A REVIEW ON SONIC WAVE PROPAGATION IN ROCKS

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Keywords: Seismic Signals, Ultrasonic Waves, Earthquake Prediction, Seismometer Frequency

Sound, which is defined by “a mechanical disturbance from a state of equilibrium that propagates through an elastic material medium”, includes seismic waves as well.

Sound waves can have a wide range of frequencies. At very high frequencies, it is very hard for a sound wave to propagate efficiently; above a frequency of about 1.25×10^{13} hertz it is impossible for longitudinal waves to propagate at all, even in a liquid or a solid, because the molecules of the medium cannot pass the vibration along rapidly enough (Ultrasonics, 2014).

Acoustic emissions from stressed rocks are used to forecast roof falls in mines. Extensive research has been conducted into the application of acoustic emissions as a precursor to rock mass failure. In this application, the emissions are detected by the sensors which are directly attached to the surface of the rock. In mine application, however, little attention had been given onto ultrasonic emissions (while the detecting device has no contact with the rock) as a precursor to rock bursts (Bigby, 2004).

Seismic attenuation is commonly described by the quality parameter Q. Q is mostly defined as the maximum energy stored during a cycle, divided by the energy lost during the cycle (Kjartansson, 1979).

Attenuation coefficient of waves in solids depends on different variable such as material, temperature, humidity, pressure, porosity, permeability, etc.

Despite of a large number of researches, different theories exist on the absorption of seismic waves in rocks. Early laboratory work showed that the absorption in rocks is independent of frequency (Kjartansson, 1979).

Born in (Born, 1941), based on experimental data of small rock samples proposed that the frequency independent solid friction losses were mainly responsible for the attenuation of the seismic waves. This concept was adopted by some other researchers, although a satisfactory nonlinear friction model has never been developed for attenuation (Kjartansson, 1979).

Nearly constant Q (NCQ) models were used in a few articles. In these models, at least one parameter related to the range of frequency over which the model gives Q nearly independent of frequency, is included. The way this cutoff is chosen is arbitrary and is different between different models. Besides, the analysis in most of the NCQ theories, are restricted to the cases where Q is large ($Q>30$) (Kjartansson, 1979).

Another theory was given by Ricker in (Ricker, 1953; 1977), which is also used by others. In this model, the absorption is defined by adding a single term to the wave equation, which brings simplicity, and therefore the theory of the transient wave propagation has been further developed. Based on the Ricker theory, wavelets have been commonly used in the computation of synthetic seismograms. In this model Q is inversely proportional to the frequency. The frequency dependence of Q in this model contradicts all experimental data (Kjartansson, 1979).

In (Kjartansson, 1979), a linear model for attenuation of waves was presented, in which Q was independent of frequency. By the model, the author gives a description of wave propagation and attenuation with Q independent of frequency, which is both linear and causal. This method, which is called constant Q theory (CQ) well fits the field observation from Pierre shale formation in Colorado (Kjartansson, 1979). The author finally concluded that “it is likely that Q is weakly dependent on frequency”, and that there was no sign that any of the NCQ theories gives a better explanation of the attenuation in rocks than the CQ theory does.

In (Merkulove, 1968), absorption of ultrasonic waves in rocks is studied. The author concluded that the dissipative loss upon frequency is maintained over a wide range of frequencies, from tens of Hz, to several megahertz.

As seen, the dominant view point in wave propagation through rocks is that the attenuation is frequency independent. Therefore, passing the high frequency earthquake shocks through the earth crustal and reaching to the surface is possible.

On the other hand, seismic activities are recorded by seismometers and accelerometers. Seismometers are instruments that measure ground motion (caused by seismic waves) at a specific location. The ground motion caused by earthquakes includes a wide range of amplitudes, from a few millimicrons to several meters. Seismometers, which come in three kinds: short-period, broadband, and strong-motion sensors, can measure signals with frequencies up to a few hundred hertz.

In the 80's, Dr. David Hill did an experiment, in Southern California near the Mexican border, to understand earthquake sounds. This test was the first recording of earthquake sounds that came solely from the earth. His team recorded the sounds from small earthquake between magnitude 2.0 and 3.0, and simultaneously measured the arrival of the P wave on a seismograph. They suspended a microphone several feet in the air and recorded its signals on a tape recorder simultaneously with those from a seismometer buried in the ground. They reported hearing sound before the S waves were recorded, and finally concluded this was the arrival of the P waves.

However Dr. Hill's experiment was only investigating the sound waves which were in a short range of human hearing. The effective frequency band of their recording system was between 40-70 hz (Hill, 1976). The existence of sound waves with higher frequencies, including ultrasonic waves was never investigated.

As seen, while sound waves that, according to literature, can travel through solid have a wide range of frequencies, seismometers cut-off frequency is very low, often around 100 Hz. So far no through research has been done to investigate the nature and quality of the sound waves (including ultrasonic waves) that come with an earthquake.

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