Development of Multifunction Scour Monitoring Device for Railway Bridge Piers Part1: Background and Concept

Osamu SUZUKI [1], Yosuke MASUI [2], Masato ABE [3], Masahiko SAMIZO [4], and Makoto SHIMAMURA[5]

[1]Member of JSCE, Assistant Manager, Disaster Prevention Research Laboratory, East Japan Railway Company
(2-479, Nisshin-cho, Kita-ku, Saitama-shi, Saitama-pref. 331-8513, Japan)
E-mail: osamu-suzuki@jreast.co.jp
[2]Member of JSCE, Researcher, Disaster Prevention Research Laboratory, East Japan Railway Company
(2-479, Nisshin-cho, Kita-ku, Saitama-shi, Saitama-pref. 331-8513, Japan)
E-mail: y-masui@jreast.co.jp
[3] Member of JSCE, Chief Researcher, BMC Corporation
(2-6, Nakase, Mihama-ku, Chiba-shi, Chiba-pref. 261-7125, Japan)
E-mail: masato@hashimori.jp
[4]Member of JSCE, Senior Researcher, Disaster Prevention Technology Division, Railway Technical Research Institute
(2-8-38, Hikari-cho, Kokubunji-shi, Tokyo-pref. 185-8540, Japan)
E-mail: samizo@rtri.or.jp
[5]Member of JSG and JSCE, Director, Disaster Prevention Research Laboratory, East Japan Railway Company
(2-479, Nisshin-cho, Kita-ku, Saitama-shi, Saitama-pref. 331-8513, Japan)
E-mail: m-shimamura@jreast.co.jp

In order to avoid fatal train accidents due to scour hazard, East Japan Railway Company set the train regulation rules based on monitoring of water level and inclination of bridge pier. There is room for improvement in current system, for example current scour monitoring device cannot directly detect the symptom of the scour of bridge foundation. In order to improve reliability of the rules, multifunction scour monitoring device is being developed. The functions of this device are monitoring of inclination of bridge pier, forecasting of inclination and evaluation of soundness of bridge pier using vibration induced by train live load or flood. The specification of this device and results of field testing are described in the companion paper. This paper describes the outlines of the scour monitoring device and discusses its functions and characteristics.

Key Words : *Scour monitoring device, railway bridge pier, inclination of bridge pier, vibration analysis*

1. INTRODUCTION

East Japan Railway Company (JR-East) is the one of seven railway companies that formed on the division and privatization of Japanese National Railways in 1987. JR- East maintains 7,527km track in the eastern part of Japan (Fig.1). In this area, there are approximately 2,500 bridges over water, and about 1/3 of these bridges are considered to be exposed to risk of scour hazard. In order to avoid fatal train accidents due to scour hazard, not only construction of protective facilities around the bridge pier foundations, but also enforcement of train suspension rule during higher risk of scour hazard are employed as hardware and software countermeasures.

2. THE TRAIN SUSPENSION RULE IN JR-EAST

JR-East set two different train suspension rules in order to avoid fatal train accidents due to scour hazard. One is based on water level monitoring. In the rule, scour depth is estimated by means of the empirical relationship among scour depth, water level and bridge pier width. When the estimated scour depth at the spread-footing base of the bridge pier reaches to certain threshold value, orders to suspend train operation are to be issued to the train operators. There are approximately 550 on-line water level gages on bridge pier and water level is measured individually on real time (Fig.2).

Another rule is based on observation of inclination of a bridge pier caused by scour around bridge pier. The rule based on water level monitoring is not reliable in some kind of site-situation, such as the bridge constructed over a flume with a river bed gradient of 0.1 (Fig.3). In this flume with steep river bed gradient, stream becomes super critical flow and water level hardly rises during flood. The rule based on observation of inclination of a bridge pier is applied to these bridges. A clinometric type scour monitoring device[1)] is placed on the top of bridge piers, and monitors the inclination angle in real time (Fig.4). The threshold angle for the train suspension is derived from geometric relationship between the inclination angle of the bridge pier and maintenance limits of track irregularity. When inclination angle of a bridge pier exceeds the threshold angle, this device gives an alarm to suspend train operation. Approximately 300 scour monitoring device are installed on bridge piers and monitor inclination of bridge pier in real time.

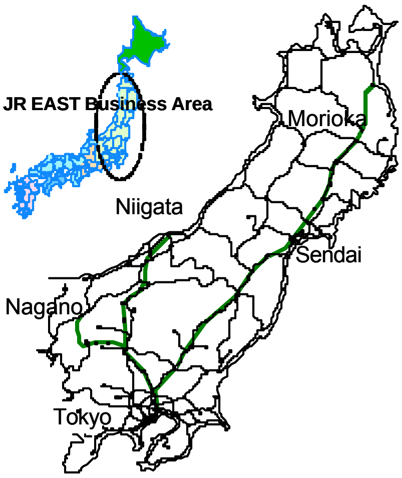

Fig.1 The network of JR East.

Fig.2 water gauge.

Fig.3 Site-situation of scour hazard occurred in 1995.

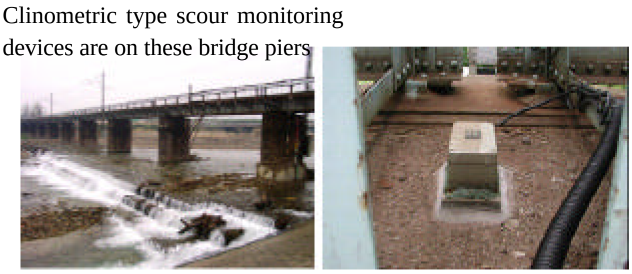

Fig.4 Clinometric type scour monitoring device.

3. PROBLEMS IN THE CURRENT TRAIN SUSPENSION RULES

These current train suspension rules have several problems, although accidents due to scour hazard have not occurred after installation of clinometric type scour monitoring device. Problems are as follows:

(a) There is a room to improve reliability of the train regulation rule based on water level monitoring. In the rule, the alarm is issued when the estimated scour depth exceeds the threshold value. To avoid train accidents caused by scour hazard, both the estimated scour depth and the threshold value are determined considering worst-case scenarios and are considerably conservative with unclear safety margin. Thus, for most of bridge piers, bridge pier foundation is sound even though estimated scour depth exceeds threshold value,

(b) Determination to resume train operation is difficult. Once the estimated scour depth exceeds threshold value and the order to stop train operation is issued, the detailed on-site inspection must be carried out before resumption of train operation. In most case, the visual inspection of the bridge pier foundation is very difficult because of high flow velocities and turbidity of flow, etc,

(c) The clinometric type scour monitoring device cannot issue an alarm before a bridge pier is inclined.

Even if inclination angle of a bridge pier is minute, reconstruction of the bridge pier requires long time period and high cost construction work accompanying suspension of train operation. In 1995, the bridge pier inclined and track distorted due to scour of the bridge foundation (Fig.3). In this case, train operation was suspended for 4 days until emergency reconstruction has been finished, and it took more than 1 year to fully reconstruct the inclined bridge pier.

4. CONCEPT OF NEW MULTIFUNCTION SCOUR MONITORING DEVICE

In order to solve these problems, new scour monitoring device is developed. The new scour monitoring device can evaluate soundness of bridge pier based on vibration analysis and realize unmanned frequent monitoring to detect symptom of scour damage of a bridge pier foundation. Moreover, the new scour monitoring device is added the function of the clinometric type scour monitoring device which issue the order to stop train operation when inclination of bridge pier is increased. The new scour monitoring device mainly contain of following three functions in addition to the function of the clinometric type scour monitoring device.

(1) Evaluation of the soundness of bridge pier by train-induced vibration

Soundness of bridge pier by train-induced vibration is evaluated by vibration measurement. Since train passes on the bridge frequently, train-induced vibration is applicable for unmanned and continuous monitoring for railway bridge piers. Suzuki et al[2)] investigated the relationship between bridge pier foundation condition and root mean square (RMS) value of acceleration responses of the bridge pier excited by train live load based on 2D analytical model, model experiment and field monitoring. From these results, it is confirmed that the RMS value is related to sediment loss at the foundation and the threshold value of the RMS can be determined as the upper and lower confidence intervals of the RMS values that is inferred statistically with the fluctuating data. This function can be used to detect symptom of the scour damage of the bridge pier foundation.

(2) Evaluation of the soundness of bridge pier by flood-induced vibration

Soundness of the bridge pier by flood-induced vibration is also evaluated during flood. In order to observe the symptom of scour damage, evaluation using the 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 based on impact vibration testing by percussion of heavy weight, such as steel ball weighting 30kg. Due to this heavy physical work, it is difficult to apply this inspection during flood. To solve this difficulty, Samizo et al[4)] measure oscillation of bridge pier during flood and develop a method to calculate natural frequency of a bridge pier using microtremor observed during flood. This function can be used to detect symptom of the scour damage of the bridge pier foundation. Moreover, it can be used to support determination of resumption of train operation after water level decreased below the threshold value.

(3) Forecast inclination of bridge pier

This function forecast inclination of bridge pier and issues the alarm before inclination of the bridge pier reaches to the threshold value currently in use. The current scour monitoring device monitors inclination of bridge pier in each specified time interval. Kobayashi et al[5)] focus on the time series of the inclination of the bridge pier and investigates the statistic model to forecast them. Through the experiments with reduced scale model, it is found that the time series of the inclination can be fitted and extrapolated by simple exponential growth model, which is robust against the influence of noise and there is less possibility of giving false alarms. This function also can be used to detect symptom of the scour damage of the bridge pier foundation.

5. PROPOSED RULE BASED ON THIS SCOUR MONITORING DEVICE

The proposed rule based on this scour monitoring device is discussed in this section. The outline of the proposed rule is shown in figure 5. The device is set on the top of bridge pier. This device monitors the acceleration response of the bridge pier and calculates RMS values during every train passing. When RMS value exceeds the threshold value, the alarm to indicate immediate detailed on-site inspection is issued. The detailed on-site inspection, such as the impact vibration testing, is carried out and soundness of the bridge pier is confirmed.

During flood, amplitude of microtremor increase as water level increase. Then this device starts to monitor the acceleration response of the bridge pier and calculate natural frequency in certain intervals. If

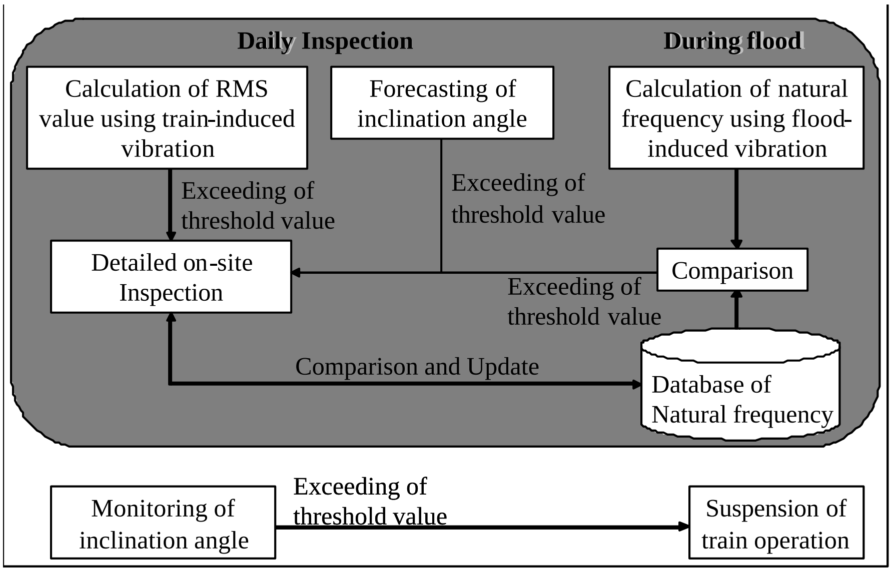

Fig.5 Outline of proposed rule based on new scour monitoring device.

the calculated natural frequency is within certain range, soundness of the bridge pier is confirmed.

The inclination of bridge pier is monitored in certain intervals and progress of inclination of the bridge pier is forecasted using time series of inclination and simple exponential growth model. The forecasting lead time is determined considering the distance from maintenance office to the bridge so that the staff can reach the bridge before inclination exceeds the regulation value. When the forecasted inclination of the bridge pier exceeds to the threshold value, an alarm is issued to indicate immediate detailed on-site inspection. If inclination of the bridge pier developed rapidly and it reaches to the threshold value, the order to stop train operation is issued.

6. CONCLUSION

The concept of new scour monitoring device is introduced in this article. In this article, the outline of the proposed scour monitoring device to solve the problem of the current scour monitoring device is described. At present, the specifications of new scour monitoring device are developed through field testing on actual railway bridge (Fig.6). The details and results of field testing are discussed in the companion paper, "Development of multifunction scour monitoring device part2: Result of field testing".

Fig.6 The field testing on actual railway bridge

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