Special edition paper

Development of a Soundness Evaluation System for Bridge Substructured

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Scour is a phenomenon that could lead to serious accidents and disruption of transport. JR East thus has equipped piers at risk of scour with water gauges, and clinometric type scour monitoring devices to raise an alert if detecting even slight pier inclination. The Disaster Prevention Research Laboratory is further developing a soundness evaluation system for bridge substructures to detect signs of scour and monitor soundness of piers. This system can monitor using vibration such as that from trains as well as inclination. We have thus far carried out a long-term field test using a prototype vibration sensor for the system, determining required sensor specifications based on the test results. We also verified the soundness evaluation system that utilizes train vibration and microtremors under flood conditions based on actual measurement data, confirming the system's effectiveness.

● Keywords: Scour, ß value, Microtremors under flood conditions, Natural frequency

1 Introduction

Damage to piers by scour is a kind of damage difficult to visually predict. Once it occurs, it often leads to serious accidents and disruption of transport. In order to prevent that, JR East has taken countermeasures both in construction and in operation. Those include foundation consolidation, restriction according to water level (train operation restricted when river levels rise by estimating scour depth from water level), and use of clinometric devices to raise an alert if detecting inclination of the pier. However, even when such damage to a pier by scour could be successfully detected and trains are immediately stopped, large amounts of money will be needed for repairs, and long-term train service cancellation will result. Prediction of scour is thus desirable. But it is difficult to evaluate deterioration of pier soundness from signs of scour, even though current monitoring devices can raise an alert.

One method to evaluate the soundness of bridge substructures is using the natural frequency of a pier obtained by impact vibration tests. This method uses the tendency for the natural frequency of a pier to decrease as phenomena such as scour deteriorate the soundness of that foundation's pier[1]. But the test cannot be carried out frequently as it involves dangerous work in high places handling a heavy suspended weight of around 30 kg.

The Disaster Prevention Research Laboratory developed in fiscal 2002 a prediction method for angle of inclination of piers[2], and it has been examining since fiscal 2004 a soundness evaluation method for bridge substructures using trains in service as on oscillator. At the same time, the Railway Technology Research Institute (RTRI) has been developing another soundness evaluation method for piers, focusing on the fact that microtremors of a pier increase as river level rises.[3] By combining those methods with current scour detection using clinometric monitoring devices and the soundness evaluation method by impact vibration, we will be able to build a constant soundness monitoring system for bridge substructures (Fig. 1).

The aim of our research is thus to develop a system that enables constant soundness evaluation of bridge substructures. The system is to be of a size similar to that of the current clinometric type scour monitoring device, and it will use both inclination and vibration sensors.

This report will introduce the results of field tests carried out in fiscal 2007 for the soundness evaluation method for piers based on train vibration and microtremors under flood conditions.

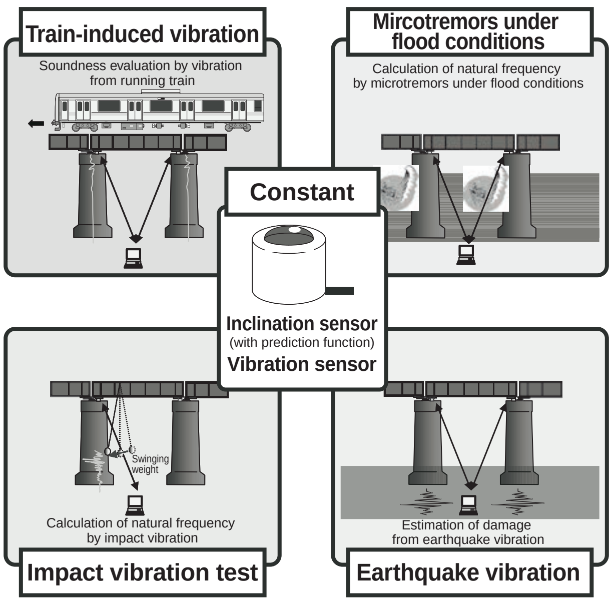

Fig. 1 Overview of a Development of the Soundness Evaluation System for Bridge Substructures

Table 1 Specifications of Sensor for Field Test

Sensor	SES60R
Acceleration measurement resolution	0.2 Gal
Frequency band	DC –20 Hz
Acceleration measurement range	+/–200 Gal
Wave shape to be recorded	Three axes for acceleration, recorded for 120 sec.
Acceleration sampling	0.01 sec
Power consumption	6W (converted into AC 100V)

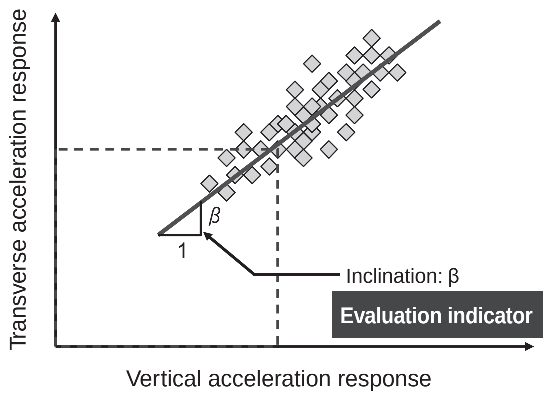

Fig. 2 Evaluation Indicator

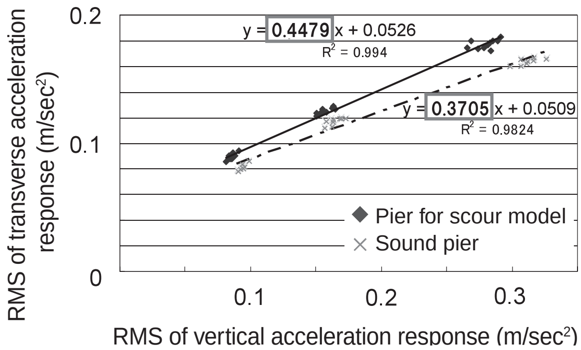

Fig. 3 Change of ß value in the model test

2 Overview of the Monitoring System Used in the Field Test

2.1 Prototype Sensor

For the vibration sensor to be used in this research, we aimed to develop a sensor that could be used for evaluation of more than one type of vibration, including vibration from train running, microtremors under flood conditions, seismic movement and impact vibration. This required a sensor that could be used in a wide acceleration range, as the required resolution, frequency band and measurement range differed in individual evaluation methods. We thus decided to make a prototype of such a vibration sensor ahead of the inclination sensor. Based on the preliminary research results, we developed a servo acceleration sensor (SES60R™) that met the specs shown in Table 1 for use as the vibration sensor in individual evaluation methods.

SES60R can automatically collect vibration wave shape for two minutes when detecting 5 Gal or larger vibration. It can also be used for arbitrary collection of vibration wave shape. In this way, we can record using SES60R microtremors under flood conditions and earthquake vibration in addition to train-induced vibration.

2.2 Evaluation Indicator for Train-Induced Vibration

When a train passes over a bridge, mainly vertical vibration occurs on the piers. But, when scour occurs at the piers, horizontal vibration is thought to become larger. That is because scour changes the lateral balance of the rigidity of the foundation. To represent as an indicator for the volume of such lateral imbalance of the pier, we use ratio of horizontal and vertical amplitude (horizontal root mean square (RMS) divided by vertical RMS) of the standard deviation of the acceleration response amplitude (RMS) of the pier. The horizontal/vertical amplitude ratio theoretically offsets effects of train running speed etc.

Unless rigidity of the foundation of a pier changes, the horizontal/vertical amplitude ratio should not change either. We have thus, as shown in Fig. 2, plotted horizontal RMSs (at right angle to the bridge axis) and vertical RMSs of individual trains to obtain ß, the inclination of the regression line (ß value), as the evaluation index. As increase of ß value means increase of horizontal vibration of the pier, we interpret that there is concern of increase of the volume of imbalance of the pier.

In order to verify the interpretation, we carried out a model test as follows. An HO gauge model train was run over piers with scour modeled and over sound piers. Calculation of the regression lines of each pier proved that the inclination of the regression line of the pier with scour modeled was greater than that of the sound pier (Fig. 3).

2.3 Evaluation Microtremors Under Flood Conditions

Pressure of water flow causes larger microtremors than usual to piers under flood conditions (Fig. 4). Calculation of the natural frequency that is difficult to measure under normal microtremors is therefore possible under flood conditions. RTRI has developed a method to detect destabilization of the foundation of a scoured pier by the change of the natural frequency in microtremor measurement under flood conditions.

In this research, we work out the natural frequency from microtremors under flood conditions by the method shown in Fig. 5, based on the results from RTRI. Specifically, we divide the vibration data under flood conditions for one minute into three parts, figure out the acceleration Fourier spectrum of each division, then overlap and average those to obtain the predominant frequency (natural frequency).

3 Field Test Results

3.1 On-site Measurement System

Based on the check result of the past data of the water gauges on bridges, we chose Bridge A in Tokyo as a bridge favorable for frequent data collection. That bridge is located at a place where we expect flooding at least once every few years. We equipped the bridge with a vibration data measurement system in September 2007. Fig. 6 shows the appearance of the system.

We can remotely collect data at the bank via wireless LAN from the data collector connected to the SES60R.

3.2 Verification of ß Value

Fig. 7 (left) is the plotted train vibration data on October 27, 2007. On that day, the river was quite calm and no rise was found. The ß value was 5.18. On Bridge A, two types of train cars with different axle load ran, but we could not detect variation of indices from either axle load difference or daytime temperature difference. Therefore, we assumed that ß value would remain stable unless change occurred to the foundation of the pier.

On the other hand, the data on November 10, 2007 (Fig. 7 right), a half month later, showed a 5.57 ß value. Comparing with the situation on October 27, however, we could find no particular change in the foundation and the river.

Human body temperature daily changes slightly, even without change of health condition. We likewise consider that the difference between ß values in October and November was within the margin of error as we could find no difference in the soundness of the pier. As shown in Fig. 8, the ß value usually remains within a certain range (normal range), and it shifts out of that range (danger range) when some change occurs to the foundation. We consider it appropriate to apply to actual work that flow where we determine abnormality (deterioration of the soundness of the pier) when such a shift is detected and carry out detailed checking.

Such normal ranges and dangerous ranges can be set based on statistical evaluation (such as probability of excess) for variation of ß values calculated from daily data over a long term.

Fig. 4 Pier in Rising River

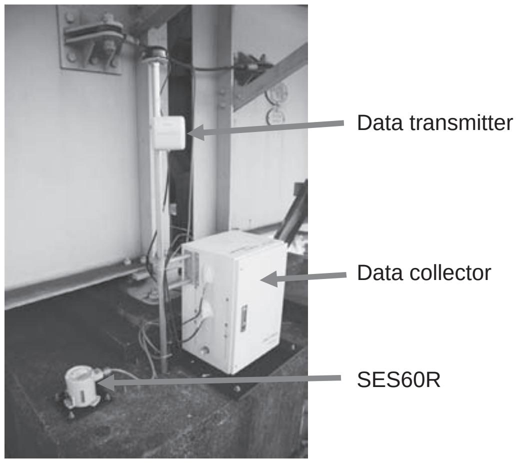

Fig. 6 Data Measurement System

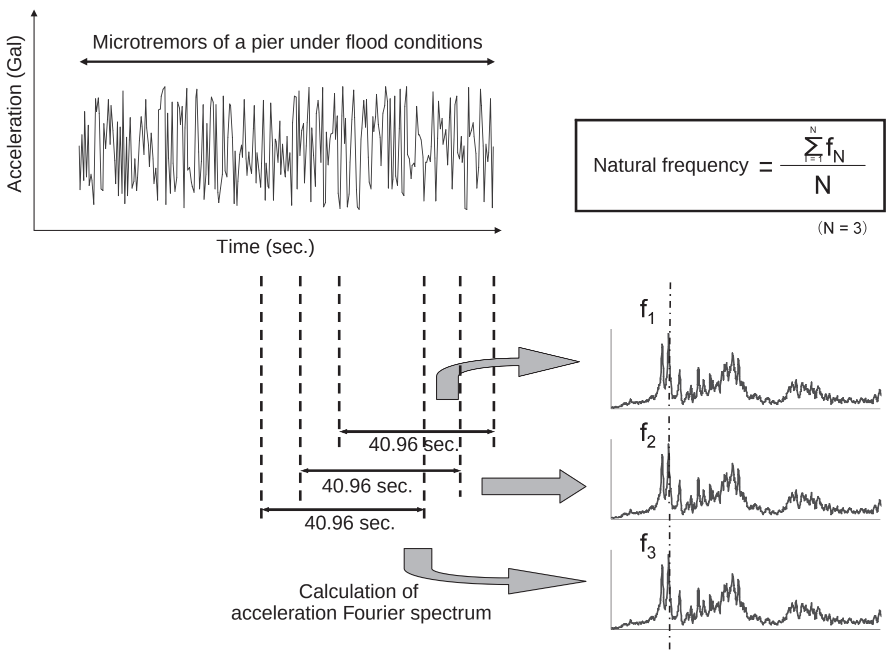

Fig. 5 Calculation of Natural Frequency from Microtremors Under Flood Conditions

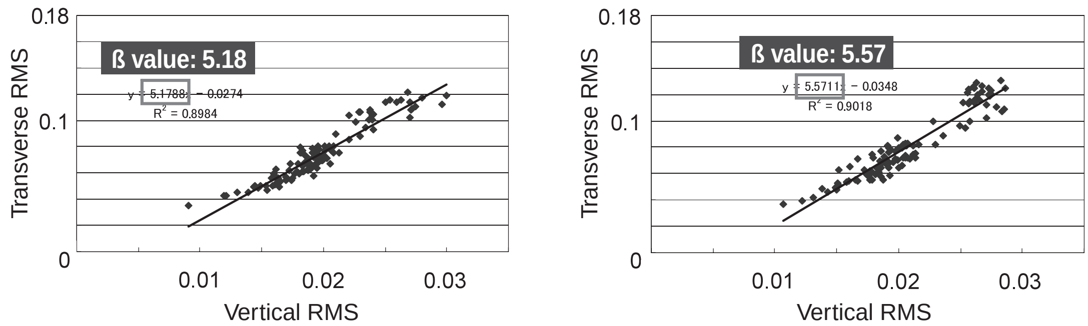

Fig. 7 Change of ß Value (Left: October 27, 2007, Right: November 10, 2007. No Rise in River Level on Both Days)

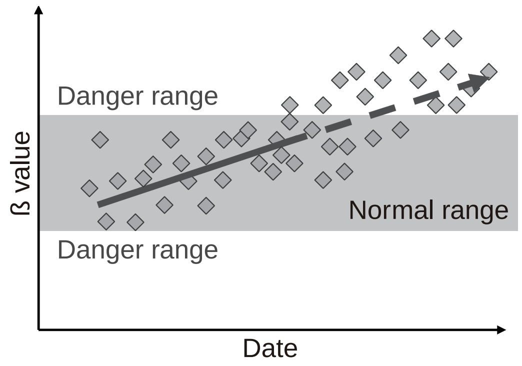

Fig. 8 Evaluation from ß Value

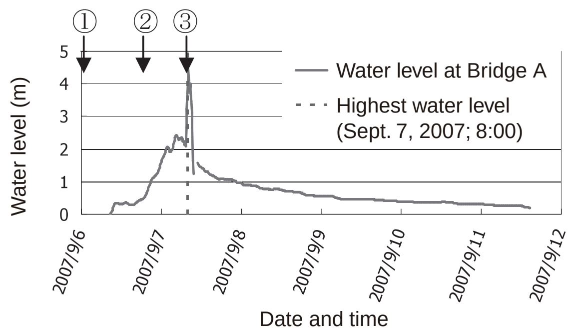

Fig. 9 Change of Water Level at Bridge A

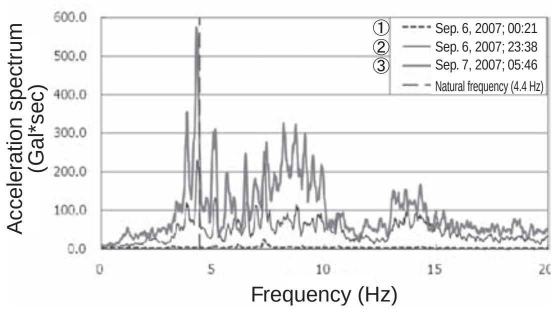

Fig. 10 Acceleration Fourier Spectrum Under Flood Conditions

3.3 Verification of the Method Using Microtremors Under Flood Conditions

From September 6 to 7, 2007, a typhoon raised the water level at Bridge A. We worked out the acceleration spectrum for the vibration of the pier at that time from by method shown in Fig. 5. As that calculation required data for approx. 30 seconds, and the spectrum analysis needs a power-of-two number of units of data, we used 4,096 units of data (40.96 sec.). Fig. 9 shows the change of the water level at Bridge A (usual level as 0 m), and Fig. 10 shows three acceleration Fourier spectra: (1) at no raise of water level, (2) in rise of water level and (3) at the highest water level. An impact vibration test told us that the natural frequency of that pier is 4.4 Hz.

That calculation of the acceleration spectrum clarified the process where the predominant frequency concentrates at around 4.4 Hz as the water level becomes higher. We can expect that predominant frequency to gradually go down if scour further proceeds under flood conditions. In this way, we would become able to presume a decrease of the natural frequency and finally monitor occurrence of abnormalities in the pier.

4 Plans for the Future

In fiscal 2008, we carried out verification of soundness monitoring for piers using train vibration. We also started field tests of a prototype inclination sensor at Bridge A. Verification of soundness monitoring using earthquake vibration is underway too.

We will proceed with development, including total system design, with an aim of putting the system into practical a few years from now.

Reference:

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2) Noritoshi Kobayashi, Makoto Shimamura; Development of a Scour Monitoring Method for Piers, JR East Technical Review (Japanese version), No. 3, pp. 49–52, May 2003
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