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A method for detecting crack wave arrival time and crack localization in a tunnel by using moving window technique

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1. Introduction

Recently, the acoustic emission (AE) technique has been recognized as a promising method for real-time structural health monitoring of a structure [1~3]. Since acoustic emission is very sensitive to the initiation and growth of cracks in materials and structures, it has been widely used to evaluate the damage mechanisms in a variety of geotechnical structures, such as mines, natural gas and petroleum storage caverns, radioactive waste repositories, geo-thermal reservoirs, rock and soil slopes, and dams [4]. Traditionally, source localization in a dispersive medium has been carried out based on the time-of-arrival-differences (TOADs) method: a triangulation method and a circle intersection technique. Recent signal processing advances have led to calculation TOAD using a joint time-frequency analysis of the signal, where a short-time Fourier transform(STFT) and wavelet transform can be included as popular algorithms. The time-frequency analysis method is able to provide various information and more reliable results such as seismic-attenuation estimation, dispersive characteristics, a wave mode analysis, and temporal energy distribution of signals compared with previous methods. These algorithms, however, have their own limitations for signal processing. In this paper, the effective use of proposed algorithm in detecting crack wave arrival time and source localization in rock masses suggest that the evaluation and real-time monitoring on the intensity of damages related to the tunnels or other underground facilities is possible.

2. Methods and Results

2.1 Proposed algorithm

The main idea comes from the frequency characteristics. The variance of a windowed noise signal in the time domain is not changed with varying length of window. This is because the noise has wide band frequency range. However, because the crack signal has narrow frequency range, the variance of a windowed crack signal is changed depending on the widow size.

With this result, we propose the algorithm to determine the accurate crack wave arrival time, when the variation starts to change as a function of window size. As shown in Figure 1, the variance of the measured signal is obtained with respect to the continuous movement of the window. The variance as a function of the window size is further obtained applying an identical method. The point when the variance value varies among the different window sizes is determined to be the crack wave arrival time of the crack wave in solids

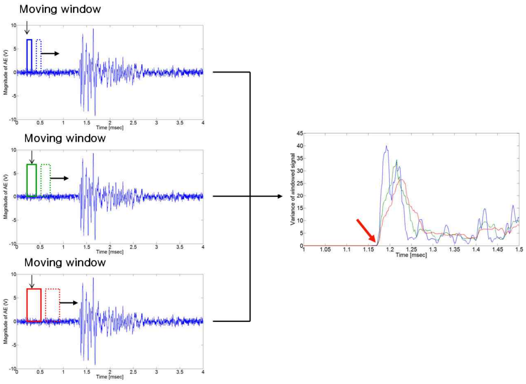


Fig. 1. Proposed algorithm for determining the crack wave arrival time. During calculating the variance as the window resizing, the point where the variances are different is the arrival time of the p-wave.

2.2 Validation using the experiment

In this paper, to verify the accuracy of the proposed algorithm for measuring the arrival time of the wave, the experiment was performed in the tunnel. The AE signal is generated by using impact hammer.

To localize the crack, 8 AE sensors (AE603SW-GA) are used as shown in Fig. 2. Fig.3. show the picture of experiments and the locations of AE sensors and sources.

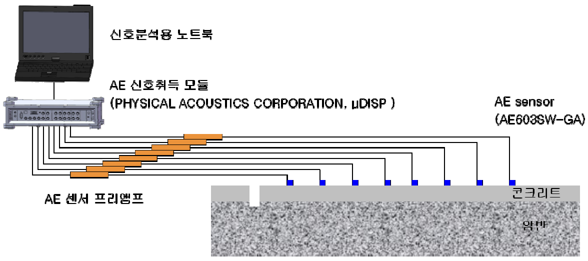


Fig. 2. Experimental setup for detecting crack location.

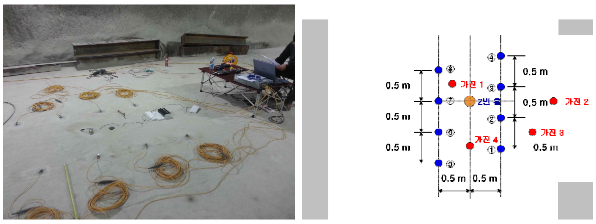
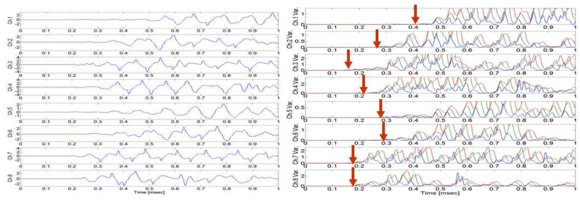


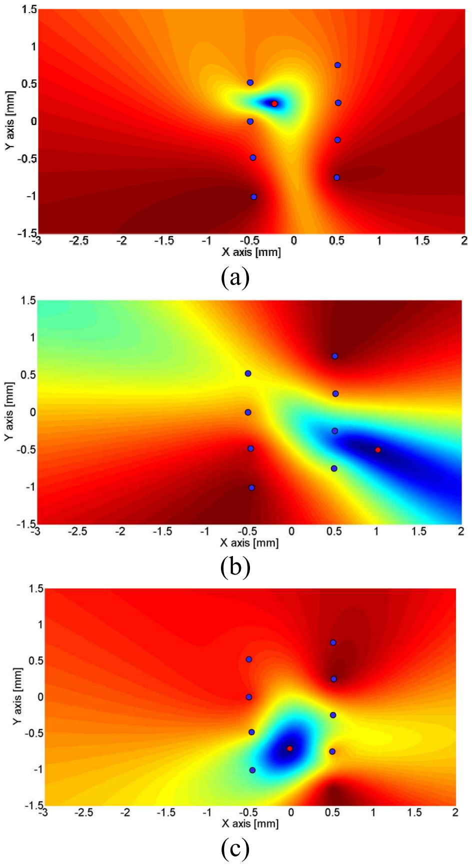
Fig. 3. (a) The picture of experimental setup and (b) Impact location.



(a) (b)

Fig. 4. (a) Measured signal from the AE sensors, (b) The analyzed signals by using moving window technique.

As shown in Fig. 4. (a), it is difficult to find the arrival time from the measured AE signals. But we can easily find the arrival time after applying the proposed moving window technique.



(a)

(b)

(c)

Fig. 5. The results of source localization. The blue points mean AE sensor location and red point is the estimated source location.

Table 1. Estimated source locations

	True location (x,y)	Estimated location (x,y)
	(-0.25m, 0.25m)	(-0.267m,0.248m)
	(1.50m, 0.0m)	(1.69m,0.003m)
	(1m,-0.5m)	(0.91m,-0.497m)
	(0m, -0.75m)	(-0.032m,-0.704m)

Figure 5 and table 1 show the estimated source locations from the results of Figure 4.

3. Conclusions

Acoustic emission (AE) is produced due to an elastic wave generated from the damage in solid materials. Thus, AE sensors have been widely used in several fields as a promising tool to analyze the damage mechanisms such as cracking, dislocation movement, etc. However, an accurate determination, by a non-destructive manner, of localization on where the damage happened in solids still remains challenging. Here, we report a novel crack wave arrival time determination algorithm of AE suitable to identify crack wave with low signal-to-noise ratios generated in rocks. Calculation of variances resulted from moving windows as a function of their size differentiates the signature from noise and from crack signal, which lead us to determine the crack wave arrival time. Then, the source localization is determined to be where the variance of crack wave velocities from real and virtual crack localization becomes a minimum. To validate our algorithm, we have performed experiments at the tunnel, which resulted in successful determination of the wave arrival time and crack localization.

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