Study on Dynamic Characteristic Variations of a Ballasted Railway Bridge

Kitami Institute of Technology Student Member ○ Youqi Zhang
Kitami Institute of Technology Member Yasunori Miyamori
Oriental Consultants Co. Ltd. Member Takanori Kadota
Kitami Institute of Technology Student Member Yuta Shirakawa
Kitami Institute of Technology Member Takehiko Saito

1. Introduction

The vibration-based structural health monitoring (SHM) technology is expected to be a promising entire bridge state evaluation method which could overcome the disadvantages of visual structural damage inspections[1]. It has been proved that under the ideal conditions in laboratory, the damage of small scale structures can be successfully detected and located[2]. However, owing to the existence of a large number of external affecting factors, the vibration-based structural damage detection method still could not well implemented in actual structures. Therefore, studying the mechanism of the external influencing factors is one of the necessary steps in this field.

This study is an investigation of the dynamic characteristics of a PC ballasted railway bridge in different seasons. The mechanism of the variations of the dynamic parameters was discussed. In order to support the discussion, a 3-dimensional finite element model was also established. Both the experimental and analytical results will be used as fundamental data for the bridge damage experiment in future research.

2. Description of the bridge

The bridge is a 5-span prestressed concrete railway bridge which construction was completed in 1976. The bridge lies over Muka River (Mukagawa) in Kitami City. Bridge length is 158.8m, and span length is about 31.3m. The service of the bridge has been stopped for several years. The sleepers and the tracks were destructed before all the experiments. A general drawing of the bridge is shown in Fig.1.

3. Dynamic tests on Mukagawa Bridge

3.1. Layout of the experiment

The vibration experiments of the bridge were started on November 2015, 4 experiments were conducted in 2016, and 1 experiment in 2017. The experiment dates are shown in Table 1. In these experiments, only the dynamic characteristics of all the single spans are discussed. On the No. 1 Experiment, 10 Imote2 wireless acceleration sensors were installed on one span. From the No. 2 Experiment, the sensor number was reduced to 6 to increase the efficiency of the experiment. The 6 sensors were installed in two lines on all the quarter points. The excitation method was human jumping and landing on the middle and quarter points.

3.2. Data processing method

As the excitation method is only human jumping and landing in the vertical direction, the horizon directions were not excited enough. So only the z direction data was analysis in this research. After the acceleration data was collected from the wireless acceleration sensors, the acceleration data was analyzed by fast Fourier transform, then the power spectrum was obtained. The natural frequencies were identified by peak picking method. Meanwhile, experimental modal shapes were estimated by cross spectrum method.

Fig. 1 General drawing of Mukagawa Bridge

Table 1 Experiment dates

Experiment number	Experiment date	Experiment number	Experiment date
No. 1	11.6th.2015	No. 4	10.18th.2016
No. 2	2.11th.2016	No. 5	11.29th.2016
No. 3	8.18th.2016	No. 6	2.3rd. 2017.

4. Modal analysis results

The bridge had highest natural frequencies in the No. 2 Experiment. The frequencies of mode 1 of all the experiments were shown in Fig. 2 as an example of the experimental results. Mode 1 is a bending mode and the experimental mode shape of span 2 of the No. 2 Experiment was shown in Fig. 3. The 5 spans on the No. 2 Experiment had the highest mode frequencies. The mechanism of this phenomenon was already explained in the previous study[3] that in No. 2 Experiment which was conducted in winter, the ballasts on the bridge was totally frozen, and the frozen ballasts increased the structural stiffness of the bridge. The frozen ballasts effect could increase the fundamental natural frequencies as much as about 20%.

5. Finite element model analysis

In order to give more quantitative support of the explanation that the frozen ballasts could affect the natural frequencies obviously，a 3-dimensional finite element model was established by the Midas Civil 2010 software. A general view of the numerical model of one span bridge was shown in Fig. 4. All the structural elements were modelled with solid elements. As line bear supports were employed in the bridge, it allows slight displacements on some translation and rotation directions. So the supports were modelled by employing a combination of direction fixed constrains and spring element constrains. The stiffness of z direction spring elements was 60 kN/mm.

Keywords: structural health monitoring, ballasted railway bridge, vibration experiment, eigenvalue analysis, finite element model
Address: No. 165 Koen Cho Kitami City Hokkaido Japan; Post code: 090-8507; Tel: 0157-26-9529

Table 2 Natural frequencies of numerical models and vibration experiments

Mode	Span 2 on the No. 4 Experiment			Span 2 on the No. 2 Experiment		
	Vibration experiment / Hz	Fundamental model / Hz	Difference	Vibration experiment / Hz	Frozen ballasted model / Hz	Difference
Mode 1	4.1	4.1	0%	4.4	4.4	0%
Mode 2	7.2	7.2	0%	7.8	7.8	0%
Mode 3	11.7	14.4	23.1%	13.1	15.4	17.6%
Mode 4	14.7	14.1	-4.1%	15.4	15.0	-2.6%

The frozen ballasts on the numerical model were taken into account by increasing the stiffness of the solid elements of ballasts. As the high difficulty of measuring the stiffness of the frozen ballasts by field test, the stiffness of the frozen ballasts on the numerical model was assigned to 16 kN/mm^2 initially and empirically. After calibration, the stiffness of the ballasts on the frozen ballasted model was adjusted to 30 kN/mm^2. Considering the ice on the walkway in the No. 2 Experiment, the elasticity modulus of walkway was increased to 30 kN/mm^2.

A comparison was made between the finite element models analytical results and bridge vibration experiment results, as shown in Table 2. The differences between the analytical results and the vibration experimental results of mode 1 and 2 were 0% and less than 5% in mode 4. On mode 3, the differences between the experimental and analytical result is about 20% in both models. By adjusting the support simulation model, it could not get a very good correlation between the experimental and analytical natural frequencies on mode 3. The natural frequency of mode 3 is not sensitive to the support condition. However, the increase of ballast stiffness still cause obvious natural frequency increase in mode 3. Therefore, the rationality of the frozen ballast effect on natural frequencies was fully proved that in winter the frozen ballasts would increase the structural stiffness and this would directly lead to the increase of the structural natural frequencies.

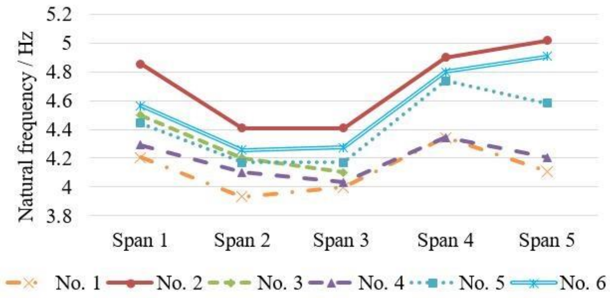

Fig. 2 Natural frequencies of mode 1

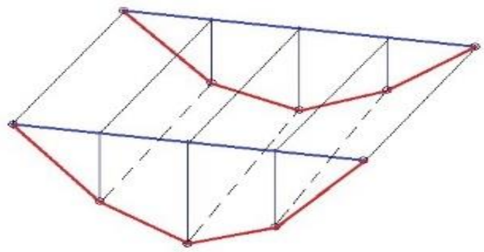

Fig. 3 Experimental mode shape of mode 1

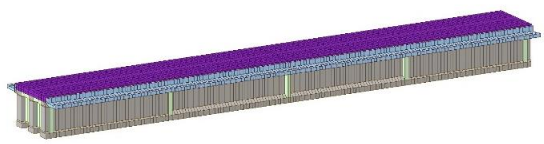

Fig. 4 General view of finite element model

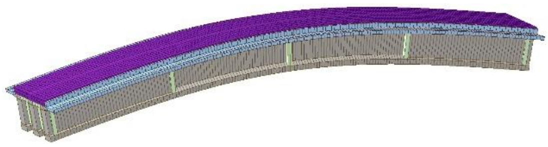

Fig. 5 Analytical mode shape of Mode 1

6. Conclusions

In this study, a discussion about the mode frequency variations under different environment conditions of a 5-span ballasted PC railway bridge was presented.

Firstly, one point was confirmed that the environment variations have significantly effects on natural frequencies in the ballasted railway bridge. The change of the ballast state can directly affect the material property of the ballasts, and this will directly lead to the change of structural natural frequencies.

Secondly, as the mode 3 is not sensitive to the change of bearing constraint condition, it was considered that some local damages or concrete degradations may happened on the bridge. Therefore, the sampling and material performance test of concrete of the bridge will be carried out.

7. Acknowledgements

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Preference

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