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機械学習とスパース推定法を利用した地震応答モニタリング記録からの橋梁のリアルタイム損傷検知

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橋梁 地震応答モニタリング 損傷検知
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1. Introduction

This study describes implementation of techniques for detecting bearing malfunction in a multi-span continuous bridge using time-varying identifications of the seismic records. The techniques include wavelet analysis, sparse representation, and machine learning techniques for real-time detecting bearing malfunction in a multi-span continuous girder bridge. The method is implemented to the seismic records of a multi-span continuous girder isolated bridge obtained from long-term monitoring system of Shin-Nakagawa and Katsuta Bridge.

2. Methodology

In this study Continuous Wavelet transform (CWT) is utilized to detect shifts in the vibration frequency of the recorded seismic accelerations of the structure by extracting the instantaneous frequency from wavelet ridges. This is based on the premise that seismic isolation behavior in normal or expected condition and in abnormal or unexpected condition under earthquake excitation would produce a distinct pattern of structural stiffness and change of the fundamental frequency. Discrete Wavelet Transform (DWT) is utilized to detect the irregularities in the high frequency response of the structure by investigating the detail functions (Di). Sparse Computation and wavelet are implemented to decompose the signal in discrete wavelet transform. Machine Learning technique is employed for Classification and Regression of the Detail component (Di). Details on the methodology is described in Fig. 1. Numerical simulation was conducted to investigate and verify the proposed method using multi-degree-of-freedom bridge model. The isolation bearings were model with bilinear hysteretic mode and bearing malfunction (locking of the transverse side stopper) is modeled as the sudden increase in the initial stiffness of the bearing. From wavelet time-frequency map and Instantaneous Frequency (Fig 2) we can identify conditions where the pier cap having malfunction bearing (locked) and the pier cap having functioning (movable) bearing. The girder response is characterized by low frequency component indicating the effect of softening by isolator. For a functioning (movable) bearing there is a frequency shift to higher frequency of the pier responses compared to the girder response as shown in Fig.2.b. Meanwhile frequency characteristics of the pier supporting the malfunction (locked) bearing is dominated by the frequency like that of the girder Fig.2.c.. This suggests that at the locked bearing the pier and girder move in the similar manner. Using DWT, the time of yielding process of bilinear system is traced from the associated signal discontinuity as shown in Fig. 3. Thus, we can classify the unlocked and locked piers based on the details component (D1) obtained from discrete wavelet transformation.

3. Implementation on Katsuta Bridge

The methodology was applied to Katsuta viaduct, a continuous multi-span girder bridge that was monitored by wireless sensor network using 20 accelerometers. The viaduct is located next to Shin-Nakagawa Cable Stayed Bridge and about 30 earthquake events were successfully recorded between 2018-2020 [2] (Fig.4).

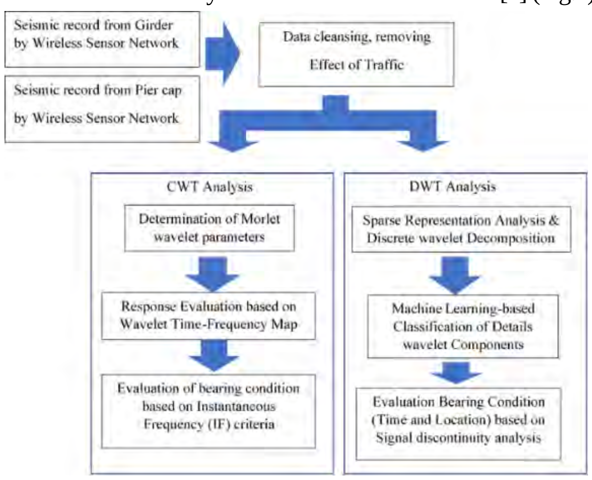

Fig.1. Methodology for Detection of bearing malfunction using CWT & DWT Analysis [1]

Two largest earthquakes March 30, 2018 and July 17, 2018 are used as examples of application. From accelerations of the girder and

Real-Time Structural Damage Evaluation of Bridges from Seismic Monitoring Records Using Machine Learning and Sparse Representation

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piers, the wavelet map was derived using procedure described in Fig.1. Fig. 5 and 6 show examples of result of analysis from March 30, 2018 earthquake and July 17, 2018 earthquake, respectively. The from wavelet time-frequency map of acceleration responses from the girder and pier cap were analyzed to identify the bearing condition during the earthquakes.

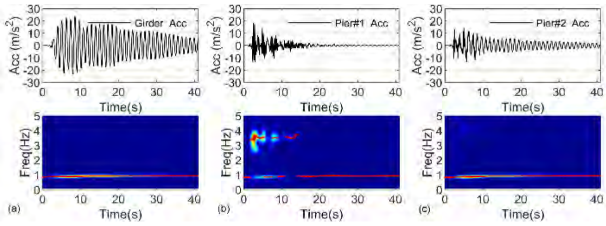

Fig.2.CWT time-frequency map and Instantaneous Frequency (IF) of acceleration responses from (a) continuous girder, (b) pier with movable bearing (c) pier with locked isolator bearing.

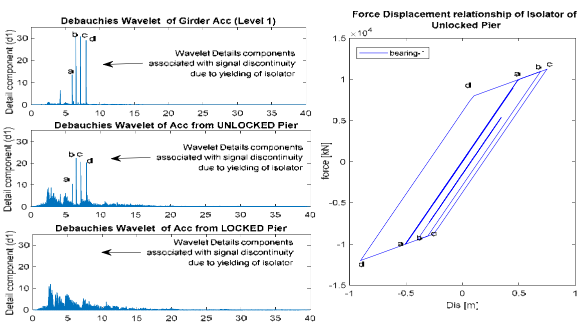

Fig.3. Example of simulation using discrete wavelet transform to detect the signal discontinuity associated with yielding of bilinear isolator system.

The objective is to determine whether the frequency shift of the pier response occur or not. Occurrence of frequency shift indicate that the pier cap has functioning (movable) bearing.　The figure clearly shows that for both earthquakes, the isolator bearing on pier 38 and 41 have functioned properly (movable) [1]. The results demonstrate that in a moveable bearing, the pier and girder response during the time interval of peak excitation were dominated by their own respective frequency suggesting they are uncoupled system. In this condition, the piers are isolated from the girder and the high frequency content of the pier is not transferred to the girder, which is expected from a functioning isolator bearing.

Additionally, abrupt change in D1 were associated with the time locations at the onset of both yielding and unloading. This information can be utilized to indicate condition of the isolator bearing. The premise is that at the time when a functioning elastomeric isolator bearing enters nonlinear stage during large excitation, abrupt change in the details D1 could be detected. On contrary, the yielding mechanism will not be initiated when the bearing is locked, and as a result there would not be any abrupt change in the detail components of DWT decomposition of the acceleration signal.

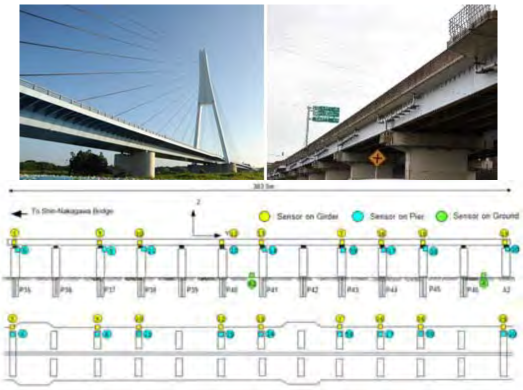

Fig. 4. Shin-Nakagawa (top left) & Katsuta Bridge(top right), Wireless monitoring system of Shin-Nakagawa and Katsuta Viaduct (bottom).

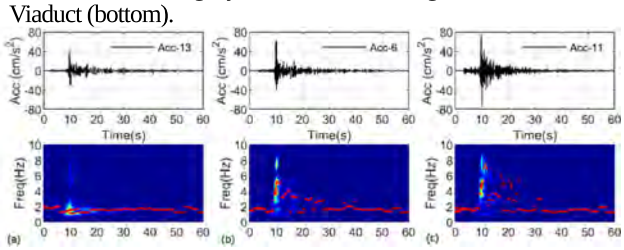

Fig. 5. CWT& IF results March 30, 2018 EQ. (a) girder (low frequency dominant), (b),(c) Piers (high frequency shift (4~6 Hz).

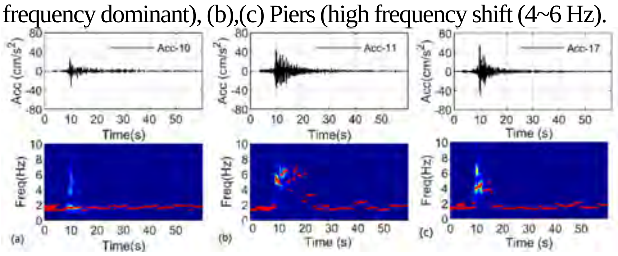

Fig. 6. CWT& IF results July 17, 2018 EQ. (a) girder (low frequency dominant), (b),(c) Piers (high frequency shift (4~6 Hz).

4. Conclusion

In this research information from both continuous wavelet and discrete wavelet transform with learning process were used to evaluate bearing condition directly from the recorded response, once earthquake occurs and signal is received without performing detailed structural analysis of the bridge.

References:

[1]. Siringoringo DM, Fujino Y. Application of Wavelet-Based Analysis for Detection of Isolation Bearing Malfunction in Multi-span Continuous Girder Bridge (in preparation for submission to SCHM 2020)

[2]. Siringoringo DM, Fujino Y, Mehta V, Suzuki M, Continuous Seismic Monitoring of Seismically Isolated Bridge by Wireless Sensor Network, 17WCEE, Sendai, Japan 2021.

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