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Crack detection of Underwater Concrete Beams Using Ultrasonic Surface Waves

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ABSTRACT

Health monitoring of underwater structures such as dams, bridge piers, and offshore structures is a complex process. This paper reports the effect of water pressure to the sensors and propagation of signal wave used for structural health monitoring. Normal plain concrete beams were casted with different notch sizes to simulate the cracks in the specimens. Surface (Rayleigh) waves were transmitted and received using gel-coupled piezoceramic sensor (GCP). Discrete wavelet transform is adopted to decompose the wave signal into several levels with multiple frequency bands. The frequencies of the decomposed levels were classified into low, medium, and high frequency bands. Root mean square deviation damage index (RMSD-DI) was selected to analyse the wave data. The results showed that ultrasonic waves are affected by the water pressure and improves the signal power. Finally, the medium frequency band was found more sensitive to the crack than other categories.

1. INTRODUCTION

Ultrasonic wave monitoring for structures submerged with water has some challenges represented by the difficulty of detection cracks filled with water (Xinjiang and Tangdai 1998) and the need for special sensor coupling (Na et al. 2002) resist the influence of water on the work of this sensor. It was shown that guided waves can be used to investigate the interface separation in concrete filled steel tube (CFST) columns under water where a water coupling transducer was used for this purpose (Na et al. 2002). Experimental test for PVC pipes was conducted under water using cylindrical Lamb waves to investigate the wave sensitivity for three degree of damage built artificially (Woo and Na 2011). It was found in that study that amplitude is more sensitive to damage than time.

The aim of damage index (DI) is to describe the damage in quantity sense by developing the signal features in time and frequency domain. In SHM application regarding concrete structure, root mean square deviation-based damage index (RMSD-DI) is very common and used by many researchers (Song et al. 2008, Yang and Divsholi 2010, Wang et al. 2011, Xu et al. 2013). Wavelet-based RMSD-DI adopted to

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quantify the debonding between concrete and steel in concrete filled steel tube (CFST) column (Xu et al. 2013). In this work, the energy of the waves before and after damage decomposed using wavelet transform was used as parameters in the RMSD-DI. It is worth to notice that the energies of all decomposed signals were summed together in this index in spite of the noticeable difference in energies of the different levels (details of the decomposed signals). For quantitative analysis of the energy distribution, it is better to divide the energy into three levels high, medium, and low frequency bands (Ding et al. 2007). In this way, sensitivity of deferent level sub-bands can be studied against crack size.

In this study, the quantification of artificial cracks created in concrete beams submerged in water is carried out using surface waves (Rayleigh waves) transmitted and received by gel-coupled piezoceramic (GCP) sensors. Wavelet based RMSD-DI is used for this purpose.

2. METHODOLOGY AND SIGNAL PROCESSING

2.1. Experimental work

The concrete beam shown in Fig. 1 is fabricated with concrete compressive strength of 40 MPa.

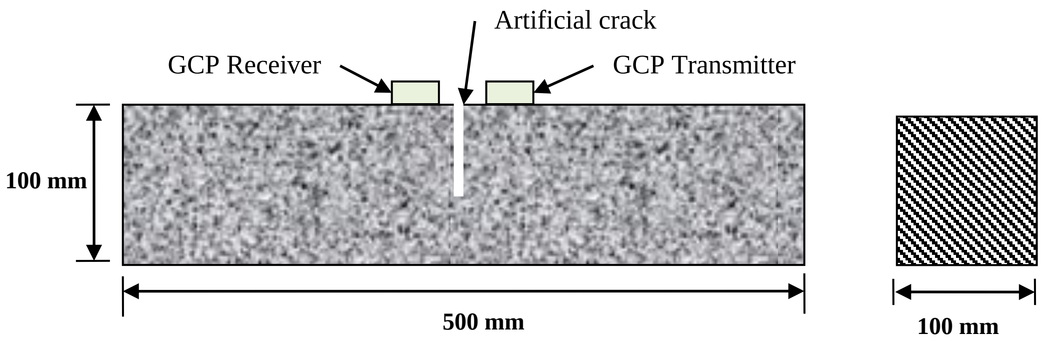


Fig. 1 Concrete beam layout showing sensors setup

Artificial cracks were created in four depths from 10 to 40 mm using steel plate planted in the middle of the top surface of the concrete beam during concrete casting. After 28 days curing the plates were removed to prepare the ultrasonic wave testing. At the day of testing, GCP transmitter and receiver were located 50 mm between each other on both sides of the crack and the equipments required for the tests were set up, see Fig. 2. A sinusoidal wave of 40 KHz driving frequency and windowed with 5 cycle Hanning window was created using Tektronix® arbitrary function generator. The GCP Sensors were fixed on the surface on the concrete beam using commercial water proof glue. The testing process was repeated for the other crack depths.

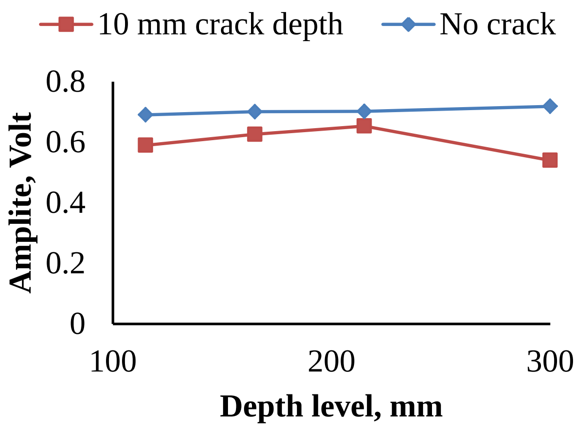
For underwater monitoring test, a water curing basin was used to submerge the samples. For water pressure calculations, four depth levels were selected to record the ultrasonic wave measurement. These levels were 115 mm, 165 mm, 215 mm, and 300 mm measured from the top surface of the tested concrete beams to the water level in the basin.

Fig. 2 Experimental setup

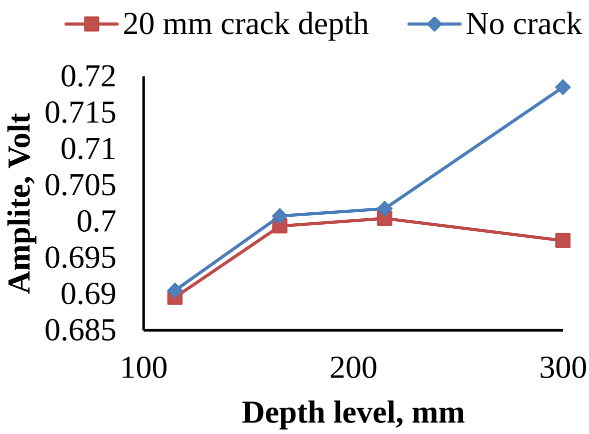
3. RESULTS AND DISCUSSION

3.1 Effect of water pressure

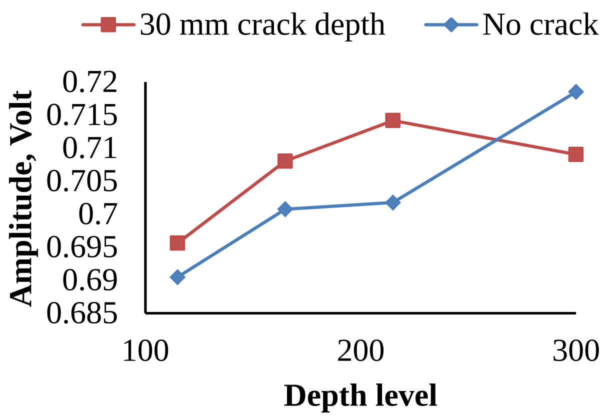
Fig. 3 shows the effect of the water pressure on the amplitude of the surface wave signal for the cracked and without crack samples. It can be seen that the results for the water depth level is proportional and consistent except for value of 300 mm. this inconsistency may be attributed to the effect of water pressure on the sensor at this value. One of the reason is the water leakage in the sensor housing under higher water pressure. The electrodes of the sensor could be affected by water leading to an inconsistent in reading.



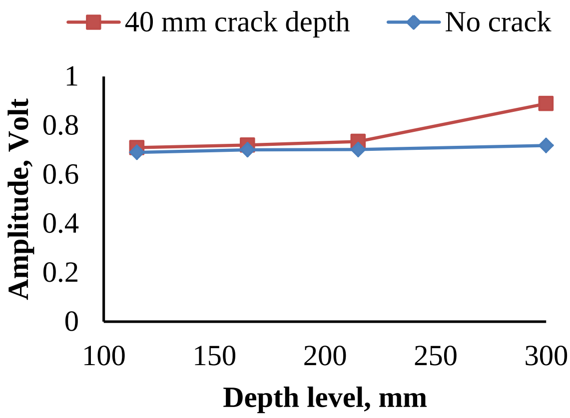
(a)



(b)



(c)



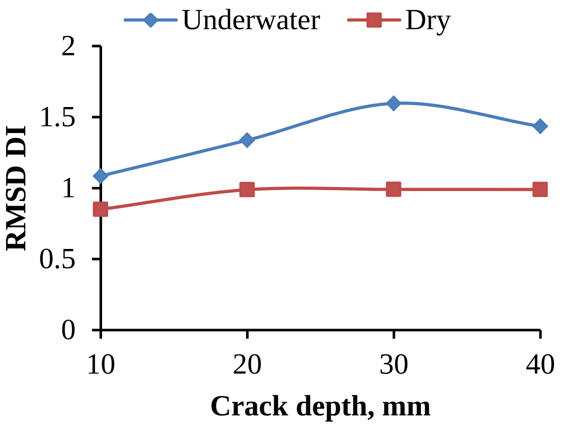
(d)

Fig. 3 Water pressure effect on amplitude of ultrasonic waves for different crack depth

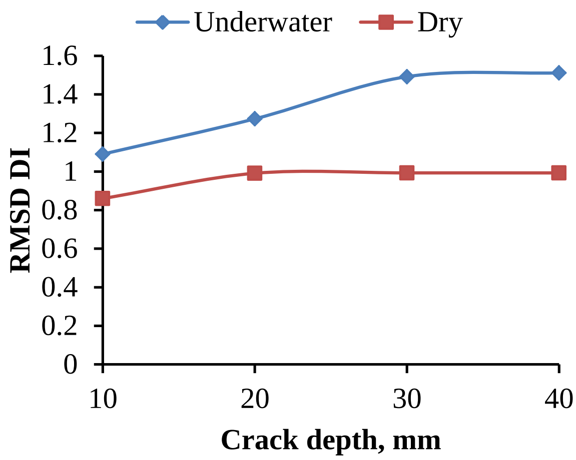
3.2. Discrete wavelet transform (DWT)

The captured wave signals were decomposed into nine levels using db4 wavelet. The nine levels start with higher frequency bands (i.e. level 1) and ends with lower frequency bands (i.e. level 9). It is clear that the higher frequencies have less resolution and much noise contrary to the lower frequencies which have a better resolution and less noise and this is one of the properties of DWT. As mentioned before, three categories were adopted to represent the frequency bands: high, medium, and low. The purpose beyond this classification is to investigate different damage size (crack) matching those frequency bands. RMSD DI was calculated for all wave signals based on these three categories.

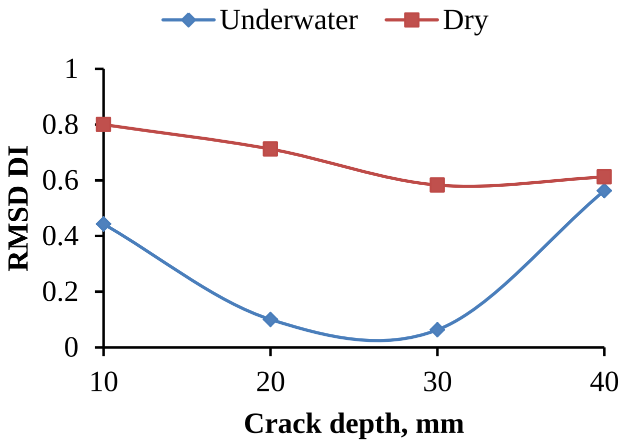
Fig. 4 shows the results of the RMSD DI for the high, medium, and low frequency bands. In this Figure, results of ultrasonic waves propagated along dry samples were compared with those immersed in water with water depth of 300 mm. It was found that the RMSD DI of the high and medium categories is more consistent than low frequency band in terms of proportionality with crack depth. The higher values of RMSD DI in high and medium bands than those of low band give the superiority of the first two categories because this index implies that higher values of DI means higher probability of presence of damage.



(a) High frequency band



(b) Medium frequency band



(c) Low frequency band

Fig. 4 Relationship between DI and crack depth for different frequency bands

4. CONCLUSIONS

Plain concrete beams are monitored by ultrasonic surface (Rayleigh) waves. Monitored process carried under water to investigate the effect of water on the propagation of the surface waves. GCP sensors were used to transmit and receive the wave signals. Water pressure was found to affect the wave signals and inconsistent results were obtained at water depth 300 mm. Among the three categories of frequency bands decomposed by wavelet, Medium category was found more sensitive to crack damage than other categories. RMSD DI results showed a different behaviour between the crack depth parameter due to the presence of water in these cracks.

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