Investigation on the Vibration of Diagonal Members in Ikitsuki Bridge

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1 Introduction

Ikitsuki Bridge is a three span continuous truss bridge with the main length of 400m, which was completed in July, 1991. In December 2009, a large crack was found in a diagonal member near the intermediate support (P6) during the daily inspection, which seriously damages the safety of the bridge. From the previous research and study, it is revealed that the crack was induced by fatigue, and was caused by wind-induced vibration. In this study, based on the information of this bridge and its damage obtained from long term remote monitoring, relations between wind condition and vibration are surveyed and identified. What is more, it can be used to prevent large-scale damage occurrence in this bridge.

2 Outline of bridge and crack

2.1 Bridge

Ikitsuki Bridge locates in the Hirado city, the northwest of Nagasaki Prefecture. It connects Ikitsuki Island and Hirado Island. The bridge is a three span continuous steel truss bridge with the span arrangement 200m + 400m + 200m. The completion of this bridge sets a new world record for the main span length of this type, and it opened to traffic in July31, 1991. The photo of bridge is shown in **Fig.1**. The main truss spacing is 13.5m, and lane is 6.5m. There are 84 kinds of diagonal members in the bridge, of which the shortest one is 13.24m and the longest one is 23.655m.

2.2 Cracks

Large crack was found in a diagonal member shown in **Fig.2** near the north side of the intermediate support (P6) in December 2009. The diagonal member has a rectangular box section with the width of flange and web is 500 mm and 574 mm, respectively. The thickness of plates is 9mm. The crack on sea-side flange has the length of 465 mm and that on upper web has the length of 510 mm, as shown in **Fig.3**. The crack propagated along the weld toe on the outside of the flange face.

Fig.1 Photo of bridge

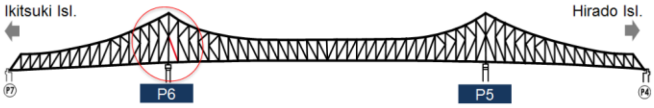
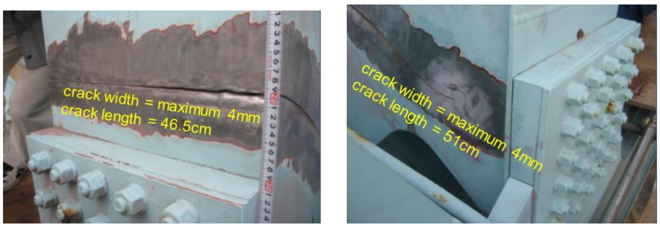


Fig.2 The loctaion of crack



(a) Sea-side flange (b)upper web

Fig.3 Photos of crack

3 Measurement systems

In order to confirm the cause of crack, a long term remote monitoring of wind condition and vibration of some diagonal members with similar structural characteristics to the cracked member had been carried out since December 2011. Some accelerometer, windmill anemometer and strain gauge were used to find the relationship between vibration behavior and wind condition. The number of them is shown in **Table1** and the location for observing is shown in **Fig.4**.

Wind direction and wind velocity had been measured by windmill anemometer at four points of each north and south side on two intermediate supports (P5 and P6). In order to reduce the influence of the following flow in the downstream side to measure the wind condition, the height of anemometer is about 5m. Vibration for eight members had been measured by accelerometer at eight points of in-plane and two points of out-planes on two intermediate supports (P5 and P6). 10 strain gauges were set on two members among them.

The sampling frequencies of acceleration and strain were 100Hz continuously. However, the sampling frequencies of wind velocity and wind direction were 1Hz. All the datas were stored ervery 10 min. The real-time datas were transfered and saved to Nagasaki University through the Internet.

Table 1 Object of measurement

Object		Location	Number of items
Vibration of member	In-plane	Diagonal member	8, 4 points at each middle pier P5 and P6
	Out of plane		2, a point at each P5 and P6
Wind condition	Direction	Top of middle pier	4, 2 points at each P5 and P6
	Velocity		
Stress condition		Diagonal member	2, 1 points at each P5 and P6 (5 gauges a point)

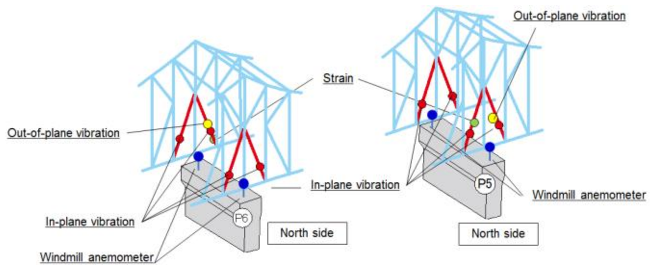


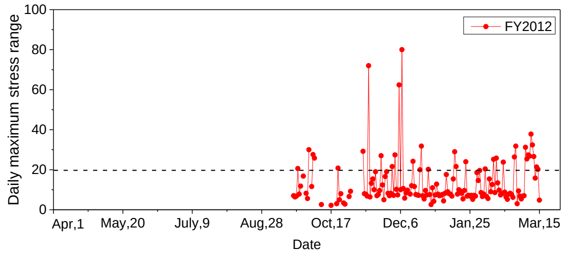
Fig.4 The location for observing vibration and wind condition

4 Cause analysis

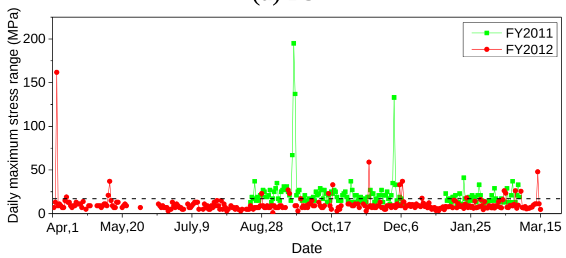
The stress range histogram was got from the time history of strain record by the rain flow counting method. **Fig.5** shows the transition of daily maximum stress range on the diagonal member of P5 and P6. Since the cut-off limit of Class E for variable amplitude stress in *Fatigue*

Design Recommendations for Steel Highway Bridges is 29 MPa, so 20 MPa is thought to be an index to judge the occurrence of vibration. **Fig.6** shows the number of days when the maximum stress range is over 20MPa.

It shows the number of the day with maximum stress range between 20 MPa and 30 MPa on P5 in FY 2012, is 25 days, between 30 MPa and 60 MPa is 6 days, and over 60 MPa is 3 days. The recorded maximum stress range is 80MPa. And the number of the day with the maximum stress range between 20 MPa and 30 MPa on P6 in FY 2011 and FY 2012 is 56 days and 9 days, between 30 MPa and 60 MPa is 11 days and 6 days, and over 60 MPa is 4 days and 1 day, respectively. The recorded maximum stress range is 195MPa and 162MPa, respectively.

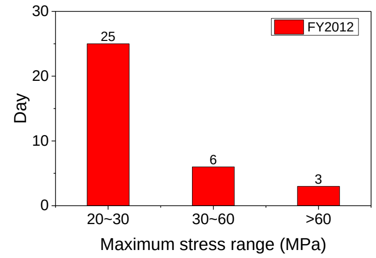


(a) P5

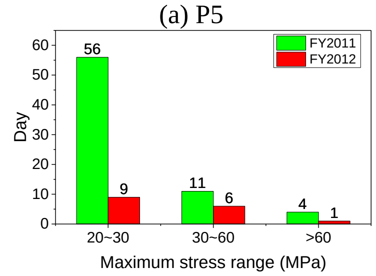


(b) P6

Fig.5 Daily maximum stress range (Unit: MPa)



(a) P5



(b) P6

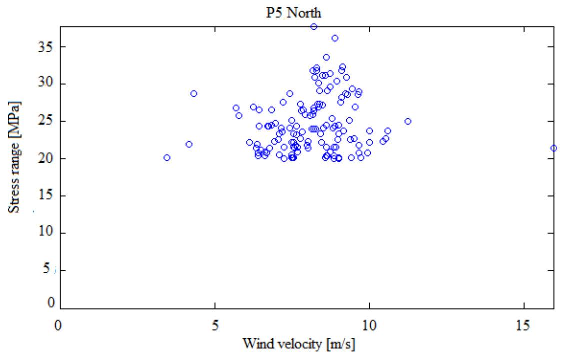
Fig.6 Number of days by daily maximum stress range

The natural frequencies were measured by impact test. As the result, the 1st natural frequencies of members in side span and center span are approximately 6.3Hz and 6.7 Hz, respectively. All of the acceleration data by every 10 minutes with the maximum stress range over 20 MPa were picked up. The time history and power spectrum of acceleration were analyzed. The vibration can be divided into two kinds. One is the vibration with the 1st natural frequency, and another is vibration without the 1st natural frequency, as shown in **Table2**.

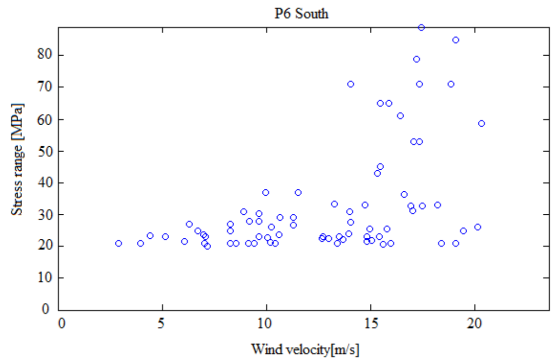
Table 2 The different kinds of vibration

		Vibration with 1st natural frequency	Vibration without 1st natural frequency
P5	FY2012	10/1, 10/4, 10/5, 11/22, 11/30, 12/2, 12/15, 12/21, 12/26, 1/15, 1/22, 2/5, 2/11, 2/13, 2/18/ 2/26, 2/27, 3/6, 3/7, 3/8, 3/9, 3/10, 3/11, 3/12, 3/14, 3/15	10/22, 11/13, 12/5, 12/7, 12/20
P6	FY2011	2/28	/
	FY2012	4/3, 5/10, 5/11, 8/28, 9/16, 9/17, 10/15,10/18, 11/3, 12/5, 12/7	2/18, 2/19, 2/26, 3/1, 3/13

The relation between the maximum stress range and wind condition were analyzed by the vibration with the 1st natural frequency. The maximum acceleration RMS for 10 seconds was calculated by every 10 minutes, and the wind velocity and wind direction of that 10 seconds were also calculated. It is shown that most of wind velocities are between 6 m/s and 10 m/s or over 15 m/s, as shown in **Fig.7**, and the wind direction is almost perpendicular to the axis of the bridge.



(a) P5



(b) P6

Fig.7 The relation between stress range and wind velocity

5 Last remarks

In this study, the long term remote monitoring of Ikitsuki Bridge had been carried out to identify the wind condition inducing vibration of diagonal members. It shows that most of wind velocities are between 6 m/s and 10 m/s or over 15 m/s, and the wind direction is almost perpendicular to the axis of the bridge. The vibration frequencies are near their 1st natural frequency.

References

[1] S. Nakamura, T. Okumatsu, T. Nishikawa,T. Okabayashi (2014), “Fatigue Damage of a Diagonal Member in a Steel Truss Bridge Due to Wind-Induced Vibration”, *Istanbul Bridge Conference*, Istanbul, August, 211-220.

[2] Japan Road Association (2002), “Fatigue Design Recommendations for Steel Highway Bridges”, *Maruzen Co. Ltd.* Tokyo, Japan. (in Japanese)