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A REVIEW ON SONIC WAVE PROPAGATION IN ROCKS

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ABSTRACT

Different theories on the propagation of sonic waves in rocks are studied. Early laboratory works show that the attenuation of sound waves, which based on the definition includes seismic waves as well, is frequency independent. Most of the theories also agreed that absorption in rocks is independent of frequency. Therefore it is possible for the high frequency signals of an earthquake to reach the distance. However, seismometers and accelerometers which are utilized for measuring the seismic wave fields, have a rather short bandwidth. An experiment was done in 1980s to measure the sonic signals accompanying earthquakes other than those measured by seismometers and accelerometers. But the effective frequency bandwidth of the recording system in this experiment was between 40-70 Hz. More measurements are needed to investigate the quality of sound waves that come with an earthquake.

INTRODUCTION

Sound, which is defined by “a mechanical disturbance from a state of equilibrium that propagates through an elastic material medium” (Sound, 2014), includes seismic waves as well. Sound waves can have a wide range of frequencies. At very high frequencies, sound waves can not propagate efficiently. Above a frequency of abourt 1.25×10^{13} hz, no medium (solid or liquid) can pass a logtudinal waves, because the molecules of the medium cannot vibrate rapidly enough (Ultrasonics, 2014).

In solids, molecules can vibrate in different directions. Therefore sound waves can propagate in four different modes which are longitudinal waves, shear waves, surface waves, and plate waves (Propagation, 2014). In longitudinal waves, particles vibrate parallel to the wave direction. In shear waves, they move sideways to the direction that the wave is traveling.

There are two types of seismic waves: surface waves and body waves. Surface waves travel over the surface of the earth. Body waves pass through the earth’s interior parts and reach to the surface again.

There are two basic types of seismic body waves: Primary waves (which are longitudinal waves) and shear waves. Primary waves travel faster than other type of seismic waves. Primary waves and shear waves are called P (primary) waves and S (secondary) waves respectively, because they are the first two types of seismic waves that reach to any point with an earthquake (Weatherwatch, 2014).

To record seismic waves in water hydrophones are utilized (Shearer, 1999). On land, a network of seismometers and accelerometers are places to monitor and locate an earthquake’s hypocenter.

The intensity of sound is diminished with distance when traveling through a medium. In ideal materials, the only cause for attenuation of the signal amplitude is wave spreading. In natural materials, sound is further weakened by scattering and absorption. Attenuation is the collective effect of scattering and absorption (Attenuation, 2014).

The attenuation of seismic waves is described by the quality parameter Q. Q is commonly 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.

In this paper, a review on existing theories on wave propagation and attenuation has been made. Then the lack of enough field experiments to qualify all the mechanical (sound) waves that come with an earthquake is discussed.

THEORIES ON WAVE PROPAGATION IN ROCKS

Despite of a large number of researches, different theories exist on the absorption of seismic waves in rocks. In below, three main categories of the models of wave propagation are described.

A. CONSTANT Q MODELS

Early laboratory work showed that the absorption in rocks is independent of frequency. 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 including (McDonal et al., 1958), (Knopoff, 1964), (White, 1966), (Gordon, 1968), (Lockner et al., 1977), and (Johnston and Toksoz, 1977); although a satisfactory nonlinear friction model has never been developed for attenuation (Kjartansson, 1979).

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.

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 fitted the field observation from Pierre shale formation in Colorado. 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 (Nearly Constant Q) theories gives a better explanation of the attenuation in rocks than the CQ theory does.

B. NEARLY CONSTANT Q MODEL

Nearly Constant Q (NCQ) models were used in a few articles including (Kolsky, 1956), (Lomnitz, 1957), (Futterman, 1962), (Azimi et al., 1968), (Strick, 1967), (Strick, 1971), (Liu and Anderson, 1976), (Kanamori and Anderson, 1977), (Minster, 1978). 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 models of (Lomnitz, 1957), (Futterman, 1962), (Strick, 1967) and (Liu, 1976). Besides, the analysis in most of the NCQ theories, are restricted to the cases where Q is large (Q>30) (Kjartansson, 1979).

C. NON-CONSTANT Q MODEL

Another theory was given by Ricker in (Ricker, 1953, 1977), which is also used by others including (Collins, 1960), (Clark, 1966), (Jaramillo, 1970), and (Balch and Smolka, 1970). In this model, a single term to the wave equation is added, which brings simplicity, and thus the theory of the transient wave propagation in rocks has been advanced. Based on the Ricker’s theory, wavelets have been commonly used in the computation of synthetic seismograms. In this model Q is inversely proportional to the frequency. However, the frequency dependence of Q in this model contradicts all experimental data (Kjartansson, 1979).

DISCUSSION

It is worth mentioning that the existence of "roars" accompanying earthquakes have been reported from long ago. Although most earthquake sounds that people reported resemble noises from man-made sources such as an explosion, but they cannot explain many of the reported booms. Dutton in (Dutton, 1889) gave a detailed report about sounds of the earthquake in Charleston, SC Earthquake (1886), which is also available on (Earthquake Booms, 2013). The earthquake sounds were also documented from the ground motions of Spokane, WA, in 2001 (Earthquake Booms, 2013).

However, there was no scientific experiment that showed the loud sound preceded the 1886 Charleston, SC Earthquake. There were even no seismographs either, so the earthquake was not recorded at all (Earthquake Booms, 2013).

In the 80's, Dr. David Hill did an experiment, in Southern California near the Mexican border, to observe earthquake sounds. This test was the first experiment to examine earthquake sounds that came merely 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 (Gedney, 2014). They reported the presence of sound waves before the arrival of S waves, 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.

On the other hand, seismic activities are recorded by seismometers and accelerometers. The amplitude of ground movement caused by an earthquake can be as low as a few millimicron to several meters. For ground motion application, seismometers, which come in three kinds: short-period, broadband, and strong-motion sensors, would measure signals with frequencies up to a few hundred hertz.

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.

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.

It is noteworthy to mentin that the 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 has been given onto ultrasonic emissions (while the detecting device has no contact with the rock) as a precursor to rock bursts (Bigby, 2004).

So far no through research has been done to investigate the nature and quality of all the sound waves (including ultrasonic waves) that come with an earthquake. To explore all the mechanical waves, with different frequencies, coming with an earthquake, more field experiments are needed.

CONCLUSIONS

Different theories on propagation of sound waves in rocks were reviewed. Most of the researchers believe that the attenuation of waves propagating through materials is frequency independent, which is consistent with the experiments. Therefore, travelling high frequency seismic waves through rocks and reaching to distance is possible. But the main devices to detect earthquake signals, i.e. seismometers and accelerometers, would have a relatively short frequency bandwidth. Almost no experiment has been done to explore the quality of the earthquake signals. More field measurements are needed to investigate the quality and characteristics of sound waves that come with an earthquake.

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