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Pittsburgh Energy Technology Center
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Attention: Ms. Maryann Lundgren
Contracting Specialist

Subject: Quarterly Project Report and Status Report; Contract No. DE-AC22-89BC14473; "Demonstration of High-Resolution Inverse VSP for Reservoir Characterization Applications," SwRI Project 15-3200

Gentlemen:

Enclosed is the quarterly project report for the reporting period of April 1 to June 30, 1990. This report includes a summary of technical progress reports, and the milestone schedule status report.

We trust that these reports will meet with your approval. Clarifications or supplemental information will be furnished upon request.

Very truly yours,

Jorge O. Parra

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Project Leader

JOP/gb

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DEMONSTRATION OF HIGH-RESOLUTION INVERSE VSP FOR RESERVOIR CHARACTERIZATION APPLICATIONS

Quarterly Report for the Period
April-June 1990

By
Jorge O. Parra

September 1990

Work Performed Under Contract No. AC22-89BC14473

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OBJECTIVE

The objective of this project is the demonstration of inverse vertical seismic profiling measurements using new experimental field instrumentation capable of providing at least an order of magnitude improvement in the resolution of structural details in comparison with conventional seismic images. This two-year project will entail instrumentation tests under controlled field conditions during the first year followed by full-scale field demonstration tests in a representative oil-bearing reservoir formation during the second year.

SUMMARY OF TECHNICAL PROGRESS

In this third quarter, the wax-melt borehole seismic sensor package containing acceleration sensors was designed, constructed, and tested in laboratory and field experiments to evaluate this novel reversible rigid-coupling method.

A Reversible Rigid-Coupling Method for Borehole Seismic Transducers

The coupling method used in present-day borehole seismic detectors is one in which mechanical locking arms are actuated outward from the sensor probe housing to contact the borehole wall and forcefully lock the probe in place for the temporary time period required for the measurements. In general, seismic wall-lock probes of this type have an average density which is much greater than the drilled rock formations in which they are coupled. As a result, a very high mechanical clamping force is required to lock these probes to the borehole wall. In practice, this technique is usually only partially successful in achieving the desired degree of coupling because of spurious mechanical resonances that occur in the clamping mechanism.

Alternatively, permanent installation of the seismic detectors is occasionally desirable. A common practice used in such permanent installations is to embed the sensor in the borehole using portland cement or other rigid casting material. In this case, the seismic detector package must be considered to be expendable since it cannot be recovered in a cost effective manner. such permanent emplacements have been used in a number of field tests using relatively inexpensive geophones which could be abandoned in place when the tests were completed. This method has proven to be very effective in providing good seismic coupling by the fact that the cement forms a rigid and conformal casting in the borehole and the composite sensor and cement has a density which is reasonably well matched to that of the surrounding geological material.

The acceleration sensors mentioned above for reverse VSP measurements are significantly more expensive than geophones and, therefore, cannot be considered to be expendable. Therefore, an alternative means of rigid and conformal coupling is needed which would allow the more expensive acceleration detector probe to be retrieved after use. A wax melt sensor coupling technique was developed for this project and installed in a shallow borehole for seismic measurements. This reversible rigid-coupling method was intended to achieve the desirable results of rigid conformal borehole coupling, an approximate match between the average density of the sensor package and the drilled rock formation, and the ability to recover the sensor package instead of abandoning it after the seismic measurements are complete.

Laboratory Experiments

Laboratory experiments were conducted to test the wax-melt coupling technique and the wax-melting control process for borehole seismic sensors. For this purpose, a prototype assembly of the wax-melt-coupled seismic detector containing the sensor package and its surrounding heating elements was placed in a closed plexiglas sleeve (tube) immersed in water. The heating elements were made of #16 AWG nichrome wire. Melted carnauba wax blended with smaller amounts of other vegetable waxes was then poured into the plexiglas sleeve. Upon cooling and solidification, the wax provided a rigid embedment of the seismic sensor package, which was reliably coupled to the surrounding plexiglas material.

To test the wax melting process experiments were conducted by monitoring the wax heating time, the wax heating power, and the temperature of the wax embedment. Seven temperature sensors (thermistors) calibrated in the range of 100-250°F and located in each wax melt zone of the sensor package were used to monitor the thermal conditions and the changes produced ion the wax by the electrical heating power controls.

The laboratory experiments demonstrated that, in order to gradually melt the wax surrounding the embedded assembly in the plexiglas tube, a maximum heating power of 950 watts was required for an application time of one hour. In addition, the experimental results indicated that, by applying different heating power, a vertical thermal gradient could be established in the melted wax column. In this case, when the upper section of the wax was hotter than the lower section, the subsequent cooling and solidification of the wax coupling occurred with minimum shrinkage of the wax embedment.

Field Experiments

A sensor package was prepared for installation in a borehole by casting it within a cylindrical billet of wax whose diameter was smaller than the diameter of the borehole and whose length was such that enough wax was available to surround and embed the sensor package in the borehole. Figure 1 shows the finished wax billet casting in a form ready to be placed in a borehole. This casting is 5.5 inches in diameter and 19 inches long and was installed in an open 75-foot deep water-free borehole having a nominal diameter of 6.25 inches. The wax billet, sensors, and preamplifier were lowered to the bottom of the borehole and then distributed electrical heating was applied to achieve a heating and melting of the wax. As was expected, by applying approximately 950 watts of heating power for a time period of one hour, the wax billet melted and reached a final temperature of 100°C in its upper section.

After the wax was solidified in the borehole, three-component seismic measurements were successfully recorded using a cylindrical bender seismic source and the wax-melt was placed in a 450-foot deep borehole at 65 feet from the 75-foot deep detector borehole. Seismic measurements were acquired using different source pulse signals in the frequency range of 750-3000 Hz and at several source depths ranging from 71 to 400 feet.

As an example of these data, Figure 2a illustrates three-component reverse VSP seismic pulse waveforms at 2500 Hz and at a source depth about 33 feet below the detector. Also, a three-component pneumatically clamped seismic detector probe was previously used at the same location borehole to record the same source pulse signal. These waveforms are shown in Figure 2b. The records contain electrical cross-feed caused by the experimental system conditions when the measurements were taken but are independent of the detector probe coupling response in the borehole and were later eliminated in the experiments with the wax-melt coupled sensors.

A comparison of the pneumatic and wax-melt sensor seismic waveforms indicates that time domain waveforms are dominated by direct waves in the form of short-duration probes and wideband signal spectrums. These results concluded that the coupling obtained with the pneumatic sensor package is comparable to the more rigid coupling obtained with the wax-melt sensor package.

Finally, after the data acquisition field experiments were completed, the coupling medium (wax) was transformed from a solid state to a liquid state to allow the sensor package to be decoupled and removed from the borehole. The heat application time and the heating power required to melt the wax was seven hours at a power of 950 watts. The seven-hour melting time appears to be caused by moisture condition at the bottom of the borehole.

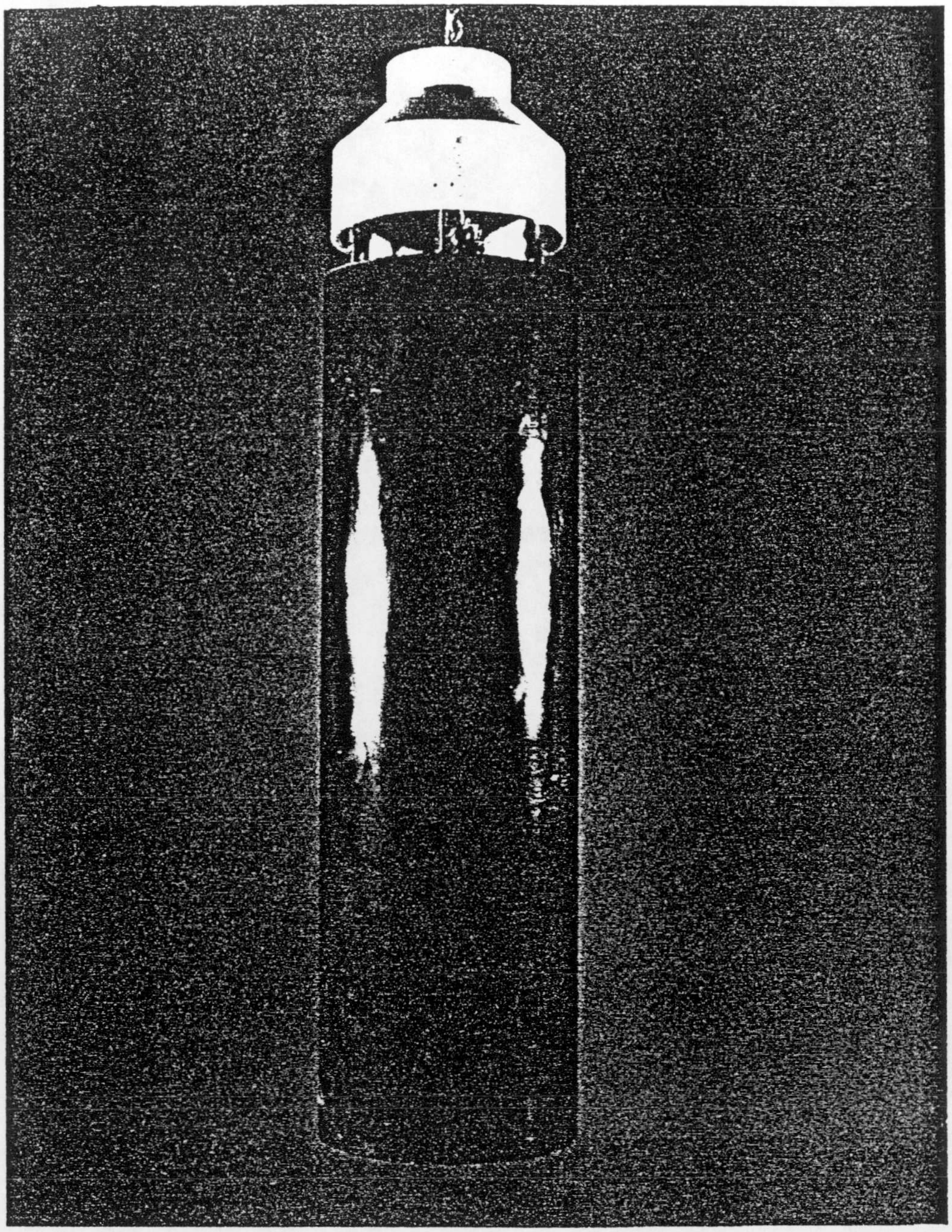
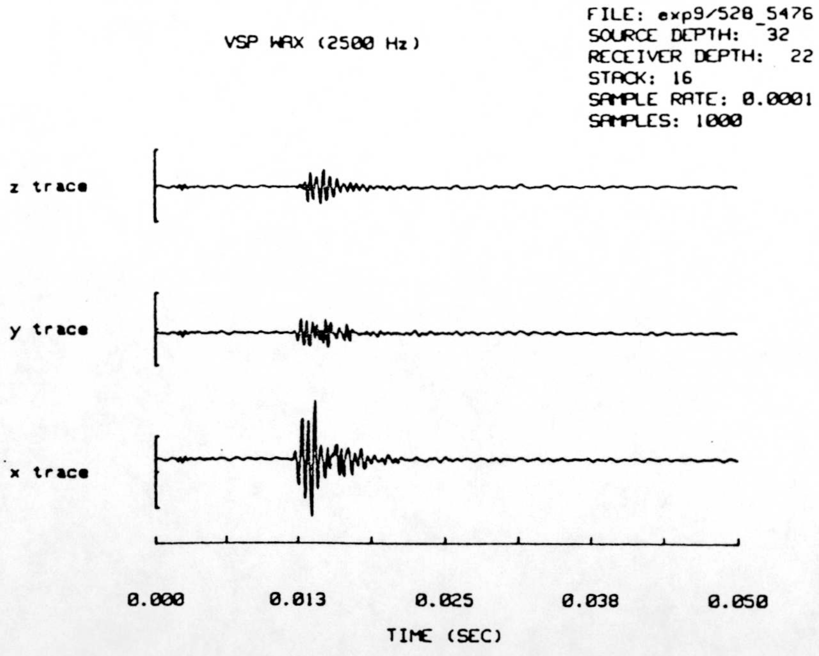
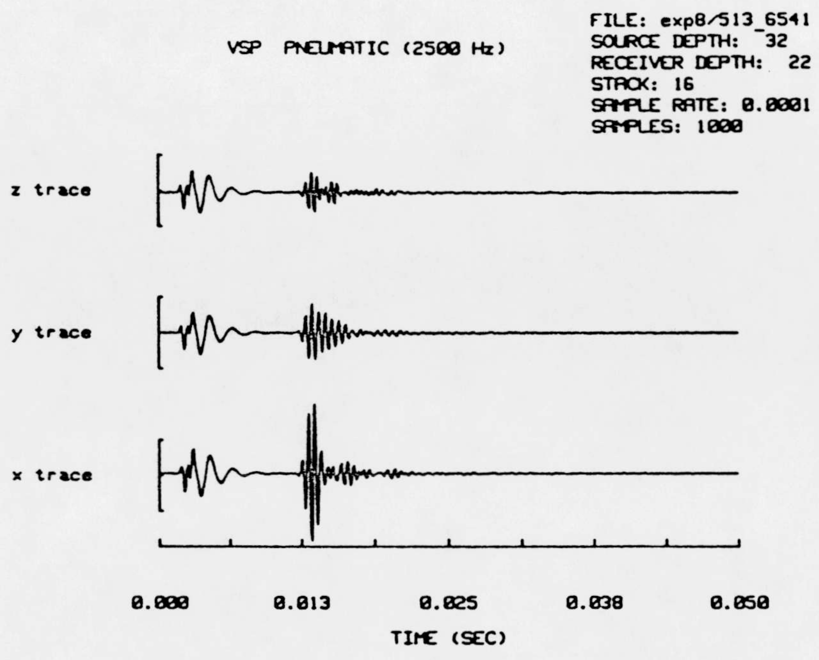


FIGURE 1. PROTOTYPE MODEL OF WAX-MELT BOREHOLE SEISMIC SENSOR PACKAGE AND NICHROME HEATER ELEMENTS



(a) Waveforms recorded with the wax-melt sensor package



(b) Waveforms recorded with the lightweight (7 lbs) pneumatic-lock detector tool

FIGURE 2. THREE-COMPONENT INVERSE VSP SEISMIC WAVEFORMS. SHOT POINTS OBTAINED WITH 2500 HZ SOURCE CENTER FREQUENCY