IN-SITU SEISMIC WAVE VELOCITY MONITORING

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USGS CONTRACT NO. 14-08-0001-17645
Supported by the EARTHQUAKE HAZARDS REDUCTION PROGRAM

OPEN-FILE NO.81-285

U.S. Geological Survey
OPEN FILE REPORT

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CONTRACT 14-08-0001-17645

TECHNICAL REPORT: 01 Oct 1979 - 31 Mar 1980

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I. TECHNICAL REPORT SUMMARY

During this report period, repairs were completed to the vibrator donated last August by Western Geophysical Company. Faulty steering and brake systems on the vibrator truck were improved substantially, and two hydraulic cylinders on the vibrator itself failed and were repaired during final testing. Recording truck steering and suspension systems were overhauled during the same period.

Field work began in March. Tests in March and early April at the Cienega Winery monitoring area showed that the vibrator operated well on the special concrete and asphalt pads discussed in previous reports. Signal strength at high vibrator drive levels was several times larger than with the previous vibrator, but several more vibrator f ailures occurred, due to operation at high drive level. Tests showed that shaking at low drive levels reduced signal strength only marginally while reducing substantially the severity of shaking of system components. Application of this discovery will improve the vibrator maintenance situation.

Repeated measurements of down-hole travel-time using the vibrator source and a borehole geophone receiver indicate that measurement errors due to source instability will be less than ±0.1 msec (the standard deviation was 0.04 msec), a significant improvement over results obtained with the previous vibrator. Tests of source reproducibility are yet to be made. An experiment using a hammer source and the borehole geophone yielded a larger but still acceptable standard deviation of 0.1 msec. These stable borehole results using both sources indicate that corrections for near-surface travel-time changes can be measured with adequate precision to correct for much of the seasonal long-term variations which can mask evidence for changes at depth.

The first monitoring measurement with the new vibrator system was made using established source and receiver sites in the Cienega Winery area in early April. The resulting first arrival travel-time was within 2-3 msec of the values measured in the springs of 1979 and 1978, indicating that no substantial change has occurred at a resolution level of a few parts in 10^{-3}. Routine monitoring is now underway at the old winery sites and at several new sites in the Stone Canyon area.

II. INTRODUCTION

This report period was largely devoted to completion of repairs to our new vibrator system, preparatory to initiating field work in the spring. Once in the field, tests were conducted of (1) vibrator stability and (2) the stability of the hammer-seismic system assembled for downhole measurements of near-surface travel-time corrections at source and receiver sites.

III. PRE-FIELD SYSTEM REPAIRS

Vibrator Truck. Steering and brake problems discussed in the previous technical report were improved substantially, to the point that the vehicle was considered safe on the highway.

Vibrator. Pre-field testing at high drive levels resulted in failure of one cylinder in the anti-oscillation system (described in the previous technical report) and one lift cylinder. These were improved during repair in an attempt to prevent similar problems in the future.

Recording Truck. The recording truck is a military surplus vehicle of indeterminate age. The eight auxiliary batteries providing power to the instruments (see Technical Report #3) have been replaced with larger units to extend operating time. This added more weight to the already overstressed vehicle suspension and enhanced steering difficulties. The heavy equipment repair firm that has handled the vibrator repairs overhauled and adjusted the steering mechanism and installed heavier rear springs.

IV. EARLY FIELD WORK

Field work commenced in March.

Vibrator Usage. As discussed in Technical Report No. 9, all vibrator sites at the Winery and Stone Canyon monitoring areas have been equipped with concrete pads approximately the size of the vibrator baseplate, surrounded by an asphalt parking apron. Tests in early April showed that the present vibrator (having the advantages over the project's first vibrator of increased baseplate hold-down weight, plus the anti-oscillation system) operates well on the concrete pads without strapping the vibrator to the pad as originally intended. This eliminates a very cumbersome field procedure.

Operating the vibrator at high drive levels continued to cause equipment failures, specifically (1) an anti-oscillation cylinder again failed, (2) certain of the welds anchoring the anti-oscillation system to the vibrator broke, and (3) bolts and electrical connections were not remaining tight.

It was then discovered that reducing the vibrator drive to a level that produced relatively gentle shaking of the vibrator resulted in relatively little reduction in signal level at the 40 m deep borehole geophone at the Winery area south vibrator site. Signal amplitude vs. drive level is shown in Figure 1. Winery area north-south path measurements corroborated this finding. We have decided to suffer the tradeoff of signal loss (about 35%) in favor of greater vibrator reliability, and thus low drive levels (drive=10) are now used routinely. Low drive level may also minimize settling of the concrete pads, which has occurred at several sites, and it may also improve source stability, if, as suspected, decoupling of the vibrator from the concrete occurs at high drive level.

Vibrator Stability. An indication of source stability was obtained from thirty repeated measurements of downhole travel-time using the borehole geophone below the Winery south vibrator site. A single 60-10 Hz vibrator sweep was used for each measurement, with a drive level of 10. The average travel-time of three extrema within the first arrival waveform varied over a 0.17 msec range with a standard deviation of 0.04 msec. This indicates errors (±2 standard deviations) can be expected of about ±0.1 msec due to source instability. This is at least an order of magnitude improvement over similar tests made with our previous vibrator (see Technical Report No. 8, Figure 2). In practice, since the normal full-path (as opposed to borehole) monitoring records are averages of a number of vibrator sweeps, the final error due to source instability should be less than the 0.1 msec if the errors are random, as they seem to be from the brief tests done to date.

This measurement system, using the vibrator as source and a borehole geophone as receiver, will be used routinely to measure corrections for variations in near-surface travel-times.

A series of further stability tests are planned to establish the precision and accuracy levels attainable with the modified field system:

1. Repeated full-path measurements over several hours time will be made to test the stability of signals received at the recording sites.

2. Source reproducibility will be tested by repeatedly reoccupying a vibrator site, while turning off all equipment between measurements.

Hammer Measurements. Corrections for variations in very near-surface travel-time under each recording site will be made using a hammer source and borehole geophones. The measurement system assembled for this purpose is shown in Figure 2. The signal processor is the real-time correlator unit which normally is used in its correlation mode during the routine data collection with a vibratory source, but here used in its "stacking" or signal-averaging mode for hammer measurements. The "hammer pad" consists of a steel plate welded to a cage of reinforcing bar which has been set in concrete. The hammer is a 4 pound plastic-faced mallet, the head of which is filled with fine lead shot to reduce rebound. The pad is struck with relatively light blows, the hammer head essentially dropping under its own weight from a height of about 40 cm. A geophone used for triggering the correlator is clamped to a projection of the steel plate. The interface or trigger box outputs a trigger pulse when the trigger geophone signal crosses a threshold. It is hoped that this arrangement will result in a stable source function and stable triggering throughout the duration of the project.

Typically, for a single measurement, 100 pulses are stacked to obtain a high signal-to-noise ratio, using a 50 msec time window with 0.1 msec sampling interval. An example of a longer window is shown in Figure 3, made using the 100 m deep geophone at the Winery area north-west recording site in the San Andreas fault zone. Repeated measurements of the travel-time of the first deep trough of the waveform had a standard deviation of slightly less than 0.1 msec.

Initial Monitoring Data. The first monitoring data were collected with the new vibrator system on the Winery area north-south path on 2 April. For comparison with previous data, the vibrator was operated on the dirt and the vibrator position and geophone array used were identical to those used during the 1977-79 monitoring period. Corrections were applied to account for known differences in signal relays and phase relationships between the new and old systems. The resulting first arrival travel-time was approximately 820 msec, which compares well with the values of 817 to 820 msec for early April during the spring periods of 1978 and 1979 (see Technical Report No. 9, Figure 3).

The present vibrator operating on the dirt at high drive level produces a signal strength roughly 2 to 3 times that of the old vibrator. Operating the new vibrator on the concrete pad produces little or no reduction of signal strength. With reduced drive level (drive=10), the new vibrator operating on the concrete pad still produces a signal amplitude that is roughly 1 to 2 times that of the old vibrator.

V. CONCLUSIONS

As presented in Technical Report No. 9, one significant limitation to effective travel-time monitoring with the previous vibrator was found to be measurement error due to source instability. While certain tests remain to be done, the initial stability tests discussed above indicate that systematic sources of measurement error are now insignificant, and thus measurement precision will depend on such parameters as the number of vibrator sweep averaged, sweep bandwidth, and background seismic noise level. This is an important (and satisfying) step forward.

Similarly, the stability of repeated borehole measurements at both vibrator and recording sites assures that high precision corrections can be made for the large seasonal travel-time variations observed previously to dominate the long-term data.

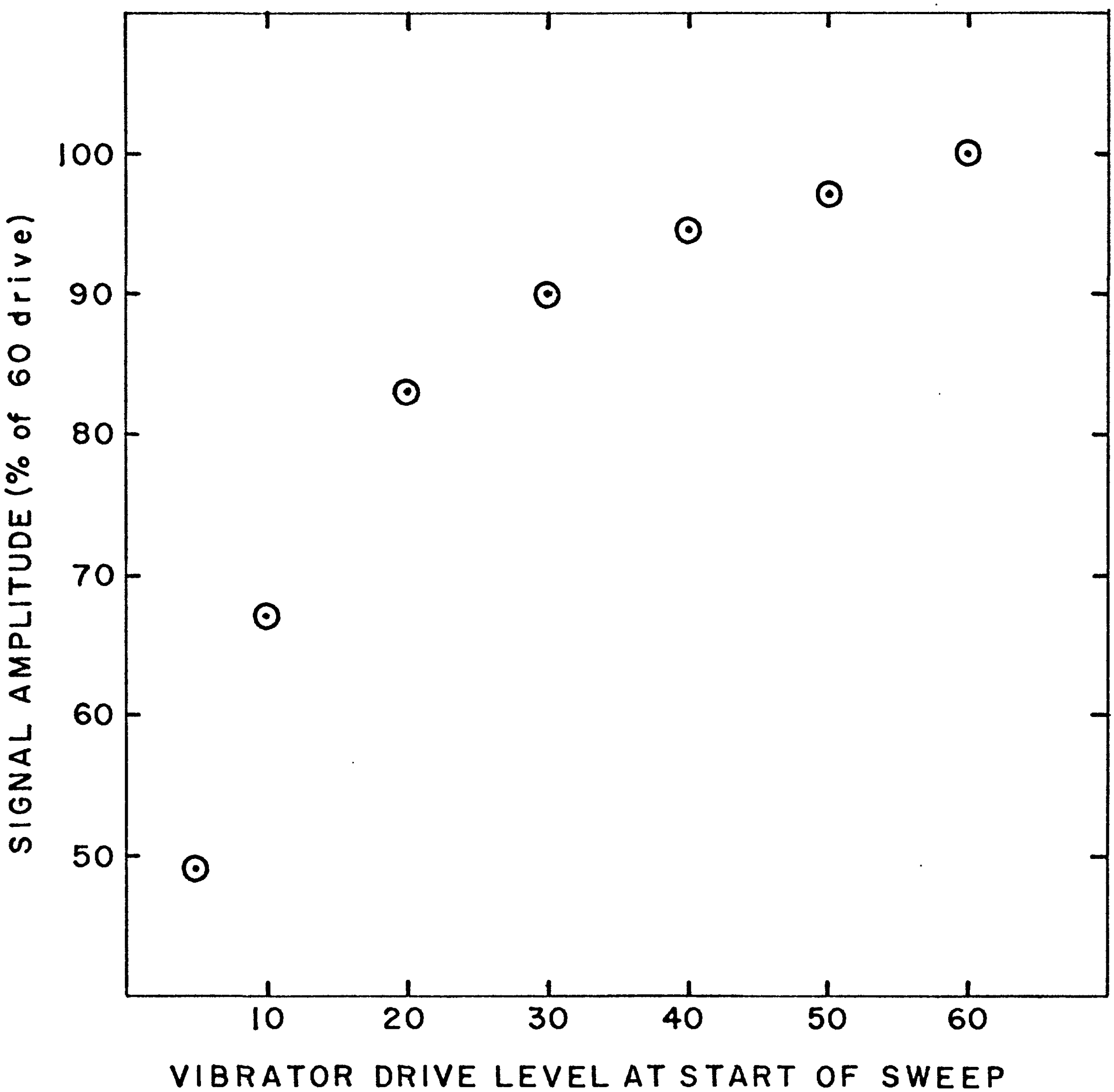

Figure 1. Vibrator drive level (at the start of a 60-15 Hz sweep) versus amplitude of the signal received at a borehole geophone 40 m below the vibrator. The severity of shaking of the vibrator as observed by the operator was significantly reduced below a drive level of 20. A drive level of 10 has been chosen for routine monitoring operations.

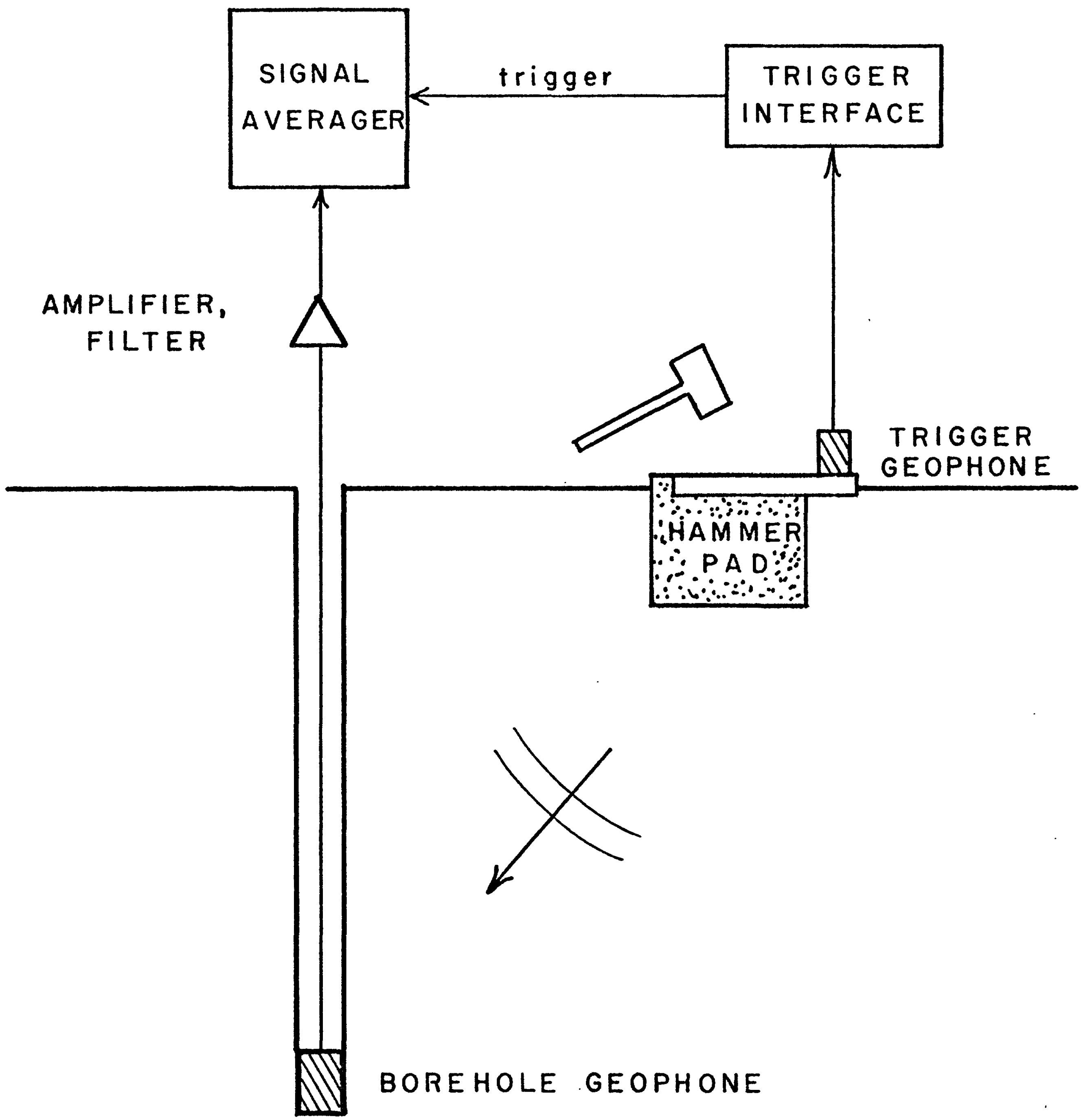

Figure 2. System used for monitoring of near-surface travel-times at recording sites. A four pound, soft-faced hammer is used to strike a steel plate set into a block of reinforced concrete measuring approximately 12" x 12" x 8" deep. The signal from a geophone clamped to the steel plate triggers the recording system's correlator which is used in its signal-averaging mode.

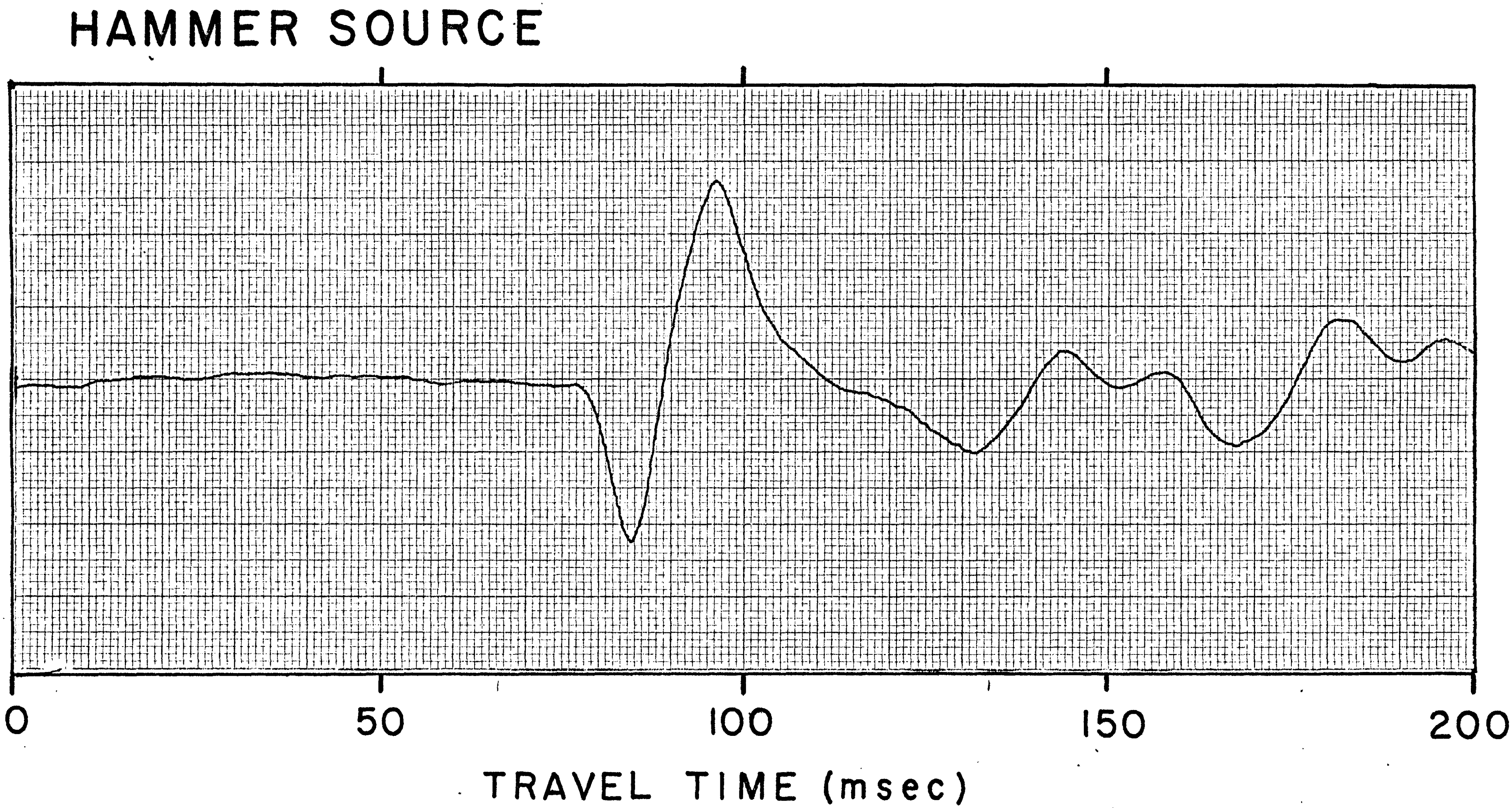

Figure 3. Vertical-component seismogram produced by the system shown in Figure 2 after 128 hammer blows. The borehole geophone used was 100 m deep.