FEASIBILITY OF AN ACOUSTIC TECHNIQUE FOR FRACTURE DETECTION*

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ABSTRACT

A field experiment was conducted at a granite quarry to determine the feasibility of an acoustic, downhole technique for location of fractures in the vicinity of boreholes. The frequency used in this test was about 5 kHz; a frequency well above the seismic frequency commonly used in reservoir evaluations. An existing flame-cut slot in the granite at the test site was filled with water to simulate a fracture. A high-energy piezoelectric transmitter was located in a borehole 8 meters from the water-filled slot, and a commercial piezoelectric transducer was used as a receiver in a borehole 4 meters from the slot. Both transducers could be rotated for maximum transmission or reception for either the compressional wave or the shear wave. During the experiment, reflections from the simulated fracture were obtained with the transducers oriented only for shear wave illumination and detection. These test results suggest that a high-frequency shear wave can be used to detect fractures located away from a borehole.

INTRODUCTION

Low-frequency electromagnetic or seismic waves are commonly used to determine the location of a reservoir. These low-frequency techniques can provide a sufficient depth of penetration. Unfortunately, low-frequency data lack the necessary resolution to accurately pinpoint the location of a reservoir. Without a precise direction, drilling can easily miss the fracture systems that connect a wellbore to a reservoir, and the well can become a non-productive dry well. In many cases, the fractures are only meters away from a borehole.

This author has reported the feasibility of a borehole VHF radar technique for fracture mapping (Chang, 1984). The resolution of such a high-frequency technique is excellent. But, in a highly conductive medium, a radar technique may not be suitable. Since the conductivity will not affect the propagation of an acoustic wave, acoustic technique might be a viable alternative for fracture detection in conductive formations. In order to investigate the feasibility of such a technique, experiments were conducted in a granite quarry where a 6 meter deep flame-cut slot exists. This slot was filled with water to simulate a fracture. An acoustic transmitter was located in a borehole 8 meters from this slot, and a receiver was located in a borehole 4 meters from the slot (Figure 1). If this receiver could observe the reflected signal from the slot, then the acoustic technique might be feasible for fracture detection. The frequency used in this experiment was about 5 kHz. Its wavelength in the formation is in the order of a few feet.

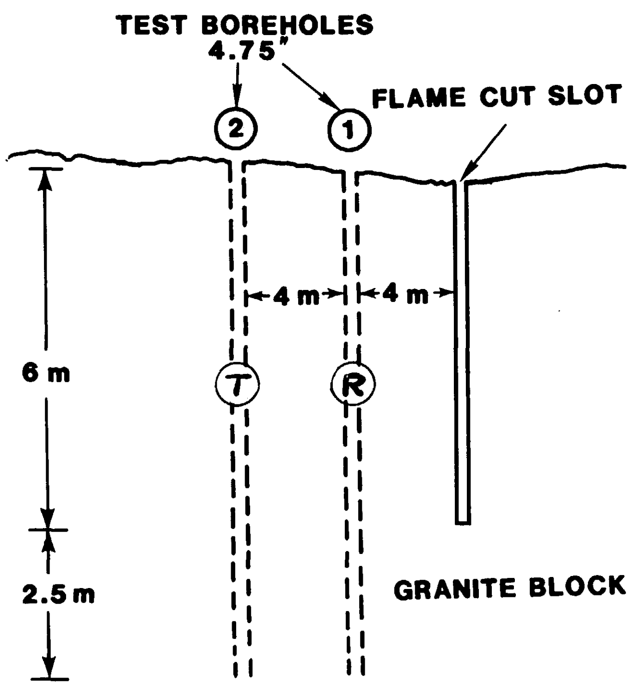

Figure 1. Granite Quarry Test Site

TEST SET-UP

The pulse-echo acoustic probes employed in the tests are prototype components of a borehole velocity probe developed by Suhler, et al (1979). This equipment consists of: (1) a borehole transmitter probe; (2) a borehole receiver probe; (3) separate hydraulic pumps, lines, and electrical cables for operating the probes in shallow boreholes; and (4) surface electronic equipment to power and operate the probes.

The transmitter contains a piezoelectric pulse transducer consisting of a multi-element stack of piezoceramic elements. This cylindrical stack of crystals is installed in a hydraulically actuated piston within the probe. Activating the hydraulic pump causes the piston to extend radially from the probe body clamping the probe in the borehole and bringing the transducer into contact with the borehole wall. The probe also contains a high-voltage power supply and a pulse discharge network. To develop a high-energy-rate pulse, the transducer stack is charged to approximately 1000 volts causing it to contract in length. The stored energy is then abruptly discharged causing the rapidly expanding piezoelectric transducers to generate a broad bandwidth acoustic impulse in the drilled formation. This highly repeatable pulse can be generated at repetition rates up to ten pulses per second.

The receiver probe is similar to the transmitter probe with the exception that the receiver transducer piezoceramic elements are configured for maximum sensitivity for converting the detected acoustic pulses to electrical signals. Separate piezoceramic elements are employed in this receiver probe to provide preferential detection of compressional and shear waves traveling parallel to the borehole axis.

The transmitter and receiver probes are connected to the surface via electrical cables and hydraulic lines. The surface unit controls the hydraulic pump and the transmitter synchronization. A receiver selector switch and acoustic preamplifier in the Surface Unit is connected to the receiver probe to amplify the signal to the appropriate level for display and recording.

Data were recorded on digital magnetic cassettes. Recording and formatting of the tapes was performed by a Hewlett Packard 9825 desktop computer. Measurements were taken to determine the mean velocity of the acoustic waves in the test location. The values obtained were 5890 m/s for the compressional wave (p-wave) and 3050 m/s for the shear wave (s-wave).

TEST RESULTS

Various test configurations were conducted during the experiment. The transmitter was rotated to provide maximum transmission of either the compressional wave or the shear wave. At a given transmitter orientation, the receiver was rotated for maximum reception of either the compressional or the shear waves. No reflections from the slot were observed except in one case when the transmitter was oriented for shear wave illumination and the receiver was oriented for shear wave detection. Data obtained under this configuration is shown in Figure 2.

In this test, the flame-cut slot is only 6 meters deep. Since the transducers used had a wide power beamwidth, the slot would not be able

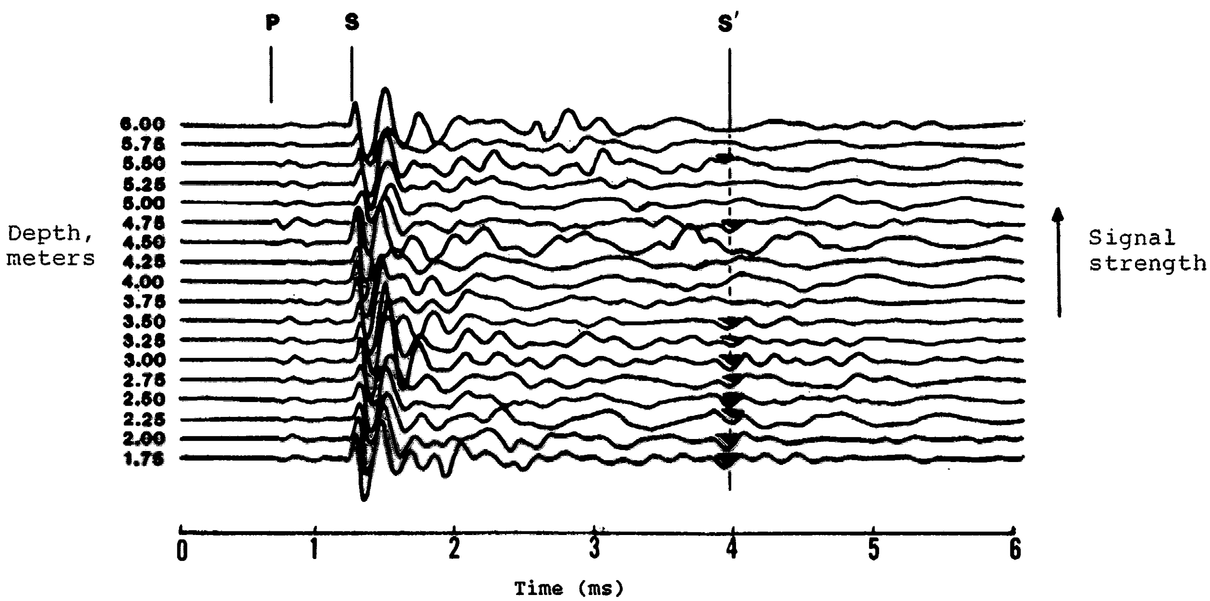

Figure 2. Common Depth Scan of an Acoustic System

to block the entire acoustic energy when the transducers were located near the 6 meter depth. Therefore the reflection was not obvious at such depths. However, the reflections were clearly shown when then transducers were located near a depth one-half that of the slot. Since the transducers were oriented mainly for s-wave illumination and reception, very little p-wave energy could be observed. The transmitter borehole was located 8 meters from the slot while the receiver borehole was located 4 meters from the slot. The direct path from the transmitter to the receiver was only 4 meters. The average s-wave velocity at the test site was 3050 m/s. The direct ray should reach the receiver 1.3 ms after the transmission. The energy would then travel another 4 meters to reach the slot. The reflected signal would need to travel an additional 4 meters back to the receiver. Therefore, reflected signals should appear 3.9 ms after transmission. The observed data shown in Figure 2 agrees with these calculations.

CONCLUSIONS AND RECOMMENDATIONS

Shear-wave reflections from a water filled slot were clearly observed by a receiver 4 meters away from the slot. This result suggests that a high-frequency acoustic technique (5 kHz in this case) can be used to detect a fracture several meters away from a borehole. The distance of a fracture estimated by such a high-frequency technique should be much more accurate than that obtained by a conventional seismic technique.

The transducers used in this system require a firm contact against the borehole walls in order to transmit s-wave to the formation. The degree of contact and pressure can affect the amount of energy being transmitted. It is desirable for the transducer to deliver a constant energy to the formation at different depths even if the borehole walls' roughness at such depths are different. This is an area in which additional investigations are needed. Another area of challenge is to design a directional transducer so that the direction of a fracture can also be determined.

REFERENCES

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*This work was supported by the U.S. Dept. of Energy at Sandia National Laboratories under Contract DE-AC04-76DP00789.