Proceedings of the 11th World Congress on New Technologies (NewTech'25)
Paris, France - August, 2025
Paper No. ICCEIA 142
DOI: 10.11159/icceia25.142

Extraction of Vibration Characteristics of Bridges Using a Mobile Shaker

Akari Shimoda[1], Kouichi Takeya[1], Yuichi Ito[1], Eiichi Sasaki[1]
[1]Institute of Science Tokyo/Japan
2-12-1 Ookayama, Meguro-ku, Tokyo, Japan
shimoda.a.aa@m.titech.ac.jp; takeya.k.aa@m.titech.ac.jp
ito.y.ca@m.titech.ac.jp; sasaki.e.ab@m.titech.ac.jp

Abstract – For bridge inspection, non-destructive testing has proven effective in capturing changes in vibration characteristics such as natural frequencies and damping ratios. However, these vibration parameters are known to vary due to external factors beyond bridge deterioration. This study investigates the influence of various conditions on the natural frequencies and damping of a target bridge. Excitation tests were conducted under various conditions, including the use of a shaker mounted onto a moving vehicle. The resonance phenomenon between vehicle and bridge was analyzed to identify the natural frequencies of the target bridge. The proposed mobile shaker system has demonstrated potential for efficient and accurate vibration-based bridge monitoring.

Keywords**:** excitation test, natural frequency, damping, shaker, excitation level, temperature, moving vehicle

1. Introduction

Many bridges constructed during the period of rapid economic growth in the 1960s and 1970s have aged, while the shortage of skilled inspectors has become a serious issue for infrastructure maintenance. Vibration-based non-destructive testing methods are widely used on site to detect structural damage and deterioration. Dynamic bridge characteristics, including natural frequencies and damping ratios are estimated using several methods: ambient vibration measurements using microtremors [1], impact excitation [2], and forced vibration tests employing shakers [3].

Among these vibration tests, impact excitation tests are most commonly used in Japan for inspecting railway bridge piers. These approaches aim to assess changes in dynamic parameters including natural frequencies and damping ratios, which are known to be sensitive indicators of structural integrity. However, excitation tests on road bridges often necessitate at least partial traffic closures and are highly dependent on the inspectors' expertise. Moreover, it has been demonstrated that these parameters are influenced not only by structural damage and ageing, but also by external factors such as temperature and the level of applied excitation during testing [4].

In order to simplify testing, excitation tests using moving vehicles that pass over a bridge have been proposed. Yang et al. [5] theoretically presented a method for estimating the natural frequencies of bridges by analysing the frequency spectrum of vehicle acceleration responses. Yamamoto et al. [6] attempted to extract the natural frequencies of bridges using the axle acceleration response of a running train. However, this method has not yet provided sufficient accuracy in estimating natural frequencies for practical bridge monitoring, and experiments on actual bridges have been limited to specific bridge types. Further studies are therefore needed.

This study aimed to investigate the factors that cause changes in the natural frequencies and damping ratios of bridges, and both simplify and improve the accuracy of excitation-based vibration tests. To evaluate fluctuations in vibration characteristics and their influencing factors, excitation tests were carried out using different excitation methods, temperatures and excitation levels. More specifically, a moving vehicle equipped with a shaker was used to excite the target bridge, and acceleration measurements from the vehicle were analyzed to identify its natural frequencies. This approach aimed to streamline conventional shaker-based testing by integrating excitation and measurement in a single, mobile setup, enabling more efficient and accurate monitoring of bridge dynamics.

2. Methodology for Bridge Vibration Characterization under Varying Excitation Conditions

2.1. Target Bridge

The target bridge is a short-span concrete girder bridge with a length of 10 m. Fig.1 shows the bridge, and Fig. 2 provides a top view of the bridge layout, which is used in the subsequent analysis.

Fig. 1: Target bridge

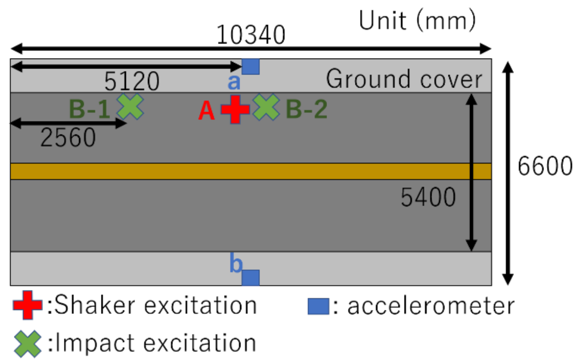


Fig. 2: Top view of the target bridge

2.2. Experiment condition

Three types of excitation tests were conducted: a shaker test, an impact excitation test, and a constant microtremor test.

Although the shaker test allows for controlled excitation, the shaker itself is heavy and makes in-service testing of bridges impossible. In this study, a shaker weighing about 70 kg was used. In the impact excitation test, the bridge was struck using a hammer weighing 4 kg and the natural frequency was obtained from the response. Although this method is simple, it is not possible to test bridges while they are in service and the test results also depend on the skill of the inspector. The constant microtremor test measures vibrations from different sources, including wind, ambient ground motion and traffic. The advantage of this test is that no special excitation is required, however the excitation force remains unknown.

Table 1 summarizes the objectives and excitation methods used in each experimental series. In the first experimental series, the objective was to compare three excitation methods: shaker excitation (at position A in Fig. 2), impact excitation (at position B-1 and B-2 in Fig. 2), and ambient vibration measurement using constant microtremors. Accelerometers were placed at positions a and b as shown in Fig. 2. The second series investigated amplitude dependency of vibration characteristics using the shaker placed at the same position as in the first series, with the excitation level was controlled over ten steps. The accelerometer was placed at position a in Fig. 2. The third test examined temperature dependency of vibration characteristics by measuring constant microtremors over an extended period using sensors at positions a and b in Fig. 2.

Table 1: The objectives and methods of the excitation tests

	Objective	Excitation methods
No. 1	Comparison of excitation methods	Shaker Impact excitation Constant microtremor
No. 2	Study of amplitude dependence	Shaker
No. 3	Study of temperature dependence	Constant microtremor (long time measurement)

2.4. Analysis method

Natural frequencies were identified using the peak of both the Power Spectral Density (PSD) and the Random Decrement (RD) method, whereas damping ratios were determined using the half power method and RD method.

The RD method reproduces a free-damping waveform by overlapping and averaging several responses over time and assumes that noise is random and has a mean of zero [7]. Curve fitting is then applied to the generated waveform to identify natural frequencies and damping ratios.

The half-power method identifies damping ratios using the frequencies where the power spectral density drops to $1/\sqrt{2}$ of its peak value. Since the target modes in this study were well-defined and the vibration data included random noise, such as constant microtremors, the half-power and RD methods were selected.

3. Influence of Excitation Conditions on Identified Vibration Characteristics

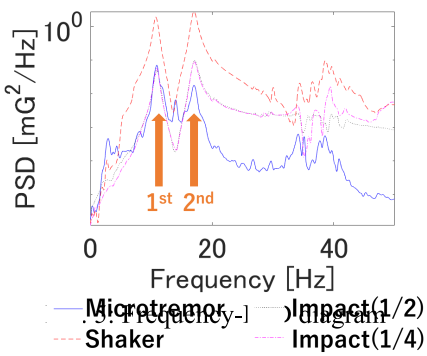
3.1. Different excitation methods

a) Excitation methods

The shaker test involved six 2-minute upward sweeps from 5 Hz to 60 Hz. In the impact excitation test, the bridge was struck 10 times at the center and at 1/4 of the span, where the data was analyzed by connecting the data obtained 10 seconds after each excitation. For the constant microtremor test, data collected over approximately one hour was analyzed. Fig.3 and Fig. 4 show the shaker test and the impact excitation test, respectively.

b) Results

From the frequency-PSD diagram for each test, as shown in Fig. 5, two dominant vibration modes were clearly identified;



the first bending mode at 10.7 Hz and the first torsional mode at 17.0 Hz. The following sections focus on these two dominant modes, as they were clearly and consistently observed across all test methods.

Fig. 6 and Fig. 7 show the identified natural frequencies and damping ratios for each test method, as well as the variation in identified natural frequencies and damping ratios across multiple tests. The peak PSD and half power method were used for analysis. In general, damping ratios exhibited greater variation than natural frequencies. However, as shown in Fig. 7, the variations in the identified natural frequencies and damping ratios were smaller for the shaker excitation test.

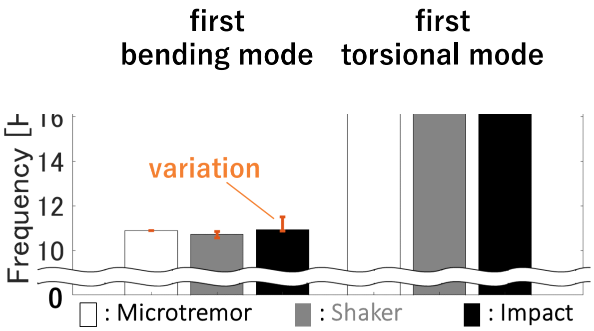


Fig. 6: Identified natural frequencies

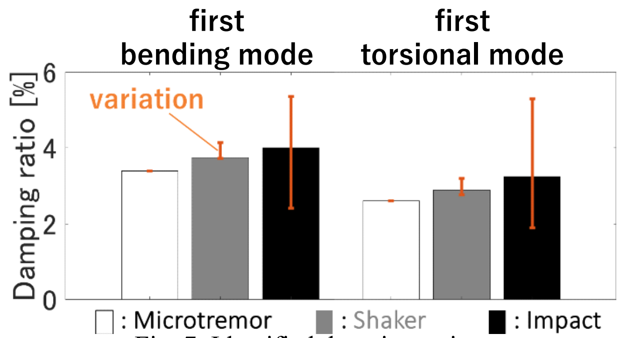


Fig. 7: Identified damping ratios

3.2. Different excitation levels

a) Excitation conditions

The shaker was set to perform an upward sweep from 5 Hz to 25 Hz in 30-second cycles, where 10 different excitation levels were applied.

b) Results

As shown in Fig. 8, the natural frequency of the first torsional mode decreased with increasing acceleration amplitude. However, Fig. 9, shows no clear correlation between the acceleration amplitude and the identified damping ratio. These observations, that frequency and damping do not exhibit the expected negative correlation under steady-state vibration, suggest that another factor is at play.

One possible explanation is that the bearing condition affected the results. At high excitation levels, slight movement in the bearings may have caused the natural frequency to fluctuate, whereas at low levels the bearings remained stationary.

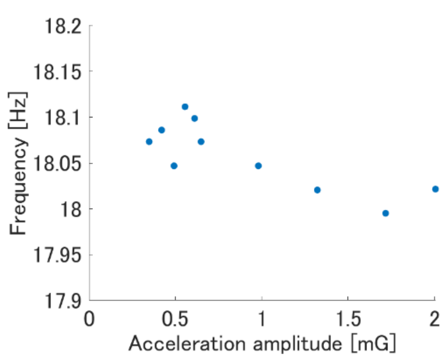


Fig. 8: Scatter diagram of acceleration vs. frequency

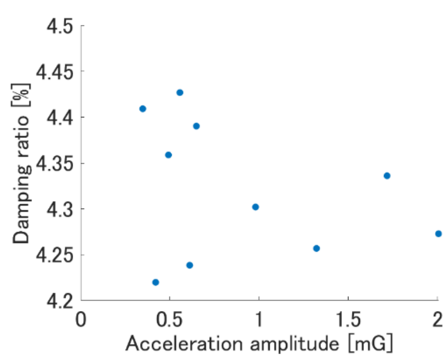


Fig. 9: Scatter diagram of acceleration vs. damping ratio

3.3. Different temperature conditions

a) Data conditions

A total of 59 data sets were used for each period during constant microtremor measurements, namely day (13:00 to 15:00) and night (1:00 to 3:00). The key difference between the two periods was in the acceleration amplitude where the night data ranged between approximately 0.02 mG and 0.04 mG, while the day data ranged between approximately 0.06 mG and 0.17 mG.

b) Results

As shown in Fig. 10 and Fig. 11, both identified natural frequencies and damping ratio values for the first torsional mode tend to decrease as temperature increases. The natural frequency of the first bending mode also showed a similar trend. This is likely because the physical property of the bridge material, namely concrete, is affected by temperature changes.

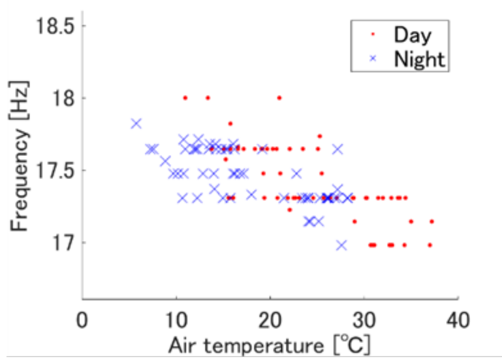


Fig. 10: Scatter diagram of temperature vs. frequency

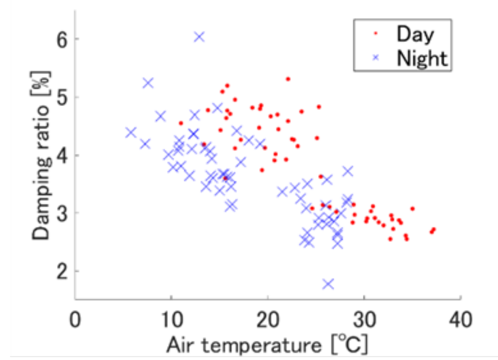


Fig. 11: Scatter diagram of temperature vs. damping ratio

3.4. Summary of excitation tests

The influence of various excitation conditions on bridge vibration characteristics has been examined, where the shaker test has proven most stable in identifying natural frequencies and damping ratios across all three tests. However, its practical application is limited due to various operational constraints. To overcome these limitations and increase the practical applicability of shaker-based testing, a simplified excitation method using a moving vehicle was further explored in this study and as follows.

4. Natural Frequency Identification Method Using a Moving Shaker Vehicle

4.1. Moving Vehicle Excitation Method

a) Overview of test method

A novel approach to monitor bridge vibration has been explored in this study, by mounting a shaker onto a moving dolly. This method aims to overcome the operational limitations of traditional shaker-based tests, offering a potentially simpler and more efficient solution for dynamic testing. While the shaker test provides high accuracy, its practical application is constrained by its complex setup. The proposed moving vehicle-based method seeks to streamline this process by combining excitation and measurements in one single mobile setup.

Firstly, the natural frequency of the dolly itself was evaluated to understand its vibration characteristics. Next, the shaker mounted on the moving dolly was used to excite the bridge while the dolly was in motion. By comparing the results with conventional stationary tests, the study evaluates the feasibility of this mobile method and proposes a new technique for identifying the natural frequencies of a target bridge during movement.

b) Vibration characteristics of moving vehicle

An excitation test was conducted on the dolly with the shaker mounted. As shown in Fig. 12, one accelerometer was placed on the shaker and six were attached to the dolly, near each of the four wheels and between the front and rear wheels. The natural frequencies of the dolly were estimated to be around 10 Hz and in the range of 16 Hz to 20 Hz, corresponding to different vibration modes of the dolly.

During preliminary analysis, it was found that sensors placed between the front and rear wheels were affected by bending deformation and thus provided unstable measurements. Therefore, sensors were confirmed by consistent phase difference and transfer function results from the wheel-mounted sensors.

Fig. 12: Excitation test of the dolly

4.2. Measurement conditions

Excitation was applied on the bridge via a moving the dolly. As shown in Fig. 13, the shaker was mounted on the dolly and accelerometers were attached to the dolly. For the moving measurements, ropes were tied to both ends of the dolly and pulled, allowing it to traverse the bridge from one end to another, as illustrated in Fig. 14 and Fig. 15. The dolly moved at approximately 0.5 m/s, and the shaker was set to adjust the excitation frequencies between 10 Hz and 12 Hz for the first bending mode and between 16 Hz and 18 Hz for the first torsional mode, using a sweep period of 1 second. For comparison, excitation was also performed with a stationary dolly at the center of the bridge.

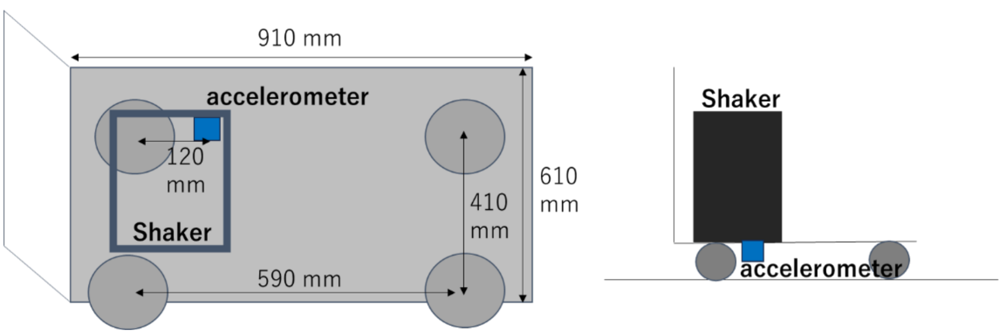


Fig. 13: Configuration of the dolly

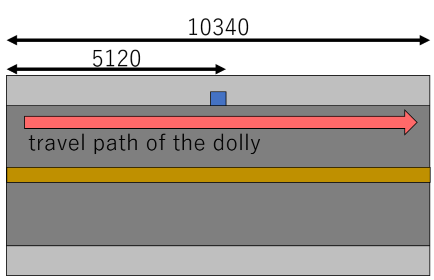
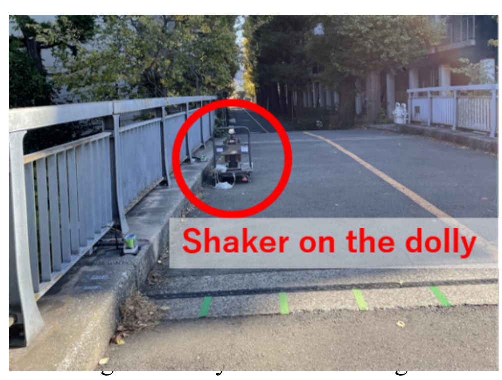


Fig. 14: Experimental location on the bridge



4.3. Proposed method to identify natural frequencies from moving vehicle

In the comparison test using the moving dolly, the natural frequencies of the bridge were evaluated under both stationary and moving conditions, as summarized in Table 2. The frequencies identified under stationary conditions were 11.5 Hz for the first bending mode and 17.7 Hz for the first torsional mode. Under moving conditions, the corresponding frequencies were identified as 11.6 Hz and 16.4 Hz, respectively. Accordingly, it was confirmed that natural frequencies can be identified with high accuracy even under moving conditions: less than 1% relative error for the first bending mode and approximately 7.3% for the first tortional mode compared to stationary measurements.

Since conventional FFT analysis is generally unsuitable for identifying natural frequencies during motion, a resonance-based method was adopted. As shown in Fig. 16, the moving average of acceleration data from the dolly was computed, and peaks corresponding to resonance between the dolly and the bridge were extracted. These peaks were then mapped onto the resulting scalograms obtained from the Continuous Wavelet Transform (CWT), enabling the identification of the natural frequencies of the bridge. The CWT-based analysis was performed separately for each of the four test runs, and the identified natural frequencies were then averaged to obtain the final values in Table 2. This method has confirmed that the natural frequencies of this bridge can be identified using a moving vehicle, where stable frequency identification was achieved through CWT analysis of the acceleration data from the dolly.

Table 2: Identified natural frequencies of the bridge

	Parking	Moving
first bending mode	11.5 Hz	11.6 Hz
first torsional mode	17.7 Hz	16.4 Hz

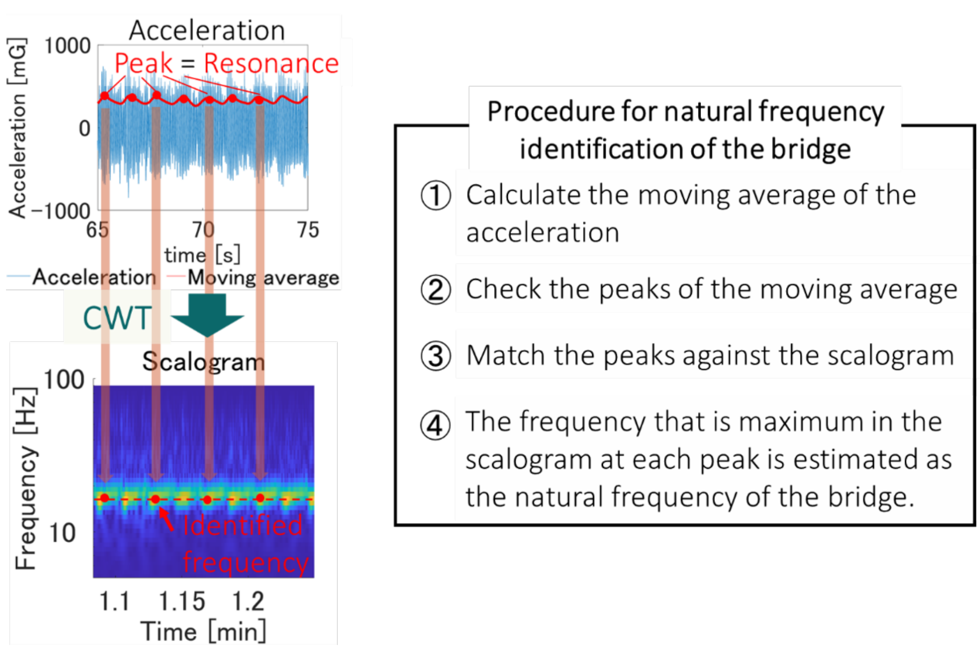


Fig. 16: Identification of natural frequency using CWT

4.4. Significance of the proposal method

This novel approach, using a shaker mounted on a moving dolly, offers a more practical and efficient bridge inspection method, by eliminating the need for fixed excitation systems and reducing operational constraints. The results indicate that despite the inherent challenges in dealing with moving measurements, analyzing the resonance between a (given) bridge and moving dolly using CWT can offer more accurate and stable identification of the natural frequencies of the given bridge. If further refined, this method could enable more accessible, cost-effective monitoring without requiring extensive infrastructure changes.

5. Conclusions

In this study, excitation measurements were conducted using different excitation methods, temperatures, and excitation levels to investigate the factors that affect bridge vibration characteristics and the applicability of a mobile shaker system.

1) Bridge natural frequencies and damping ratios were identified using multiple excitation tests. The results show greater variability in damping ratios compared to natural frequencies. However, the use of a shaker minimized fluctuations in the identified values, demonstrating its effectiveness in achieving stable vibration measurements.
2) It was found that natural frequencies decrease as the acceleration amplitude of bridge increases. This phenomenon was likely related to the movement conditions of the bridge bearings, which can shift under higher excitation levels. Moreover, both natural frequencies and damping ratios decreased with increasing temperature, which is likely due to temperature-dependent changes in the material properties of concrete.
3) A simple system for identifying the natural frequencies from a moving vehicle was examined, considering excitation methods and external disturbances. The results demonstrate the possibility of identifying the natural frequencies of a bridge from a moving vehicle, using the resonance found between the bridge and the moving vehicle with CWT. This method enables faster and more efficient structural health monitoring compared to conventional shaker-based tests, offering a flexible approach that does not require extensive modifications to infrastructure.

This study evaluated fluctuations in the vibration characteristics of bridges under varying excitation and environmental conditions. In addition, a new approach was proposed for identifying natural frequencies using a moving vehicle, offering a practical alternative to conventional excitation methods. The proposed method to identify the natural frequencies of a bridge using a moving vehicle offers significant advantages over conventional methods, paving the way for more accessible and cost-effective monitoring solutions. These findings are expected to contribute to advancing practical bridge inspection technologies as well as the development of more efficient infrastructure maintenance strategies.

References

[1] Ryuji TAKESHIMA, Reem AI SEHNAWI, Akinori NAKAJIMA, Susumu NAKAMURA, Hideaki YOKOKAWA: A Study on Change of Vibration Property of Bridge Structure with RC Pier in Different Vibration Level, Journal of Japan Society of Civil Engineers, Vol. 70, No.4, pp. I_130-I_139, 2014.

[2] Akihiko NISHIMURA, Satoshi NAKANO: "*Shōgeki shindō shiken ni yoru kōzōbutsu shindō tokusei no hakku*" [in Japanese], [Understanding the Vibration Characteristics of Structures through Impact Testing], Proceedings of the JSCE Earthquake Engineering Symposium, Vol. 19, pp. 481-484, 1987.

[3] Isao OKAUCHI, Toshio MIYATA, Masaaki TATSUMI Nobuyuki SASAKI: Field vibration test of a long-span cable stayed bridge by large exciters. Proceedings of Japan Society of Civil Engineers, No. 455, pp. 75–84, 1992.

[4] Masafumi KATO, Shizuo SHIMADA: Statistical Analysis on the Measured Bridge Vibration Data, Proceedings of Japan Society of Civil Engineers, No. 311, pp. 49-58, 1981.

[5] Yang, Y. B., Lin, C. W. and Yau, J. D.: Extracting Bridge Frequencies from the Dynamic Response of a Passing Vehicle, Journal of Sound and Vibration, No. 272, pp.471-493, 2004.

[6] Kodai MATSUOKA, Kiyoyuki KAITO, Munemasa TOKUNAGA, Tsutomu WATANABE and Masamichi SOGABE: Identification of the Vibration Properties of Bridge Using the Axle Acceleration Response of a Running Train, Journal of Japan Society of Civil Engineers, Ser. F4 (Construction and Management), 68(3), pp. 175-192, 2012.

[7] Yukio TAMURA, Atsushi SASAKI, Haruo TSUKAGOSHI: Evaluation of Damping Ratios of Randomly Excited Buildings Using the Random Decrement Technique, Journal of Structural Construction Engineering, AIJ, No.4544, Dec, 1993.