Assessment of a Real-life Concrete Bridge Structure using Vibration-based Damage Detection Method

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Abstract. Structural damage is usually presented in the form of decrease in stiffness resulting changes in the dynamic behavior of the structure, and natural frequency of the structure being one of the dynamic variables. A vibration-based damage detection method was employed to evaluate the structural health condition of a deteriorated bridge. The bridge has been closed for the traffic due to owing the extreme deteriorated health condition because of the immense existence of chloride ion in the airborne particles of the saline environment. This study presents, the comparison of natural frequencies of the year 2017 to that acquired in the year 2016 using vibration-based damage detection method. Even though the bridge was not exposed to the service load during the study period, yet, the results manifested decrement in natural frequencies revealing decline in structural stiffness in this period.

1. Introduction

Bridges are expected to have long service period among civil infrastructures. During this period, they are inevitable to suffer from different aspects such as Material aging, long term loading and environmental effects [1,2]. The recent catastrophic collops of the bridges confirmed lack in structural maintenance practices as it relates to bridges and, also highlighted the seriousness of the problem [3]. The importance of the bridge structures comes from the fact that they are one of the vital section of transportation infrastructure [4] which do not only affect economic, social and other various undertaking of a country but also have a huge an impact on safety of the people and their properties. Structural health monitoring systems have been widely utilized on engineering structures, especially bridge structures [5] Furthermore, corrosion of concrete reinforcement members has been acknowledged as one of the predominant deterioration mechanisms for steel reinforced concrete structures, whereas, reinforced concrete structures constitute the majority of civil infrastructures of the world. Therefore, SHM for concrete structure has attracted a lot of attention. A wide variety of techniques have been reported in the literature that may be suitably employed for non-destructive evaluation and detection of damage.

In this study, Vibration-based damage detection method is employed to evaluate structural health condition of a four-span reinforced concrete T-beam bridge located on a small river on the seaside in Nago city, Okinawa Prefecture, Japan, as shown in figure 1. The bridge was constructed and opened for the traffic 58 years back in the year 1962, and looking to be sound outwardly, has suffered severe deterioration underneath due to exposure to the aggressive environment in form of large salt mass accumulation at the bottom extent of the bridge girders. As mentioned, corrosion of embed steel is one
of the main causes of deterioration. In this case, most of the reinforcement bars are exposed and corroded by chemical attack due to existence of large-scale cracks in concrete as seen in figure 2, and the main cause of deterioration is the existence of chloride ion in the immense saline environment. Taking its critical health condition into consideration, the bridge has been out of service in the past few years. However; evaluation results show the structure being still in the state of deterioration. Most of the time, environmental factors and lake in structural maintenance over time are considered to be the main causes of deterioration by mean of influencing load bearing capacity and durability of an engineering structure. The aggressive environment was able to deteriorate concrete and steel, since steel is very susceptible to the saline environment and the airborne particles were able to reach the reinforcement bars that resulted in corrosion of steel bars. This deterioration of concrete and corrosion of reinforcement bars could decrease load bearing capacity, bending stiffness and other factors of the bridges. For this purpose, VBDD assessment was conducted to illustrate the variation occurred in the structural dynamic behavior which usually leads to increase in flexibility and decrease in modal parameters notably in the natural frequency of a structure. Natural frequency is one of the widely used diagnostic tool for damage detection of a structure, which can be easily obtained and identified from modal tests with satisfactory level of accuracy [6].

2. Experimental program

2.1. Outline of the bridge
The study was performed using one of the oldest T-beam concrete bridge in the area which was constructed on a small river near the seaside in 1962. The bridge consists of four equal spans of 9.25 m x 6 m with the total length of 37 m. The schematic of the bridge illustrating sectional dimensions is shown in figure 3.
2.2 Experimental setup
To demonstrate the concept of an integrated damage detection system, vibration-based damage detection method is set up to evaluate the target bridge as shown in figure 4. The bridge is assessed several times during the period of few years. The aim of this evaluation is to compare the result of the year 2017 with that obtained in 2016. A drop-load excitation vibration method is performed to present the perturbation occurred in natural frequencies of the bridge in the period of one year.

2.3 Data acquisition
For measuring acceleration response, AR-10TF-type transducer of TOKYO SOKKI, which can measure acceleration in three directions up to 10g with a frequency range of DC-180Hz is placed on the top-mid surface of monitored span and is connected to a personal computer through EDX-11 (Kyowa) using DCS-100A software. The free vibration response (time domain waveform) is obtained from each span within the period of ten seconds by dropping a mass of 30kg from 70cm height on the middle of the span next to the accelerometer shown in figure 5. These time domain waveforms are transformed into frequency domain waveforms by Fast Fourier Transform (FFT) using DAS-200A data analyzing software. FFT is the fast-computational algorithm for Discrete Fourier Transfer (DFT) and the basic concept underlying the FFT has to do with taking an array of time-domain waveform samples and processing them to produce a new array of frequency spectrum domain samples. Frequency peaks in the resulting frequency spectrum are used to evaluate the integrity of structural components because the integrity of structural members affects their cross-sectional vibration modes and the corresponding natural frequencies [7].

2.4 Evaluation procedure
To record the vertical acceleration response of the bridge, the assessment procedure starts from span A to span D accordingly as shown in figure 6. The sensor is placed in the center of each span and a sandbag of 30 kg mass is hanged and released perpendicularly on the span to generate free vibration waves.

![Figure 4. Data acquisition system.](image1)

![Figure 5. Method setup and bridge assessment.](image2)

![Figure 6. Accelerometer and load dropping positions at the time of bridge evaluation.](image3)
3. Results

3.1 Results of the year 2016
The evaluation was carried out in 2016 for acquiring the vibration from each span separately A, B, C and D respectively and, the results are presented in the form of time domain and frequency spectrum graphs as shown in figure 7. Legends X, Y and Z present acceleration in three directions with Z being vertical component of acceleration which illustrates the health condition of the structure. Time domain waveforms and natural frequencies of the assessed spans are presented illustrating the health condition of the referred spans. The frequency peaks are used to demonstrate the integrity of the structural components.

Figure 7. Time history and frequency domain of the bridge.
3.2 Results of the year 2017

Graphs in figure 8 show the vibration response of each span after a period of one year in 2017. The data obtained from the bridge was compared with that acquired in 2016. Decrease in frequencies confirmed decrease in serviceability of structural members of the bridge.

![Graphs showing vibration response](image)

**Figure 8.** Time history and frequency domain of the bridge.
4. Discussion
The overall results showed degradation in natural frequencies leading to decrement in stiffness of the structure corresponding to the deterioration experienced by the structure throughout the period of one year. The reason of increase in flexibility is the existence of cracks which gradually lengthened and widened till the airborne particles reached reinforcement bars. Each span of the bridge is evaluated in the year 2016 and compared with that for 2017 to study variations in natural frequencies. The natural frequency of the bridge structure at spans A, B, C and D changed from 33.3Hz, 35.5Hz, 36Hz and 36.4Hz in year 2016 to 32.7Hz, 35.1Hz, 35.1Hz and 35.6Hz in 2017 respectively, as shown in figure 9. Among all the spans, the highest decrement observed at span C (0.9 Hz). The average natural frequency of the structure obtained in the year 2016 to be 35.3Hz, which reduced to 34.625Hz in 2017 presenting the descendant trend of the natural frequency of the bridge structure is shown in figure 10.

5. Conclusion
Vibration characteristics of a reinforced concrete bridge were monitored using potable vibration measurement system with a load drop impact excitation. The changes in natural frequencies of the bridge structure during the period of one years were adopted to illustrate the health condition of the bridge. The bridge even being out of service during the study period manifested decrement in structural stiffness in the form of changes in natural frequencies detected by the vibration based non-destructive testing method, rooting from severely saline environment. The proposed method was found to be sufficient as well as convenient for structural damage detection in terms of using dynamic characteristics as a diagnostic tool.

6. References
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