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Attenuation Characteristics of AE/MA Waves in Charcoal Granite
차콜 화강암에서의 AE/MA 파의 감쇄특성

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요약 / ABSTRACT

세립화강암 시료에 개별 보정된 6개의 탐촉자를 부착하고 연필심 파괴로 급재하하여 AE/MA파를 발신시키면서 고주파인 AE/MA파의 감쇄특성을 연구하였다. AE/MA파의 강도는 거리뿐만 아니라 발신원과 수신점의 상대적인 방위에 의하여 결정되며 Charcoal 세립화강암의 감쇄상수는 1.058이다. 이 상수는 AE/MA파의 주어진 경로에 대하여서 발신원과 수신점의 상대적인 방위에 무관하게 적용 가능한 것으로 평가된다.

Attenuation characteristics of AE/MA motions which involve high frequencies were investigated through pencil-lead fracture tests on a fine-grained granite specimen. For the study, calibrated six transducers were employed to detect the signals and the pencil-lead was fractured as a step unloading force to generate AE/MA signals. The amplitude AE/MA waves is affected by the relative orientation of source and transducer as well as the source distance. The attenuation constant for Charcoal granite is obtained as 1.058 which could be applied for a given ray-path regardless of the relative orientation of source and transducer.

INTRODUCTION

Many factors can affect AE/MA (Acoustic Emission or Micro-Seismic Activity) amplitudes measured at transducers distant from the source. These include source mechanisms, orientation of microfracture planes, direction of ray-paths, frequency content of motions, material properties along the ray-paths, incident angles of rays and the transducer sensitivity factor. Where all of these factors are constant, the amplitudes are dramatically affected by an absolute travel distance and a relative wavelength to the distance.

Attenuation characteristics of AE/MA motions which involve high frequencies were investigated through pencil-lead fracture tests on a fine-grained Charcoal granite specimen which is purchased from Cold Spring Granite Co., Cold Spring, Minesota. The specimen is very fresh rock and thus the only fissures present would be on a scale equal to the crystal and/or grain size or boundaries between grains. And the grain size of the specimen is in the range of 1.0 to 3.0 mm which is only one tenth of the wave length of typical AE/MA motions and thus causes virtually no diffraction.

The data acquisition system employed in this study, manufactured by the LeCroy Corporation, consists of 1)amplifier/attenuator and trigger generator, 2)transient recorder, and 3)a computer automated measurement and control unit. The details of the system are well described by Kim (1989). The transducers which are calibrated by the methods described by Kim (1996a) are the piezoelectric "pressure" type, manufactured by Physical Acoustic Corporation (Model μM80D). The resonant frequency of the transducer is 1,000 kHz with fairy flat frequency response between 200 and 1,000 kHz.

ATTENUATION THEORY

Theoretical amplitude attenuation in relation to distance for homogeneous, isotropic, elastic material is well established in many texts (Richard, Wood, and Hall, 1969; Aki and Richard, 1980). In seismology (Aki and Richard, 1980), the attenuation property is generally represented by a Q value which is a dimensionless measure of internal friction. The attenuation is expressed at a far field as :

$$A_d = A_0 \exp\{-\pi fR/(v_pQ)\}, \qquad (1)$$

in which f is the frequency and v_p is the P-wave velocity.

The Q values in typical concrete-like materials were found to range between 10 and 100 by Bagoshi (1980). For Q=10, f=275 kHz, R=1 m, and v_p=4,800 m/s, the amplitude is $1.53\text{x}10^{-8}A_0$, which corresponds to an attenuation of -121 dB/m. This means that high frequency AE/MA motions are practically not detectable at a few meters with present equipment.

ATTENUATION OF AE/MA MOTION

The attenuation relation for AE/MA induced motions has not been investigated intensively. Dowding and Mueller (1987) have determined the attenuation constant, n, of AE/MA motions based on the results of laboratory fracture tests on granite using the following expression;

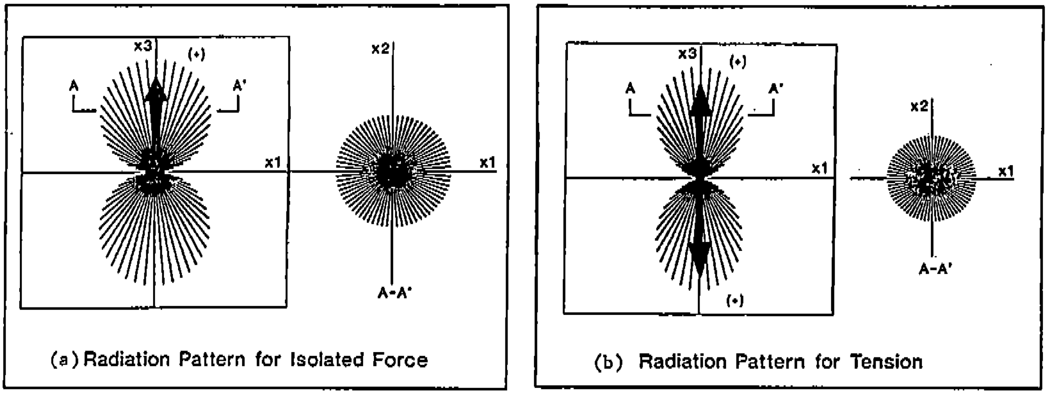
$$A_d = A_0\, R^{-n}, \qquad (2)$$

where A_0 and A_d are amplitudes at a unit distance from source and at a source distance R, respectively, and n is the attenuation constant. This attenuation constant is thought to be dependent on material properties but independent of the source strength. This equation may be a lumped-parameter attenuation relationship containing material damping as well as geometric attenuation. However, radiation patterns of AE/MA motions depend upon the source type as shown in Figure 1. Thus this equation is useful only for the case of dilation type of AE/MA source as shown Figure 1 (d).

The relationship shown in Equation 2, however, may also be useful to express the attenuation of other types of AE/MA motions when the radiation patterns (which are dependent upon the directivity angles θ and ф) are taken in consideration. The equation may then be rewritten as:

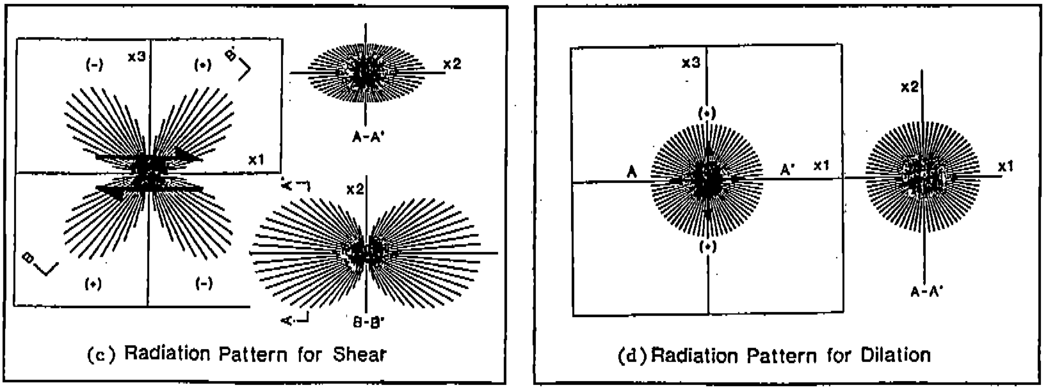
$$A_d(R,\ \theta,\ \phi) = A_0(1,\ \theta,\ \phi)\ R^{-n}, \qquad (3)$$

where $A_0(1,\ \theta,\ \phi)$ is the amplitude at a unit distance from source (source strength) in the ray-path direction of θ and ф in the coordinate



(a) Radiation Pattern for Isolated Force

(b) Radiation Pattern for Tension



(c) Radiation Pattern for Shear

(d) Radiation Pattern for Dilation

Figure 1. Radiation patterns by different source types of AE/MA motions (Kim, 1989).

system shown in Figure 2.

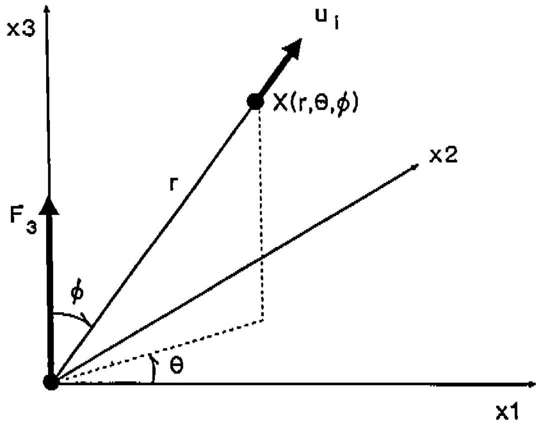


Figure 2. Geometrical relationships to describe three dimensional amplitude.

For a homogeneous and isotropic medium, the attenuation constant, n, used in Equation 3 is thought to be independent of the source intensity, and can be determined from two transducer responses along the same ray-path at different distances. More generally, the overall attenuation constant deduced from the regression of all available data may be employed if the data were from the same source mechanism and source angle. The attenuation constant, n, can also be determined from Equation 3 with the Q value defined in Equation 1 as following.

$$n = \frac{\pi f R}{v_p Q} \cdot \frac{1}{\ell n(R)} \qquad (4)$$

CHARACTERISTICS OF AE/MA WAVES

The source intensity may be defined as the amplitude at a unit distance, d_o, from the AE/MA source. The intensity is represented by A_o in Figure 3 and expressed as the amplitude lobe of d_o in Figure 4. The maximum source intensity, $A_{o(max)}$, is then expressed as an apex of the d_o amplitude lobe. This lobe lies on the maximum force or displacement axis (i.e., $\theta=0^\circ$ and $\phi=45^\circ$) for the compression lobe of the shear source in Figure 4.

In Figure 5, attenuation effects are combined with directional effects for the two basic source mechanisms of AE/MA events to show transducer responses at different locations. The attenuation is expressed by the shorter length of the solid lines at the wavefront with increasing source distance. Note that the polarity of the first motion at Transducer B (BS wave form) from the shear fracture induced motion, is opposite to other polarities. Also the amplitude of the first motion at Transducer A (AT) at a near distance is less than that of Transducer B (BT) located at a further distance due to the ray-path orientation. If the bottom transducer B is moved only a fraction of the specimen width to the left (Location B′), the amplitude by the shear event (B′S wave form) declines by a factor of more than 3. This is because of the change of source angle, distance, and incident angle at the transducer. Because of this effect, the first

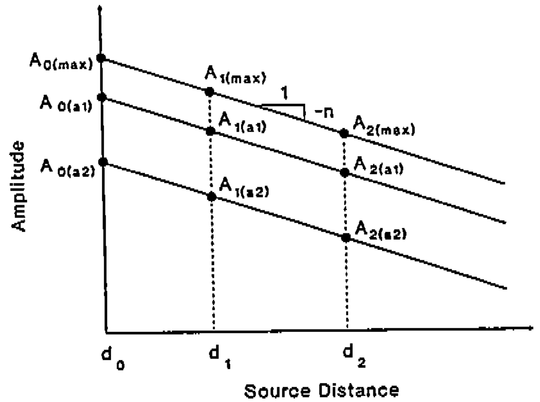


Figure 3. Schematic of amplitude attenuati with distance and ray-path directivity showing source angle-dependency and distance-dependency of amplitudes.

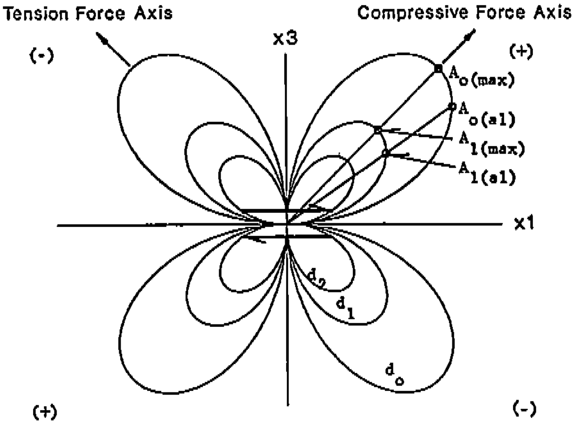


Figure 4. Spatial distribution of amplitudes related to P-wave radiation pattern from shear fracture comparing amplitudes at a unit distance (d_o), A_o with those at a d_o distance, A_1 for d_1, and A_2 for d_2 in Figure 3(Kim, 1989).

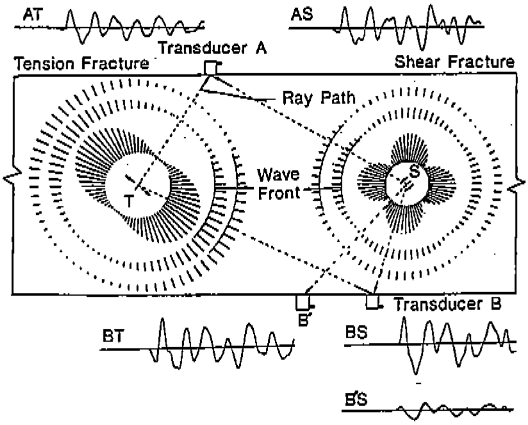


Figure 5. Attenuation and transducer response from different source mechanisms showing polarity and amplitued changes depending on transducer locations(Kim, 1989).

arrival determined by eye may, in some cases, not be the "true" arrival of the directly transmitted P-wave. More chances to miss the true arrivals are anticipated from thin specimens because of the low incident angles with a shallow focal depth. According to Kim (1996a), the sensitivity of transducers at an incident angle less than 20 degrees is only approximately 10% of the maximum sensitivity at incident angle of 90 degree. Thus calibration of the measuring system including transducers as well as all linkage lines should be carefully performed for quantitative AE/MA study.

EXPERIMENTAL STUDY

In order to obtain the attenuation constant of the AE/MA motions of which frequencies are generally in the range between 100 and 600 kHz (Dowding and Kim, 1988) and mostly concentrated in the range between 200 and 350 kHz (Kim, 1996b), a series of tests was conducted with the specimen configuration as shown in Figure 6. The six transducers are placed at distances of 30, 75, 120, 150, 200 and 250 mm from the source. And more than thirty trials are performed to get the clear first motions of wave.

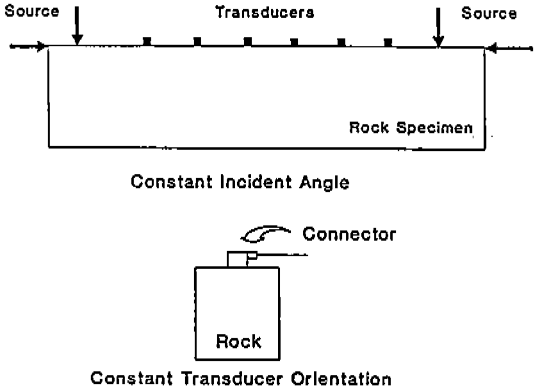


Figure 6. Configuration for determination of attenuation constant showing consistent of θ and ϕ angles for each transducer.

This configuration maintains constant θ and ϕ to all transducers, and the result of the tests on the Charcoal granite is shown in Figure 7. The amplitudes were normalized based on the sensitivity factor of individual transducer as described by Kim (1996a). As shown in Figure 7, the attenuation relation of motions from pencil-lead fractures for constant θ and ϕ indicates the attenuation constant, n, to be approximately 1.058.

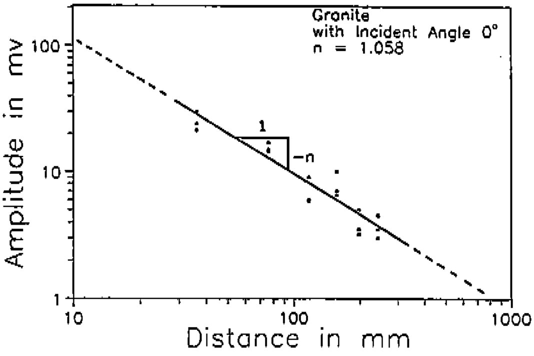


Figure 7. Attenuation relationship of AE/MA waves in Charcoal granite.

CONCLUSION

Measured amplitudes of the first arrival of AE/MA waves are affected by many factors such as transducer distance, source mechanisms, orientation of microfracture planes, direction of ray-paths, frequency content of motions, material properties along the ray-paths, incident angles of rays and the transducer sensitivity factor. Among these factors, the absolute travel distance to transducer and the direction of ray-paths (or the relative orientation of source and transducer) dramatically affect to the amplitudes. Thus determination of the attenuation constant of

AE/MA motions as well as transducer calibration is an important process for quantitative AE/MA study.

Through a series of experimental study, the attenuation constant for the Charcoal granite is obtained as 1.058 which could be applied for a given ray-path regardless of the relative location of source and transducer. Then the source intensity to deduce the size of the AE/MA event could be extrapolated by using this attenuation constant with the three-dimensional source location which can be determined by employing four transducers or more.

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