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Development of Multifunction Scour Monitoring Device for Railway Bridge Piers Part 2: Results of Field Testing

Development of Multifunction Scour Monitoring Device For Railway Bridge Piers Part2: Results of field testing

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East Japan Railway Company (JR-EAST) has developed a new scour monitoring device which consists of one clinometer and triaxial accelerometer. The device is set on the top of a bridge pier, and evaluates the soundness of the bridge pier based on observation of the inclination of the bridge pier, the acceleration response of the bridge pier excited by various sources, such as, train live load, microtremor, and earthquake. The current paper reports the results of field testing to determine the specifications of sensors, and confirm these methods.

Key Words : *Scour monitoring device, triaxial accelerometer, microtremor during flood, evaluation of soundness of bridge pier*

1. INTRODUCTION

The train operation should be suspended whenever the bridges are at risk of scour damages. It is difficult for railway engineers to evaluate the extent of scour damage under flood water by visual inspection. Therefore, JR-EAST set train regulation rules based on monitoring of water level and inclination of bridge pier in order to avoid fatal train accidents due to scour of bridge pier foundation during flood. The current rules have following problems:

(a) There is a room to improve reliability of the train regulation rule based on water level monitoring. The current rules are considered overly conservative.
(b) Determination to resume train operation is difficult. The visual inspection of the bridge pier foundation is very difficult under flood water.
(c) The clinometric type scour monitoring device cannot issue precautious alarm before a bridge pier is inclined.

Table 1 The characteristics of the bridge piers where monitoring is carried out (P4)

	Height	Material	Foundation	Penetration depth	Natural frequency
P4	10.0m	Concrete	Caisson	15.0m	4.4Hz

Table 2 The characteristics of the accelerometer where monitoring is carried out

Item		Contents	
		SES60	SES60R
Basic specifications	Acceleration measurement range	±2000Gal	±200Gal
		(X-,Y-,and Z-axis)	
	Acceleration measurement resolution	2Gal	0.2Gal
	Acceleration sampling	10ms	
	Acceleration waveform recording	10ms-sampling for 120s, X-,Y-,and Z-axis waveform	
	Threshold of beginning measurement	5Gal	
	Measurement time	2 minutes	
Electrical specifications	Rated voltage	12Vdc±10% or 24Vdc ± 10%	
	Current consumption	380/180mAdc	

In order to solve above problems, a new scour monitoring device which can monitor soundness of the bridge pier in real time is being developed. More details of background of the development and concept of the new scour monitoring device are discussed in the companion paper, "Development of Multifunction Scour Monitoring Device for Railway Bridge Piers, Part1".

2. NEW SCOUR MONITORING DEVICE

The new scour monitoring device consists of one clinometer and triaxial accelerometer. This device is set on the top of a bridge pier. Inclination of the bridge pier is monitored by the clinometer, and when the inclination angle exceeds the threshold value, the order to suspend train operation is issued. This function is as same as that of current scour monitoring device. Furthermore, the new scour monitoring device forecast the future inclination using time series data and simple exponential growth model[1]. The added triaxial accelerometer measures the acceleration response of the bridge pier excited by train live load, microtremor, and earthquake, and soundness of the bridge pier is evaluated based on those acceleration responses.

3. FIELD TESTING

(1) Objectives of field testing

The new scour monitoring device evaluates the soundness of bridge pier using three kinds of vibration; train-induced vibration, microtremor during flood and earthquake. The specifications of the triaxial accelerometer are so designed to measure all kinds of vibration which have different characteristics, e.g., the train-induced vibration has strong higher frequency component, the amplitude of microtremor during flood is small, and so on. Therefore, it is necessary to confirm the applicability of the selected triaxial accelerometer through the long-term observation under various loadings. The evaluation method using acceleration response excited by train-live-load has been proposed by Suzuki et al[2]. In order to confirm reliability of this method, long-term observation is also necessary.

For these objectives, a field testing was carried out on actual railway bridge.

Fig.1 The view of bridge A
(Bridge A: Single-track bridge, Steel plate girder, Span 26.5m)

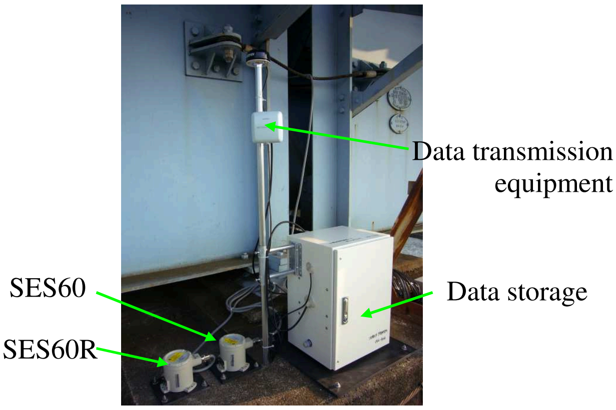


Fig.2 The experimental observation system

(2) Configurations of bridge

The field testing was carried out for three months on an actual railway bridge pier. The view of the bridge is shown in **Fig.1**. This bridge is single truck bridge over river and consists of truss girders, deck plate girders, concrete bridge piers and caisson foundations. The deck plate girders span between P3 to P21. The triaxial accelerometer is set on P4 of this bridge, and the acceleration responses excited by train live load are observed. The characteristics of the pier are shown in **Table 1**. The natural frequency of P4 was measured by impact vibration testing[3)] on December 20th, 2007.

(3) Experimental observation system

The experimental monitoring system is developed upon commercial seismometers; Yamatake SES60 and SES60R. The characteristics of the accelerometer embedded into the seismometers are shown in **Table 2**. SES60R is modification of SES60 with enhanced capability of higher acceleration measurement resolution. These two types of sensors, data transmission equipment, and a data storage are assembled and mounted on P4. The experimental observation system is shown in **Fig. 2**.

4. EVALUATION OF SOUNDNESS OF BRIDGE PIER BY TRAIN-INDUCED VIBRATION

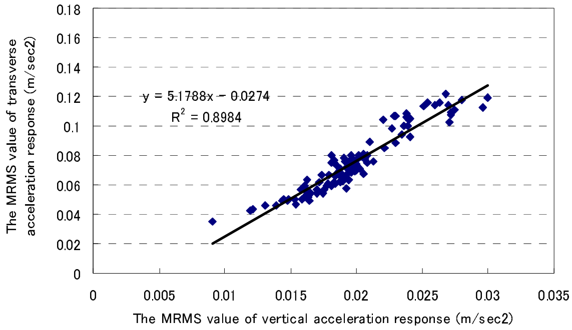
(1) Method for estimation of RMS-Index

In order to evaluate soundness of bridge pier by train-induced vibration, "root mean square (RMS)" is calculated by the time series of acceleration response. Although each RMS value scatters, there is the strong linear correlation between the vertical and transverse RMS values. As scour of bridge foundation developed, the gradient of linear regression line is expected to change[2)].

(2) Observations on actual bridge piers

The relation between the vertical and transverse RMS values observed on P4 of bridge A is shown in **Fig.3**. The observed strong linear correlation has similar tendency with the previous studies using reduced experimental model and other actual bridge piers[2)]. Throughout the field testing, two types of train passed on this pier. Each load is about 10t and 8t per an axle. As a result of more than three months observation, it is found that this correlation relationship is stable even with considerable the temperature fluctuation and the difference of train loads.

According to reference 2, it is proposed that the gradient of linear regression line is applied as the indicator for evaluation of soundness of bridge piers. In theory, the increase of the value of the gradient, i.e., larger relative transverse response, shows the increase of the risk of the scour hazard. To obtain the relationship between structural integrity and the value of the gradient of linear regression line, accumulation of statistical data including other piers with longer period is required.



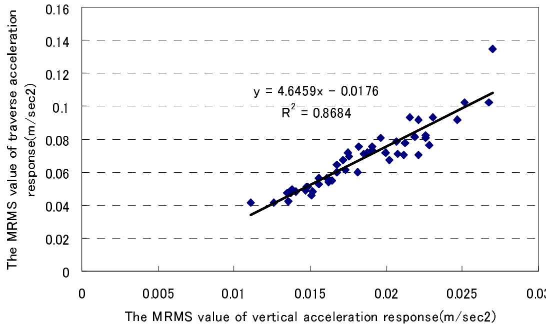


Fig.3 The relation between the vertical and transverse RMS values
(left: observed on October 27th, right: observed on November 20th)

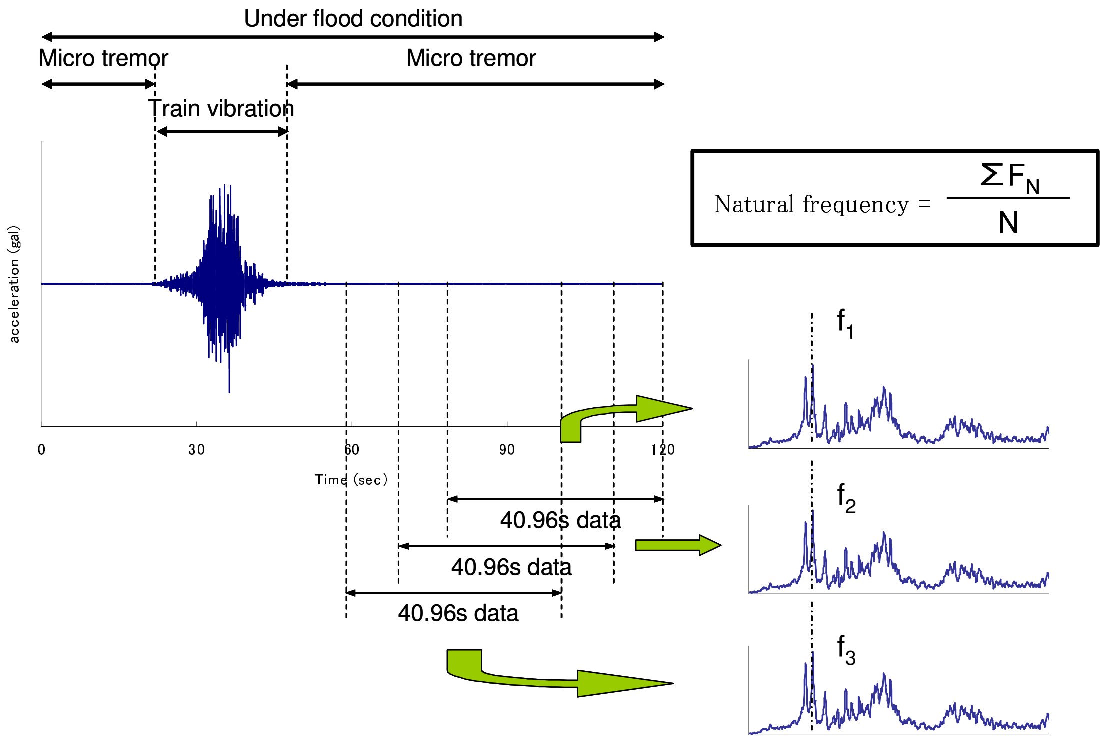


Fig.4 The calculational procedure of a natural frequency during flood

5. EVALUATION OF SOUNDNESS OF BRIDGE PIER BY FLOOD-INDUCED VIBRATION

(1) Method for calculation on natural frequency

In order to observe the symptom of scour damage, evaluation using a natural frequency of the bridge pier is popular in Japan[3], because the natural frequency generally decreases as scour develops. The technique for this evaluation is mainly carried out with percussion of heavy weight, such as steel ball weighting 30kg. Due to this heavy physical work, it is difficult to exercise this inspection during flood condition.

In order to develop a practical method to quantitatively and easily evaluate the structural integrity of bridge pier foundations during flood, Samizo et al. proposed method to calculate natural frequency of a bridge using microtremor observed during flood[4].

In the observation, a natural frequency was calculated by the method shown in **Fig.4**. The measurement time is 2 minutes. Since train-induced vibration is trigger to start measurement of microtremor, the first half of the data is under the influence of the strong train vibration. Thus the second half of the data is employed. The time history is split into 3 series of data which are shifted 10 seconds and that has 40.96 seconds data.

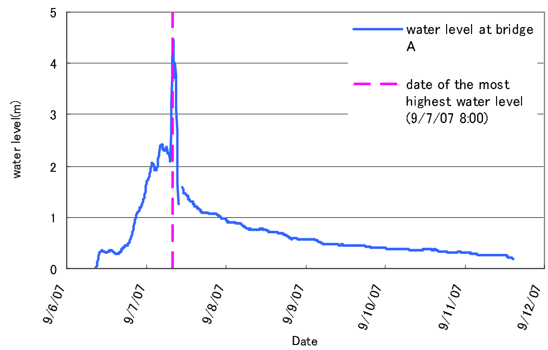


Fig.5 The time series of the water level at Bridge A

(2) Observation of the microtremor during flood

During the field testing, typhoon hit the area and the microtremor of P4 during flood could be observed. The water level began to rise at 9:00 a.m. on Sep. 6th, and reached maximum at 8:00 a.m. on Sep. 7th. The time series of the water level which is measured by water level gauge set at P4 is shown in **Fig.5**.

The frequency spectrum is calculated using microtremor obtained at 0:10 a.m. on Sep 6th when water level is about the same as usual (**Fig.6**). As of this time, no distinct peak appeared at the point of the natural frequency. The data obtained at the most highest water level is shown in **Fig.7**. It is clear that the spectrum peak largely similar to the natural frequency. Using this method, it is possible to

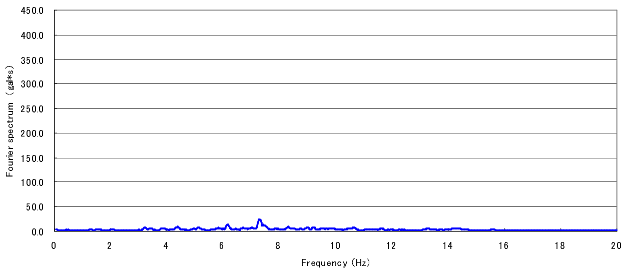


Fig.6 The result of the calculation of P4 at 0:10 a.m. on Sep 6th

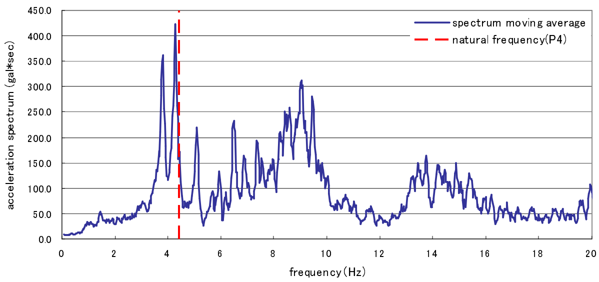


Fig.7 The result of the calculation of P4 at the most highest water level

evaluate the integrity of the pier by comparing the natural frequency before and after flood.

6. CONCLUSION

From this field testing, following results are obtained.

(a) The relation between the vertical and transverse RMS values are stable even with considerable the temperature fluctuation and the difference of train loads.

(b) Using the microtremor during flood, a natural frequency of a bridge pier can be obtained.

From these results, it is found that natural frequency obtained during flood can be used to support determination of resumption of train operation. Moreover, it is found that a symptom of a scour damage of a bridge pier foundation can be detected using RMS-Index or natural frequency calculated during flood before the bridge pier is inclined.

At present, prototype of the scour monitoring device is designed based on the results and further field testing of the prototype is planned to be carried out from this summer.

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