NATURAL VIBRATION CHARACTERISTICS OF FOUR-SPAN CONTINUOUS STEEL BOX GIRDER BRIDGE WITH LRB SHOES

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1. INTRODUCTION

Bridge Structural Health Monitoring (SHM) is known as an effective tool for diagnosing current damage and/or stability level. Health of bridge may be evaluated comparing the dynamic response characteristics at current state with those at the beginning of common use. To achieve this, dynamic characteristics for new or existing bridges have been investigated conducting field tests and/or monitoring the vibration using the sensors installed into the bridges[1)].

The numerical analysis can be used for evaluating the dynamic response characteristics of the bridge before common use. The finite element analysis was tried to verify an applicability of the method comparing with the experimental results[2)].

In this paper, to evaluate the dynamic response characteristics of a four-span continuous steel box girder bridge with LRB shoes before beginning of common use, the field vibration test using highly sensitive vibration meters was conducted. Also, proposing the numerical analysis method, the applicability was investigated comparing with the experimental results.

From this point of view, to investigate the natural vibration characteristics of a four-span continuous steel box girder bridge which has not opened the traffic yet, for the field vibration tests were implemented to get the initial values the effective management and operation of the bridge. And, to numerically investigate the natural vibration frequencies and modes obtained from the field experiment, three-dimensional finite element (3D-FE) analysis was conducted.

2. OUTLINE OF BRIDGE

Field test was conducted by using Shin-Atsubetsu River Bridge located in Hidaka district of Hokkaido, Japan, which is a four-span continuous steel box girder type bridge and has not opened to common use yet. In this bridge, LRB (lead Rubber Bearing) type shoes were installed for all supports. Photo 1 shows overview of the Shin Atsubetsu River Bridge. Detail of this bridge is summarized in Tab. 1 .

Table 1　Characteristics of Shin-atsubetsu River Bridge

Design	4-span continuous steel box girder
Total length	221 m (62+51+50+58 m)
Width	12.89 m
Box height	2.7 m
Longitudinal gradient	0.3%; 2.01 %

3. OVERVIEW OF EXPERIMENT

3.1 Measuring system

In this study, to precisely evaluate the natural vibration frequencies and modes of the bridge, highly sensitive servo-type vibration meters were used for this experiment. The locations of measuring points were shown in Fig. 1 . In this experiment, a total of 44 channels were used for the cases 1 and 2, and 18 channels for the case 3.

According to the procedures of experiments, in the cases 1 and 2, a dump truck was used for excitation of the bridge, in which a total weight of the truck including freight was adjusted to 20 ton. In the case 3, the bridge was vibrated due to human jumping. Vibration of the bridge was measured after passing the truck off the bridge and/or human jumping. Measuring data were collected applying a wireless LAN system and recorded by using note type computers, in which sampling time was set to 5ms (200Hz). Photo 2 and Fig. 2 show the dump truck and a wireless LAN system applied in this field test, respectively.

3.2 Evaluation of dynamic characteristics of the bridge

In this study, the vibration characteristics of the bridge were investigated by using Fourier spectrum of acceleration waveforms at each measuring point. The vibration modes of the bridge were specified based on the following procedures[3)]:

1) Calculate Fourier spectrum for each measured acceleration waveform with 81.92 s by means of FFT technique;
2) Specify predominant natural vibration frequencies due to in-

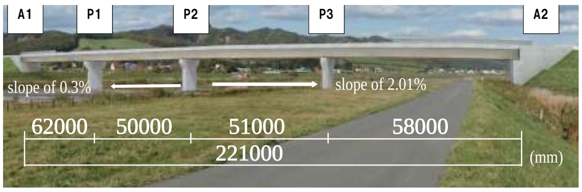


Photo 1　View of Shin-atsubetsu River Bridge

Photo 2　Truck used in the test

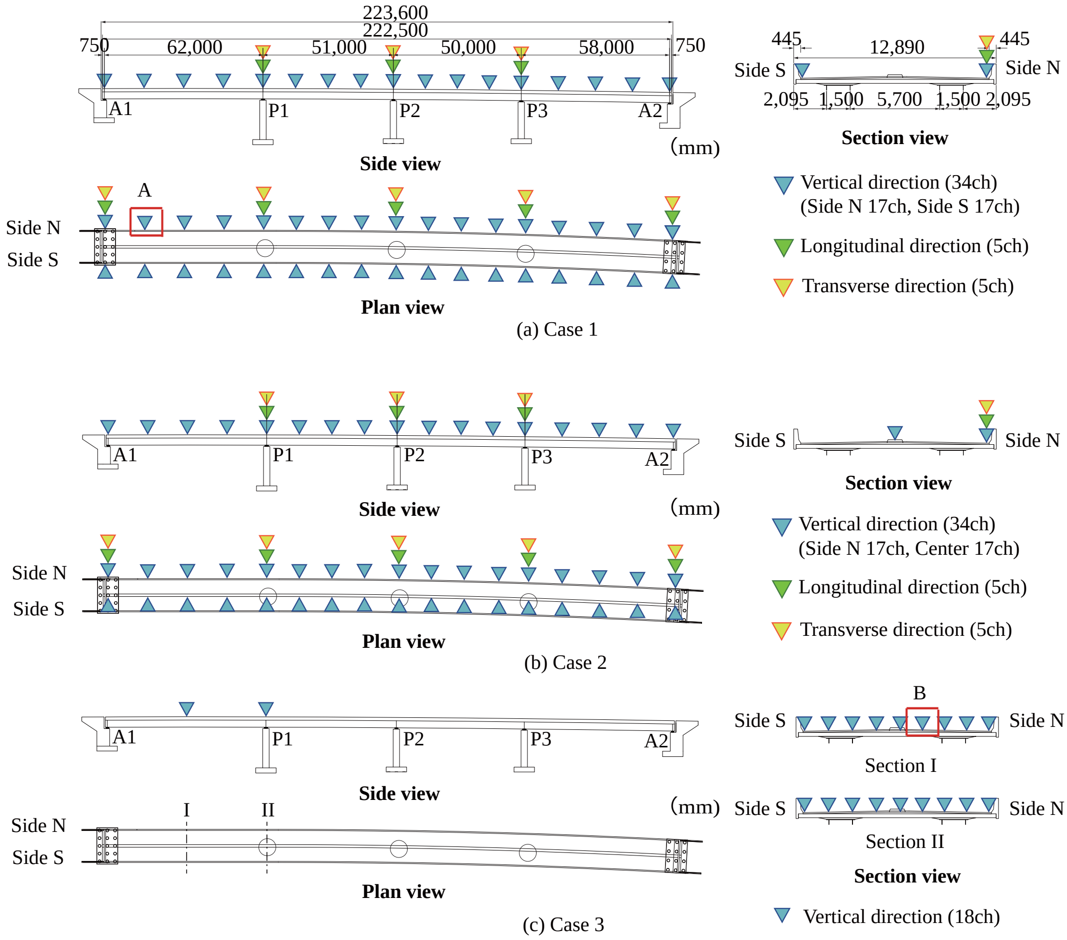


Figure 1　Location of measuring points in three cases

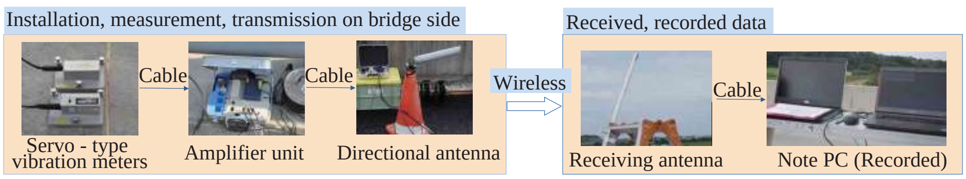


Figure 2　Wireless LAN system

specting Fourier spectra;

3) Make harmonic vibration waveforms for each predominant frequency by using Fourier and phase spectra for the whole measuring points;
4) Plot acceleration amplitudes at each one-fourth period of the harmonic vibration for the whole measuring points; and
5) Specify uncoupled natural vibration mode confirming that the vibration modes at every one-fourth period are similar.

3.3 Experimental results

Fig. 3 shows examples of acceleration waveforms and their Fourier spectra at point A in case 1 with 30 km/h of truck speed and at point B in case 3. From this figure, it is observed that maximum amplitude of the acceleration waveform is around 1 gal and some predominant frequencies can be found.

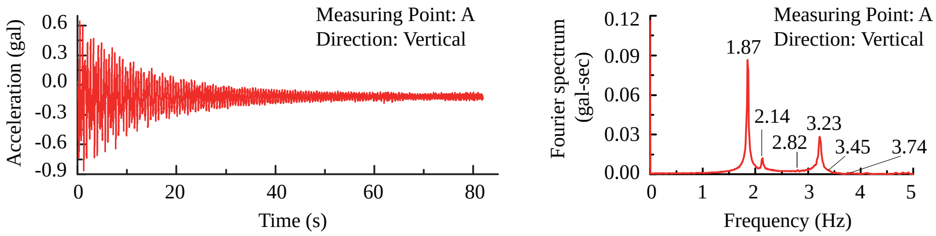
4. FINITE ELEMENT ANALYSIS

To numerically investigate natural vibration characteristics of the bridge, 3D-FE analysis was carried out by using ABAQUS code[4]. In this analysis, following assumptions were made: (1) All materials were elastic and homogeneous; (2) The base of piers and abutments were fixed; (3) bridge deck was level; and (4) load-displacement relationship of LRB is linear elastic.

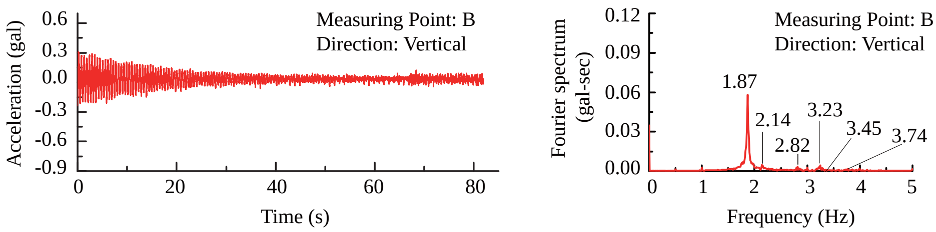
Table 2　List of material properties for numerical analysis

Material	Density ρ(g/cm^3)	Young's modulus E(GPa)	Poisson's ratio ν
Steel	7.85	200	0.3
Concrete	2.35	28	0.167
Asphalt	2.3	9.8	0.35
LRB	2.8	55	0.3

Fig. 4 shows the finite element analysis model of the bridge. The model was composed of slab, box girder, abutments, and piers and was made following the drawing.

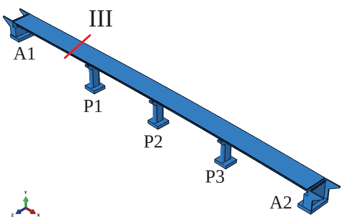


(a) Point A (case 1)

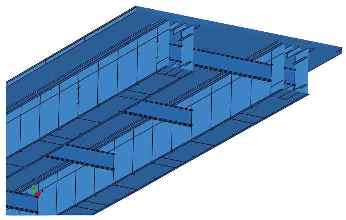


(b) Point B (case 3)

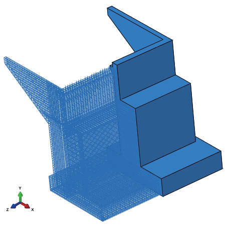
Figure 3　Acceleration response and Fourier spectrum of point A and point B



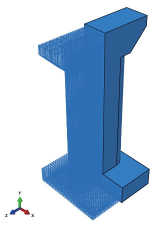
(a) Bridge model



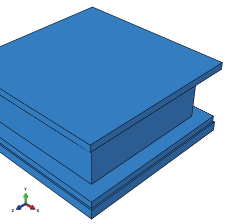
(b) Cross-section III at bridge



(c) Abutment A1



(d) Pier P1



(e) LRB

Figure 4　Finite element model

The steel plate and box girder were modeled by using quadratic shell element of type S8R which is a quadratic 8-node reduced integration element. The slab and asphalt layer were modeled by using quadratic solid element of type C3D20R which is a 20-node quadratic brick and reduced integration element. The connections between steel girder and steel plate and between asphalt layer and concrete slab were defined as tie constraints via contact surfaces. The steel-concrete composite slab was also modeled by using shell and solid elements.

Abutments and piers were modeled by using quadratic solid elements. Rebars were modeled by using embedded rebar elements.

LRBs were modeled by using quadratic solid elements. Even though load-displacement relationship of the LRB is nonlinear inelastic, it is simplified to be linear elastic because excited vibration amplitude was very small. Elastic modulus of LRB was determined based on the preliminary analysis. The material properties of concrete, steel, asphalt, and elastic were listed in Tab. 2 .

5.　COMPARISON OF THE EXPERIMENTAL AND NUMERICAL RESULTS

In this study, four flexural and two torsional vibration modes were specified from the experimental results. Fig. 5 shows comparisons of the vibration modes between field test and numerical results. All modes are normalized with respect to the maximum amplitude at the side N of the bridge.

From this figure, it is observed that: 1) 4 flexural and 2 torsional vibration modes were clearly identified from the field test predominant natural vibration mode; 2) in the cases of higher order natural vibration, the stiffness of LRB may be affected to the mode shapes and the supporting points sometimes can not form so as to be fixed and move vertically; and 3) in the cases of torsional natural vibration, one side span more predominantly behave than the inner spans.

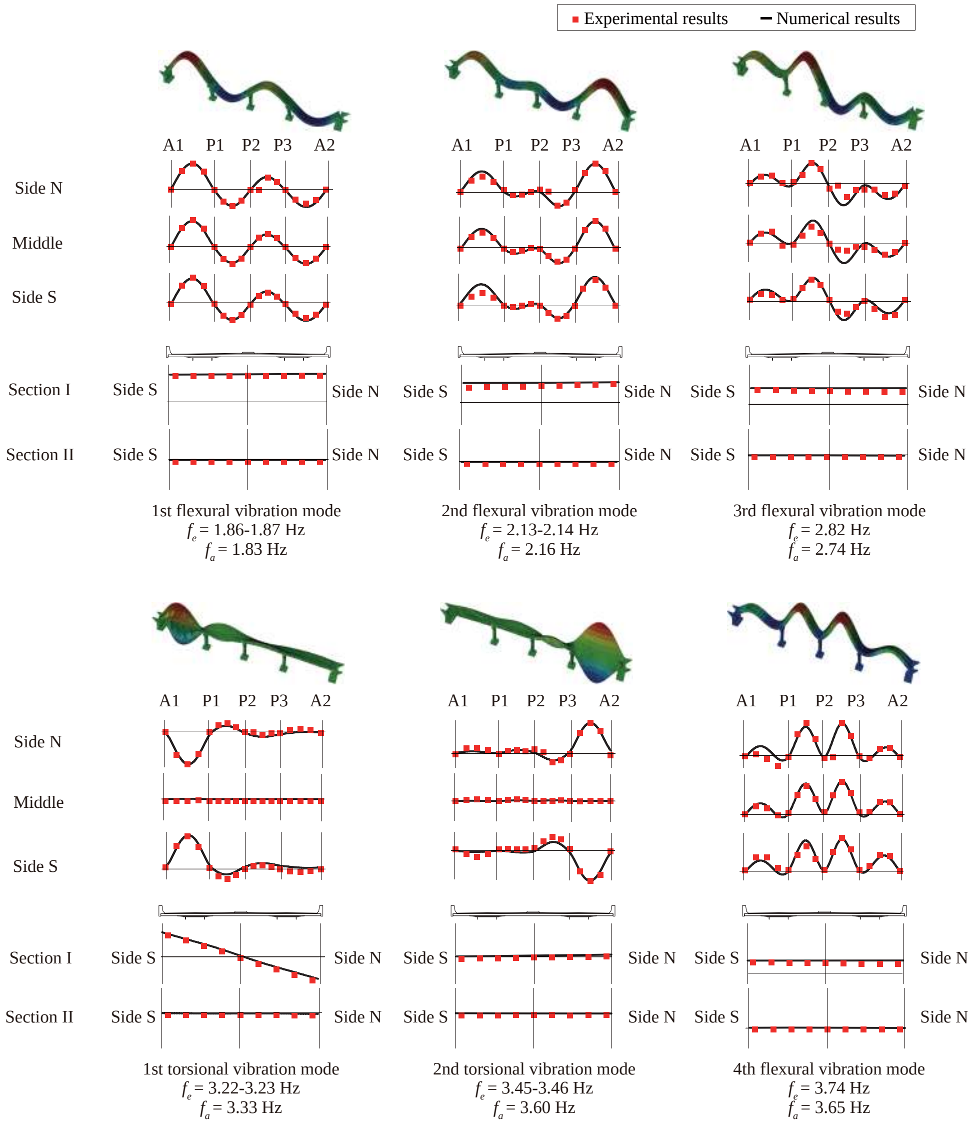


Figure 5　Comparison of the mode shapes between the numerical and the experimental results

Comparing the vibration modes and frequencies between numerical and experimental results, it is seen that: 1) numerical results on flexural vibration modes are almost in good agreement with the experimental ones; 2) in the cases of torsional vibration modes, the numerical results of frequencies may be a little larger than those of experimental one; and 3) however, the vibration modes can be better predicted by applying the proposed numerical analysis method.

Then, the proposed numerical analysis method may be applicable to estimate dynamic response characteristics of the bridge with LRB supports just before opening for public use.

6. CONCLUSION

In this study, in order to inspect dynamic response characteristics of the continuous bridge with LRB supports, the field vibration test was conducted by using highly sensitive vibration meters and digital data were automatically collected into note type computers by using wireless LAN system. The results obtained from this study were as follows:

1) The natural vibration frequencies and modes of the bridge can be appropriately evaluated conducting the field test;
2) The natural vibration frequencies and modes of the bridge before starting of common use can be specified; and
3) An applicability of the proposed numerical analysis method to estimate natural vibration characteristics can be confirmed.

REFERENCES

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4) ABAQUS: Standard User's Manual, Dassault Systemes, 2018.