第 I 部門 **Identification of soil stiffness of railway bridge pier from vibration monitoring and finite element update**

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1. Introduction

Bridge scour is the removal of sediment such as sand and gravel from around the bridge abutments or piers, which will leave behind scour holes. These holes have the effect of reducing the stiffness of foundation systems and can cause bridge piers to fail without warning. In the majority of cases, the scour occurred in the underwater part, and it is not easy to visually inspect the change of the soil condition around the pier. Therefore, vibration-base scour monitoring has been proposed to simply detect potential occurrence of the scour. This study aims to identify the change of soil stiffness utilizing identified frequency of the target pier through a vibration monitoring and do the Finite Element (FE) model update. If it is possible to timely know about the health condition of the soil part that around or below the pier after scouring occurred, it provides useful information for more efficient repairing and strengthening works.

2. Target railway bridge pier

The target railway bridge pier is shown in **Figure 1**, which supports a steel plate girder railway bridge with a span length of 22.5 m and an overall width of 9 m, designed for single railway track. The height of the pier is 11 m and width is 3 m. An impact test was conducted on the target pier in 2006 and natural frequency of the transverse rocking mode was identified as 9.0 Hz. A trial long-term monitoring had been conducted since November 2017, and an impact test was conducted again before the long-term monitoring. The mode shape for the rocking mode from the impact test in 2017 is shown in **Figure 2**.

3. Preliminary Finite element model

Eigenvalue analysis using the FE model of the target pier was conducted by utilizing the ABAQUS 2019 student version to investigate the dynamic characteristics of the target pier. The target pier is modeled with two-dimensional beam elements. As shown in **Figure 3**, three horizontal springs (k_{h1}, k_{h2} , k_{h3}) and one vertical spring (k_v) are considered in the model to respectively represent the translational soil interaction around the pier and the piles under the footing. Furthermore, a rotational spring is considered to simulate the rocking motion of the pier. All spring constants were decided utilizing N-values obtained from the standard penetration test that implemented in November 2015 (see **Figure 4**).

4. Model updating

The sensitivity analysis for the five springs is conducted to minimize the variables in the model updating. Based on the sensitivity analysis, it was observed that rotational spring is the most sensitive parameter in FE model update, while the other springs were negligible and rocking mode obtained considering updated spring stiffness is shown in **Figure 5**.

Figure 1 Photo of target pier

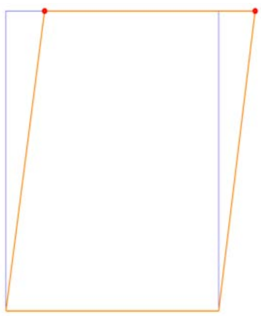

Figure 2 Mode shape for rocking mode of the pier (9.3Hz)

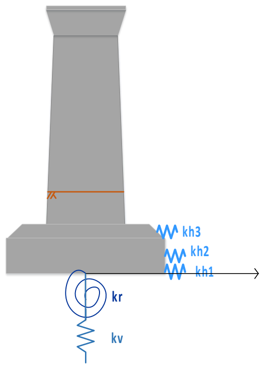

Figure 3 Location of springs

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Figure 6 shows comparison of the change in frequency for the rocking mode with respect to seven different conditions. It is obvious that the effect of the transverse springs on changes in the frequency for the rocking mode can be negligible compared with the influence of rotational spring. Hokkaido Railway Company reported similar conclusion which was derived in an investigation of damage caused by scouring occurred on the Atsubeitsu river bridge due to the typhoon No.10 generated on Aug. 3rd, 2002 [1].

In order to identify the change of soil stiffness due to decreasing frequency, the effect of decreasing frequency on the change of rotational spring will be discussed. Since there is no specific standard value for the frequency when scour occurred, this study uses the judgment of bridge soundness obtained from "Railway structures maintenance management standard and commentary" [2]. The soundness index κ is defined as monitored frequency divided by frequency of healthy condition. The frequency of 85% of the natural frequency in the healthy condition is adopted as a threshold of occurrence of scouring. In order to show the relationship between change of frequency with change of rotational spring stiffness, the stiffness change ratio k_s with index value k is summarized in **Table 1**. The stiffness change ratio k_s is defined as rotational spring stiffness corresponding to the monitored frequency divided by rotational spring stiffness corresponding to frequency of healthy condition.

5. Conclusion

The influence on the change in the frequency for the rocking mode is respectively small if only overburden layer is scoured, compare with the condition that soil under the footing part is also washed away. The judgment of bridge soundness related to a corresponding change of rotational spring stiffness is obtained when $0.681 < k_s \leqq 1.00$, there is a low possibility of the abnormal condition, and when $0.432 < k_s \leqq 0.681$, the progress of deterioration need to be checked and when $k_s \leqq 0.432$, repair and reinforcement are needed.

References

[1] Hasegawa and Konishi: Typhoon damage and corresponding measurement on Atsubetsu river bridge located on the JR Hidaka Main Line, Hokkaido Railway Company (2009). (in Japanese)

[2] Ministry of Land, Infrastructure, Transport and Tourism, Railway Bureau, (2007), Railway structures maintenance management standard and commentary (structural edition), 169-170. (in Japanese)

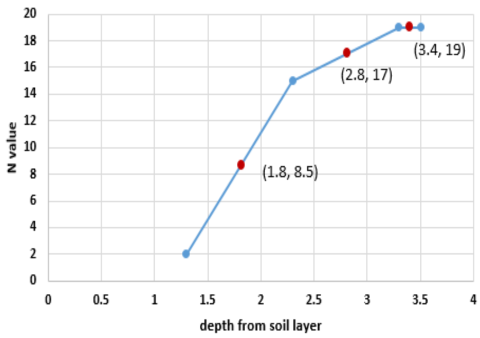

Figure 4 N value obtained from the standard penetration test

Figure 5 Final result obtained from model updating (9.3Hz)

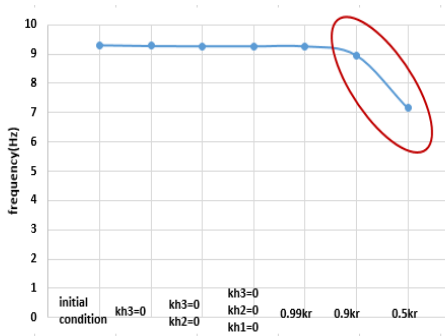

Figure 6 Seven different conditions with the corresponding frequency

Table 1 New judgment of bridge soundness with index value k [2] and stiffness change ratio k_s

Soundness index value k	Stiffness change ratio k_s	Rank	Treatment
$k \leqq 0.70$	$k_s \leqq 0.432$	A1	Abnormal condition: repair or reinforcement are needed
$0.70 < k \leqq 0.85$	$0.432 < k_s \leqq 0.681$	A2	Need to check progress of deterioration: e.g. decrease of frequency, etc.
$0.85 < k \leqq 1.00$	$0.681 < k_s \leqq 1.00$	B	Low possibility of abnormal condition
$1.00 < k$	$1.00 < k_s$	S	Healthy