第 I 部門　Feasibility of Utilizing Mahalanobis Distance of Modal Parameters as an Indicator for Long-term Bridge Monitoring

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1 Introduction

Maintaining civil infrastructure, including bridges, has been a keen technical issue in the field of civil engineering these years. Bridge health monitoring (BHM) focusing on the change in dynamic property of the bridge is widely recognized as an economical and effective technology that aids decision-making for bridge maintenance. This research focuses on long-term BHM expecting that changes in physical properties of the bridge subject to aged-deterioration progress slowly. In the practical application of long-term BHM, one of the difficulties is that the observed vibration data include environmental influences. In order to achieve high accuracy in identifying modal parameters of the bridge, variation in passing vehicles and temperature change, proved as the main environmental factors affecting the target bridge of this study[1)], were taken into consideration. The Mahalanobis distance (hereafter MD)[2)], a multivariate statistical distance, is adopted to emphasize potential changes in the identified modal parameters. The validity of the proposed approach is investigated utilizing vibration data measured at an in-service real bridge.

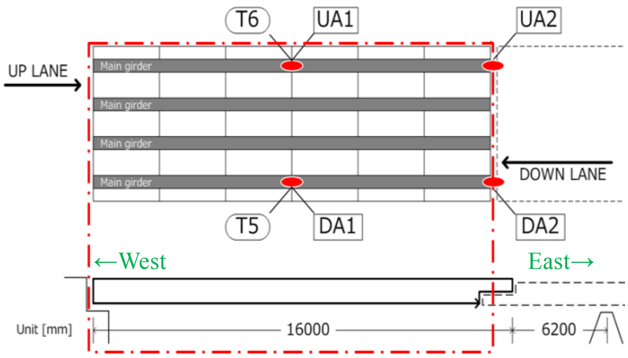

Figure 1 deploying map of sensors

2 Real bridge monitoring

The monitoring data used in this study was taken from four accelerometers (UA1, UA2, DA1 and DA2) and two thermometers (T5 and T6) deployed on the first span from the west abutment of a 55-year-old seven-span Gerber-plate bridge, as shown in **Figure 1**, from August 10, 2008 to July 13, 2014. According to the results of two recent visual inspections, one in 2008 and the other in 2013, clear increases in both number of cracks in the paint film and number of structural cracks were noticed. Besides those, the data of October 18, 2007, on the morning of which a traffic accident took place on the monitored span of the bridge, is used to test the sensitivity of MD.

3 Long-term bridge monitoring focusing on the Mahalanobis distance of modal parameter

Derivation of damage-detecting indicator With AR model, modal parameters including natural frequencies and damping constants can be identified from acceleration data with high accuracy[3)]. Apparently, the identified modal parameters contain environmental influences, of which variation in passing vehicles and temperature change are considered to be the most dominant factors. For convenience, influence of variation of passing vehicles was minimized by using data of only Sunday 7 a.m. whose traffic volume showed the smallest variation. The linear regression model, $mp = kT + C$ (mp and T stand for modal parameters and temperature respectively, and k and C are regression parameters), is adopted to eliminate temperature effect on modal parameters. Finally, with the modal

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parameters, MD is calculated with the following equation[4]:

$$MD = \left(\frac{1}{n}\right) \boldsymbol{X}^T \boldsymbol{C}^{-1} \boldsymbol{X} \tag{1}$$

where n, $\boldsymbol{X}$, and $\boldsymbol{C}$ represents number of modal parameter used in calculating MD, a sample, and the correlation matrix.

MD quantitatively shows the difference between current condition and intact condition. It is adopted as the indicator because it can integrate information of multiple variables, which are modal parameters in this study, and amplify the minimal changes into more noticeable one, which makes it easier for making decisions[2].

<u>*Application to long-term monitoring data*</u> With data of the first year, which are the closest to intact condition, as reference data, MD of three types (damping constants (MD(d)), frequencies (MD(f)), both frequencies and damping constants (MD(f&d))) are plotted, as shown in **Figure 2**, **Figure 3** and **Figure 4** respectively. Those MDs show changes over the years, albeit, it needs comprehensive investigations to discuss about the annual changes. **Figure 5** shows an example of the change in modal parameters in the monitoring period, which are much less than MDs.

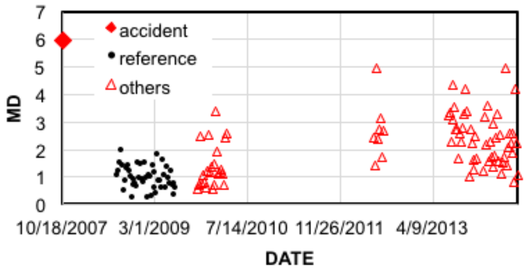

Figure 2 MD (d)

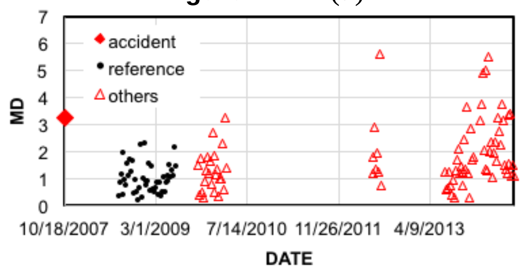

Figure 3 MD (f)

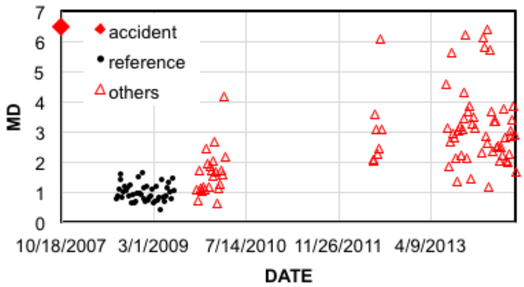

Figure 4 MD (f&d)

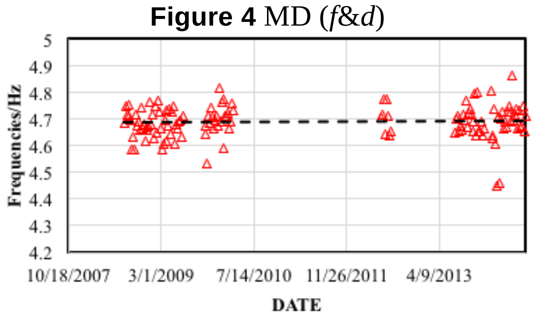

Figure 5 an example of modal parameters

4 Conclusions

This study investigates the validity of utilizing Mahalanobis distance (MD) of modal parameters as the damage-detecting indicator for long-term bridge monitoring. Conclusions drawn based on the results of this study are summarized as follows:

(1) All three MDs, such as damping constants (MD(d)), frequencies (MD(f)), both frequencies and damping constants (MD(f&d)), showed noticeable increasing tendencies through the six years of monitoring, which could support the possibility of change in health condition of the bridge;

(2) MD was useful for amplifying changes in modal parameters into more noticeable changes;

(3) MD calculated with both frequencies and damping constants seemed to have the best quality to be used as the indicator; and

(4) Based on current results, MD showed potential usefulness for damage detection, and thus is worthy of further investigations.

[References] 1) Heng, et.al., "One year monitoring of fridge Frequency and traffic load on a road bridge," in Proc. of 24th KKHTCNN Symp. on Civil Eng., 2011; 2) Taguchi and Jugulum, The Mahalanobis-Taguchi strategy: A pattern technology system, John Wiley & Sons, Inc., 2002; 3) Okabayashi, et.al., “High accurate estimation of structural vibration-frequency by ambient vibration with AR model,” J. of JSCE, No.759, I-67, pp. 271-282, 2003 (in Japanese); 4) Kim, et.al., "Structural fault detection of bridges based on linear system parameter and MTS method," J. of JSCE, Vol.1, No.1, pp. 32-43, 2013