The Evaluation of KAWANE Bridge by distributed FBG sensors and by FEM analysis

Kejian YANG 1, Akito YABE 1, Kazumi YAMAMOTO1, Hideaki ARAKI 2, and Zhishen WU 3

1 Seismic Eng. Dept., KOZO KEIKAKU Eng. Inc. 4-5-3, Chou, Nakano-Ku, Tokyo, 164-0011, Japan
2 Create Coordination Dept., KOZO KEIKAKU Eng. Inc. 4-5-3, Chou, Nakano-Ku, Tokyo, Japan
3 Dept. of Urban and Civil Eng., Ibaraki University, Nakanarusawa-Cho 4-12-1, Hitachi, Ibaraki, 316-8511, Japan

ABSTRACT: In this paper, an actual survey for an old under-use reinforced concrete (RC) bridge based on distributed long-gage fiber Bragg grating (FBG) sensors was carried out. Furthermore, an extended numerical study by finite element method (FEM) was performed. The evaluation of the bridge and its measurement were done by the comparison between survey data and analytical results. The practical utility about determination of the optimum length of a FBG sensor and the method of load level identification for flexural RC Structure from distributed strain measurements proposed by authors was verified here.

1 INTRODUCTION

Because of the advanced researches on structural health monitoring in last decade, it becomes possible to use the FBG sensor system to monitor and evaluate the under-use bridges much more exactly and scientifically than current monitoring method based on the veteran technician’s judgment by his sense and experience.

On the bases of a series of lab experiments and theoretical studies for the utilities of distributed long-gage FBG sensor system by authors, Li & Wu (2007) and Yang et al. (2006 & 2007), the actual survey for an old under-use RC bridge named KAWANE located in Ibaraki Japan has been performing from last spring.

Before installing the FBG sensor system on the bridge, the sensor arrangement plan was determined based on the conclusion of past research about the optimum length of long-gage FBG sensor system by authors, Yang et al. (2006). The finite element analysis of KAWANE bridge was also performed to give a reference for the arrangement of sensor installation.

After installation of FBG sensors and in the monitoring process, the evaluation of current situation of the bridge and its measurement were done by the comparison between monitoring data and analytical results. The practical utility about method of load level identification for flexural RC Structure from long-gage FBG distributed strain measurements proposed by authors, Yang et al. (2007) was verified in this study. Furthermore, the analysis by the traffic vibration
simulator developed by authors, Yabe et al. (2008), was done and the comparison between monitoring data and analytical results show that the numerical approach gives good simulation of FBG sensor’s measurement.

2 THE MEASUREMENT OF KAWANE BRIDGE BY FBG MONITORING SYSTEM

2.1 About KAWANE Bridge

Fig.1 Location of KAWANE Bridge

Fig.2 Picture of KAWANE Bridge

Fig.3 Image about Whole Span of KAWANE Bridge

Fig.4 Traffic of KAWANE Bridge

Fig.5 Girders of Bridge and FBG Sensors

KAWANE Bridge is located in a swamp river named KAWANE in Ibaraki Japan, which was built in Oct. 1963. As shown in Fig. 1, it takes heavy traffic every day as shown in Fig. 4 because it is near a highway interchange. Fig.2 and Fig.3 show a picture and the image of the whole span of KAWANE Bridge.
Fig. 5 is a picture about the girders of bridge and the installation of distributed FBG sensing system under the girder. Fig. 6 gives sizes of girder and the position of distributed FBG sensors.

![Fig. 5: Girders and FBG Sensing System](image)

**Fig. 6 Size of Girders and the Position of Distributed FBG Sensors**

2.2 Monitoring by distributed long-gage FBG sensor system

![Fig. 7: Long-gage FBG Sensing System](image)

**Fig. 7 Detail of Distributed Long-gage FBG Sensing System**

![Fig. 8: FBG Sensor Detail](image)

**Fig. 8 Detail of Each FBG Sensor**

According to the past research about the sensor arrangement plan of distributed long-gage FBG sensor system by authors, Yang et al. (2006), it is known that the optimum length was about 1/8
length of span to 1/12 length of span. In this case, it was determined that the length of one sensor and FRP joint equals to 1/12 length of span based on the above conclusion. Before sensor installation, a finite element analysis of KAWANE Bridge was also performed to give a reference for the decision of which girder should be choose for the measurements. After a detail monitoring plan, a distributed long-gage FBG sensing system shown in Fig.7 and Fig.8 was installed at the bottom of a center girder in first span of bridge as shown in Fig.3, Fig.5 and Fig.6. Unfortunately, because the sensor of No. 12 was broken in the process of monitoring, we show the monitoring results without sensor No. 12 in this paper.

2.3 Measurement under bus loading

In order to confirm the utility of distributed FBG sensing system, verify the method about evaluation of current situation of the under-use bridge, and the method of loading identification, a bus was reserved as a load for the measurement. Total weight of bus is 100kN, the weight on
front wheel is 30kN, the weight on back wheel is 70kN. The bus was stopped on the fix position of bridge as a static load, also was driving through the bridge at the speeds of 10km/h, 30km/h and 40km/h. Fig.9 gives the detail position of bus in case of static load.

3 THE MODEL OF FINITE ELEMENT ANALYSIS FOR KAWANE BRIDGE

3.1 FEM model, Material and Boundary

Fig.10 FEM Model and Boundary

Fig.10 is the mesh and boundary condition for finite element analysis of the measuring span of KAWANE Bridge. The material of bridge is FC21 of JIS code, for concrete, Ec=23.5kN/mm2, νc=0.167, for reinforcements, Es=210kN/mm2, νs=0.3. A static elastic finite element analysis was performed here first, then a traffic vibration simulation by a substructure method on the basis of interaction between vehicle and bridge shown in Fig.11 proposed by authors, Yabe et al. (2008), was carried out.

Fig.11 Image of Traffic Vibration Simulation with Interaction between Vehicle and Bridge

3.2 The cases of analyses

Fig.12 (a) Case of Bus Stopping on the center of Measured Span of Bridge
Fig. 12 (b) Cases of Bus Running with 10km/h, 30km/h, 40km/h in Different Position of Bridge

The static elastic finite element analyses were performed in cases of bus stopped at the center of measured span of bridge shown in Fig. 12 (a), and running at the speeds of 10km/h, 30km/h and 40km/h in three positions shown in Fig. 12 (b).

4 THE RESULTS OF MEASUREMENT AND ITS SIMULATION

4.1 The comparison of monitoring data and its simulation by static bus loading

Fig. 13 Comparison between Monitoring and Analysis in case of Bus Stopping on the Bridge

The comparison between monitoring data and analysis results by finite element model is shown in Fig. 13 in case of bus stopped at the center of measured span of bridge. It is clearly that the strain distribution of monitoring data is coincided well with the result of elastic analysis. It means that this span of bridge is still on good condition and no damage. We also verify the healthy state of this measured span of bridge in other exact method of evaluation of structure health monitoring and will report that in other paper.
4.2 The comparison of monitoring data and its simulation by moving bus loading

Fig. 14 shows the comparison between monitoring data and static FEM analysis results in cases of bus moving on the bridge at different positions with speeds 10km/h, 30km/h, 40km/h. Because monitoring data is agree relatively well with analysis results in each position with different speeds of bus, it can be concluded that static analysis can give a relative good simulation for moving loading if it is under speed 40km/h in monitoring.

a) Distribution of strain when bus in north side of span with speeds 10km/h, 30km/h, 40km/h

b) Distribution of strain when bus in center of span with speeds 10km/h, 30km/h, 40km/h

c) Distribution of strain when bus in south side of span with speeds 10km/h, 30km/h, 40km/h

Fig. 14 Comparison between Monitoring and Analysis in case of Bus Moving on the Bridge

4.3 The result of load identification

Using the method of load identification proposed by authors, Yang et al. (2007), the load distribution can be estimated from measured strain distribution as shown in Fig. 15.
4.4 The comparison of monitoring data and its simulation by traffic vibration simulator

![Graph](image)

Fig.16 Dynamic Responses of Strain in Cases of Bus Speeds 30km/h and 40km/h

Using a substructure method considering with interaction between vehicle and bridge shown in Fig.11 proposed by authors, Yabe et al. (2008), the dynamic responses of strain in the center position of measured span in cases of bus speeds 30km/h and 40km/h were calculated, and their comparison with monitoring data were shown in Fig.16.

5 CONCLUSIONS

Main conclusions about evaluation of the bridge and verification of load identification method and dynamic simulator with interaction of vehicle and bridge can be drawn as follows.

1. The measured span of bridge is in good condition and has no detectable damage yet.
2. Static analysis can give a relative good simulation for moving loading under speed 40km/h.
3. In monitoring for old under-use bridge, proposed method of load identification can estimate load level and position roughly, but it is difficult to calculate load distribution exactly.
4. Proposed substructure method on the basis of interaction between vehicle and bridge can give a good simulation in dynamic response of structure under moving load. It is applicable for actual survey of the old under-use bridge.
5. The distributed long-gage FBG sensing system has good accuracy in old bridge monitoring.

REFERENCES

Li, SZ, and Wu, ZS. 2007. A non-baseline algorithm for damage locating in flexural structures using dynamic distributed macro-strain responses, Earthquake Engineering and Structural Dynamics, 36, 9, 1109-1125.