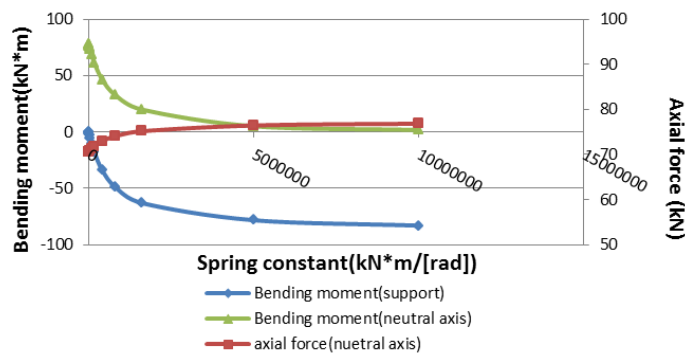


Fig. 16 Reaction near the support

## 6. CONCLUSIONS

Fatigue cracks were observed around the sole plates in pier section of 17-years in service existing steel half through Lohse bridge. For determining the cause of fatigue damage, measurement and simulation for the objective bridge were conducted. Conclusion of this paper is summarized as follows.

- 1) Stress ranges near the crack generation are over the  $80\text{N/mm}^2$  which is 2million times of strength of E class in any measurement points. This means that these areas are under severe condition of stress concentration.
- 2) Estimated fatigue life using by modified minor rule was 3.3 years in E class. With an assumption of stress of 1.5 times are generated by cracks tentatively, the fatigue life will be 1.5 cubed, and the fatigue life of 11.1 years for the E class. It is revealed that there exists the possibility of occurrence of the fatigue cracks with 18 years in service.
- 3) Bending moment by the eccentricity is around two times of the moment of the one by the rotation restriction of the supports, the influence of the bending moment by the axial force is bigger at the rate of two to one.
- 4) When the support is installed on the neutrality axis position for the FE analysis, the bending moment of the edge of stiffening girder, which is equivalent to the one at the center span, are to be neglected. It is important to consider the eccentricity for live/dead load analysis for the type of the bridge with rigid connection between the stiffening girder and arch rib.

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