CHANGE OF PHASE SPACE TOPOLOGY DUE TO TENDON DAMAGES OF A PRESTRESSED CONCRETE GIRDER

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1. INTRODUCTION

Nowadays, several prestressed concrete bridges have been deteriorated and the damage should be detected before it reaches a critical level. However, there are difficulties in detection of PC tendon damages because they are located inside a structure and do not much effect on modal parameters. Therefore, this paper presents an alternative method to detect the damage of PC tendon based on a change of phase space topology. Tendon damages are simulated by artificial cut in experiment and their results at each cutting event are compared.

2. DAMAGE DETECTION METHOD BASED ON PHASE SPACE TOPOLOGY

2.1 Phase space reconstruction

Phase space analysis is a novel approach for damage detection. The method alters measurement data of a time series into a spatial domain, where all possible state of a system can be represented. The reconstruction of phase space is based on delay coordinate and embedding dimension. The corresponding phase space $\mathbf{x}(n)$ of the measurement of a time series $x(n)$, $n = 1, \ldots, N$ can be reconstructed as (Taken 1981)

$$\boldsymbol{x}(n) = [x(n), x(n+T), \ldots, x(n+(d-1)T)\,], \tag{1}$$

where T is the delay time determined from the first minimum of Average Mutual Information and d is the embedding dimension determined from the lowest value of False Nearest Neighbors (Jiang et al. 2010, Rhodes & Morari 1997).

2.2 Change of Phase Space Topology (CPST) as a damage index

Since changes of a system result in changes in phase space topology, Nie et al. (2013) proposed the CPST index and used it to detect damages of reinforce concrete slab. They found that the CPST index was very effective in identifying the existence of damages in structure because its value increased with damage levels regardless of damage location.

Calculation of CPST, as shown in Fig. 1, starts with the selection of fiducial point on the damage state $\boldsymbol{y}(n)$ at time index r as $\boldsymbol{y}(r)$. The nearest p neighbors $\boldsymbol{x}(p_j)$ of the fiducial point $\boldsymbol{y}(r)$, mapped on to the reference state $\boldsymbol{x}(n)$, will be determined by the nearest distance. The future value at the next s-time step, $\boldsymbol{y}(r+s)$, of the damage state can be predicted as $\hat{\boldsymbol{y}}(r+s)$, by an average of the evolved nearest p neighbors, $\boldsymbol{x}(p_j+s)$. Finally the CPST index can be determined as follow:

$$CPST = \frac{1}{p}\|\hat{\boldsymbol{y}}(r+s) - \boldsymbol{y}(r+s)\|\,, \tag{2}$$

3. EXPERIMENTAL PROGRAM

The specimen of this experiment is a pretension concrete girder taken from and existing PC bridge in Kyushu area. The PC girder is simply support with a span length of 8.5 m with I-shape cross-section as shown in Fig. 2. The PC tendons have nominal diameter 10.8 mm. Four point bending test was performed on the PC girder with two levels of loading. Three accelerometers KIONIX (KXR94-2050) were attached at the bottom surface of PC girder; CH01, CH02, and CH03, measuring only vertical vibrations with a sampling rate of 1 kHz.

Damages were simulated by cutting the PC tendons. Concrete parts covering on the damaged PC tendons were assumed to be simultaneously deteriorated and were removed as shown by dash line in Fig. 2c. PC tendons at the bottom part were cut in sequence as shown by the blue arrows in Fig. 2b. At each state of damage, free vibration testing and impact hammer testing were performed. Free vibration testing was conducted by hanging and releasing a mass of 50 kg at the middle of girder while impact hammer testing was conducted by using impact hammer type PCB086C03 hitting at target locations. An example hitting target location is shown in Fig. 2a.

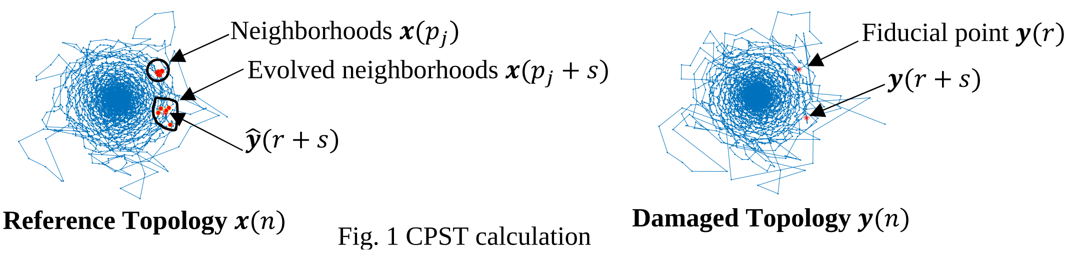

Fig. 1 CPST calculation

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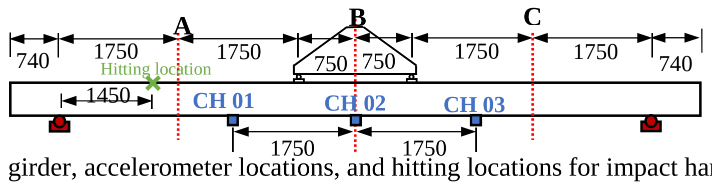
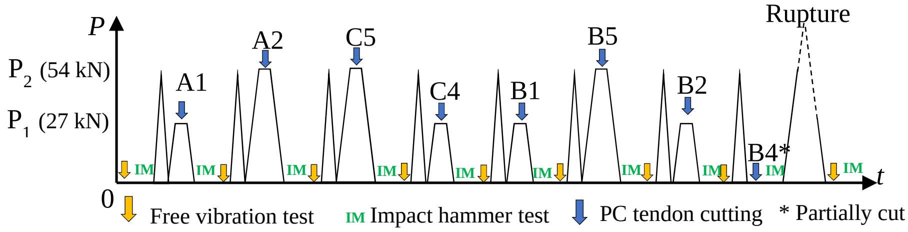
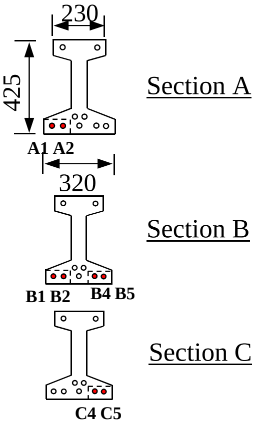


(a) PC girder, accelerometer locations, and hitting locations for impact hammer

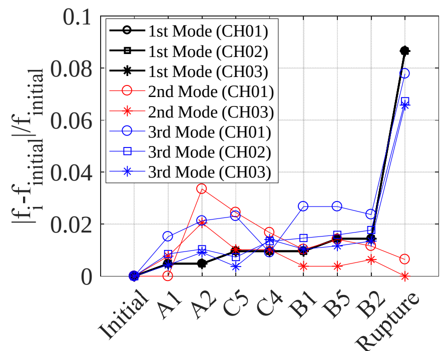


(b) Sequence of loading, PC tendon cutting, and vibration test.

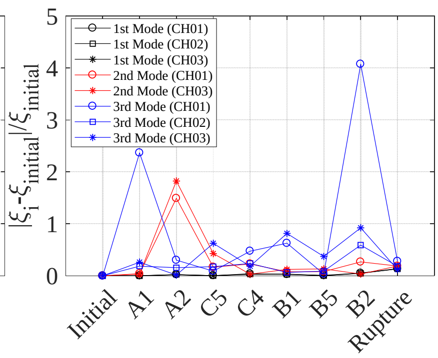


(c) Cutting location

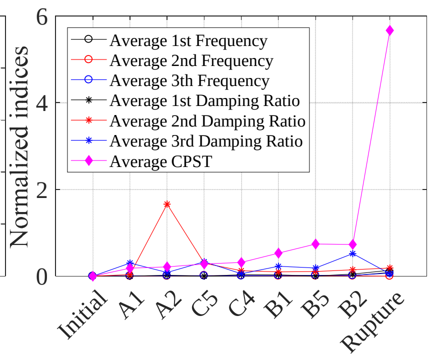
Fig. 2 Experimental plan



(a) Natural frequency



(b) Damping Ratio



(c) CPST, Natural frequency, and Damping Ratio

Fig. 3 Normalized indices at each event

4. RESULTS AND DISCUSSION

In this section, measured acceleration data from free vibration testing is considered. Fast Fourier Transform and Half Power Method are adopted to determine natural frequency and damping ratio, respectively. Fig.3a illustrates that 1st and 3rd mode of natural frequency gradually change during the PC tendon cut and dramatically change when the PC girder ruptures. The 2nd mode of natural frequency has been changed during the cutting event but such change could not be found at the rupture. This is because severe damage of the PC girder located at the middle span which is the node of the 2nd mode. Fig. 3b shows that damping ratio of the first three modes oscillate and there is no relation with the damage of PC girder.

Phase space topology of each event was reconstructed from delay time T=20 and dimension d=20. CPST was calculated from 5 nearest neighbor points with 5 s-time step. The CPST value gradually increase during each cutting event and suddenly increase when the PC girder ruptures. Each index is normalized with its initial event and is compared with each other as shown in Fig. 3c. It is obvious that the CPST is more sensitive indicator than frequency and damping ratio which implies that CPST might be an effective index to detect the damages of PC tendon. Noted that results of impact hammer test are also investigated but because there is a large percentage of false nearest neighbor in phase space reconstruction due to the less impact force causing the short duration of data, further investigation is needed.

5. CONCLUSION

Phase space analysis is adopted to solve the problem of tendon damage detection in prestressed concrete girder. The index called Change of Phase Space Topology (CPST) shows its sensitivity on the damages than the measuring of modal parameters which implies that CPST might be an effective index to measure such damages.

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