MISCELLANEOUS PAPER S-69-30

DEVELOPMENT OF A VIBROPACKER SYSTEM FOR INDUCING POLARIZED SHEAR WAVES AND COMPRESSION WAVES AT DEPTHS

by

R. F. Ballard, Jr.
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Sponsored by

Assistant Secretary of the Army (R&D)
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ARMY-MRC VICKSBURG, MISS.

FOREWORD

This investigation was funded by Department of the Army Project 4A061101A91D, "In-House Laboratory Independent Research Program," Item AM, sponsored by the Assistant Secretary of the Army (R&D). The investigations were conducted by personnel of the U. S. Army Engineer Waterways Experiment Station (WES) in connection with the feasibility of using the WES borehole vibropacker system to induce shear waves at various underground depths and of utilizing the new automatic correlator as the prime tool for data reduction and interpretation. The field investigations were performed at the WES during the months of May 1966, December 1966, and April 1967, and at the Pre-GONDOLA I test site near Fort Peck, Mont., during October 1966. Field support in Montana was provided by the U. S. Army Engineer Nuclear Cratering Group (NCG).

Personnel of the WES who were actively engaged in the data acquisition, analysis, and report phases of this investigation were Messrs. R. W. Cunny, Z. B. Fry, R. F. Ballard, Jr., R. E. Leach, and F. K. Chang of the Soils Division and Messrs. H. C. Greer III and E. T. Estes of the Instrumentation Branch. This report was prepared by Messrs. Ballard and Leach.

The work was performed under the general supervision of Messrs. W. J. Turnbull and A. A. Maxwell, Chief (retired) and Acting Chief, respectively, of the Soils Division.

COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE, were Directors of the WES during the conduct of the investigation and publication of this report. Messrs. J. B. Tiffany and F. R. Brown were Technical Directors.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
feet per second	0.3048	meters per second

SUMMARY

This report describes the development of the U. S. Army Engineer Waterways Experiment Station (WES) borehole vibropacker system and a technique for applying the apparatus for generation of vertically polarized shear waves at any predetermined point within an existing borehole. Methods of receiver and transducer placement and orientation are also discussed. In addition, techniques of data acquisition and interpretation are presented along with comparisons of data from in situ surface vibrations and laboratory dynamic shear test data. When comparing shear and compression wave velocities, it was found that a good correlation exists between the three comparable test methods: the vibropacker system, surface vibrations, and laboratory testing.

As a result of this feasibility study, it was determined that the vibropacker system will prove to be a useful tool for the determination of shear and compression wave velocities.

DEVELOPMENT OF A VIBROPACKER SYSTEM FOR INDUCING POLARIZED SHEAR WAVES AND COMPRESSION WAVES AT DEPTHS

PART I: BACKGROUND, PURPOSE, AND SCOPE OF STUDY

1. Site exploration work often requires a large number of borings to adequately define the subsurface stratigraphy, the geologic conditions, and the engineering properties of the underlying materials. A reduction in exploration costs and a better definition of pertinent properties of the subsurface materials can be realized by reducing the number of boreholes and by using seismic methods to delineate the occurrence and character of the underlying materials. An increasingly important seismic technique often called "crosshole shooting" involves the generation of a seismic signal in one borehole and the detection of this signal in adjacent boreholes. Information concerning the subsurface material between the holes is derived from an interpretation of the transmitted seismic signal record as the source and detector are sequentially positioned along their respective boreholes.

2. The most common method of generating the crosshole signal is by the use of an explosive; a suitable velocity pickup or geophone is used to receive the signal. While this method is economical and convenient, it has certain disadvantages:

- a. The data obtained are limited to the first arrival time and amplitudes of the peak motion.
- b. The coupling of the explosive energy to the wall of the borehole is not constant.

c. Each detonation pulse has a somewhat different pressure-time signature.

There is a need, then, for an improved seismic system that can overcome these shortcomings and provide additional information, such as signal attenuation properties and shear wave propagation velocities, for the subsurface material. A feasibility study and critical evaluation of a vibropacker controlled frequency and energy system are the purposes of the report. It is anticipated that data obtained on the physical properties of a test site can lead to insight in geologic stratification interpretation and even energy transfer coefficients. Such parameters are currently lacking in most state-of-the-art ground motion prediction equations.

3. The scope of this study has been limited to feasibility studies and mechanical development of test techniques and equipment necessary for the controlled propagation of shear and compression waves at depths. Actual field data presentations are restricted to only those that are considered necessary to demonstrate the feasibility of the vibropacker system. In addition, purely as a matter of interest, various tests were performed using acoustically coupled sound waves as an energy source. Comments on these tests are also included in this report.

PART II: TEST PROGRAM

Location and Description of Test Sites

4. The location selected on the U. S. Army Engineer Waterways Experiment Station (WES) reservation was an area near the Soil Dynamics Test Facility where vibratory and surface refraction seismic surveys had been conducted. A general layout map of the test area is shown in plate 1. The site was a level area with soil that consisted of a uniform silty clay and clayey silt to a depth of approximately 30 ft with silt, clay, and sand layers down to limestone at 126 ft as shown in part on the boring log in plate 2 and in greater detail in plate 3. The water table in the area was at about 16 ft below the surface during the conduct of tests.

5. An abbreviated study conducted in May 1966 made use of three existing shallow boreholes drilled for previous ground-motion tests; the total distance between the first and third hole was 40 ft. The boreholes were not cased and had caved in below the water table. A study conducted in December 1966 utilized three 5-1/2-in.-diam boreholes located 50 ft apart in a line, as shown in plate 2. Hole 1, which housed the packer, was cased to a depth of 22 ft but caved in at a depth of 35 ft, limiting the tests to this maximum depth. The two receiver pickups were located at the same depth as the packer in holes 2 and 3, which were not cased. The study conducted in April 1967 made use of the latter three boreholes, but they were adapted for more extensive study. The boreholes were re-drilled into the limestone layer 129 ft deep and cased (plate 3).

Incorporated as a matter of secondary interest in this study was hole 4, which was 65 ft from hole 3 and its effective depth was approximately 16 ft (the water table).

6. The location selected for the tests in October 1966 was a relatively level area consisting of Bearpaw shale at the Pre-GONDOLA I test site near Fort Peck, Montana. Four 5-1/2-in.-diam boreholes drilled in a line were 20 ft apart and 25 ft deep. Another borehole approximately 150 ft away was available and was used to obtain data at a greater distance from the pickups.

Equipment Development

7. A recent concept for evaluating the properties of an in situ mass is directed toward measurement of attenuation and wave shape characteristics through earth materials at depths between two or more points in a horizontal plane. The energy source normally utilized for generation of stress waves in a media has been seismic blasting caps and/or other explosives, which results in the initiation of a relatively uncontrolled amount of energy over a wide range of frequencies. Not only is the amount and the frequency of energy uncontrolled, but repetitive tests have not been successfully conducted with explosives; thus, an improved energy source was needed.

First WES packer design

8. WES, May 1966. Shortcomings of current test techniques prompted a feasibility study by the WES using a vibrator mounted on a drill rod attached to a packer that was placed in firm contact with the sidewall

at different depths. The packer developed for these initial tests, May and October 1966, was an inflatable rubber tube approximately 5 in. in diameter. It required about 35-psi internal pressure to hold it securely against the sidewall.

9. Pre-GONDOLA I. A field party began work at the Pre-GONDOLA I test site on 22 October 1966. The Nuclear Cratering Group (NCG) provided a drill rig for packer placement and for drilling 5-1/2-in.-diam boreholes 25 ft deep. The holes were spaced in line 20 ft apart. Triaxial velocity transducers were placed in two separate holes 20 ft apart and the vibrator-packer arrangement was placed in the first borehole in the line and inflated to 35 psi. The first tests were conducted by sweeping the frequency range from 15 to 1000 Hz with the vibrator and noting predominant frequencies received by the transducers; then a tone-burst generator was used to gate (i.e., interrupt) the signal so arrival times could be observed. Various depths of packer-transducer placement were tried.

10. The second-phase experiments were conducted as a matter of interest to determine the effectiveness of a loudspeaker as signal source. This was accomplished by placing the speaker over different boreholes spaced at various distances from the receiving pickups. Again, frequency sweeps were utilized to scan for maximum amplitudes. The boreholes, of course, resonated at different frequencies, depending upon the effective depth to water. Results were highly encouraging.

11. Observations. The following tentative observations were made at this point in the investigation:

a. Signal transmission through rock materials is feasible with both vibropacker and acoustical sources.

b. Vertical particle velocities are predominant.

c. Pulsed signals will aid in the establishment of wave arrival times.

d. Vibropacker signals can be received at distances as great as 40 ft from the source.

e. Acoustical signals seem to transmit much better and considerably further than the vibrator. Reliable signals were received 150 ft from the acoustical source.

Prototype vibropacker system

12. As previously stated, earlier tests conducted at the WES utilized a vibrator mounted on a drill rod attached to an inflatable packer and triaxial pickups that were located in separate borings up to 40 ft from the signal source. Since recognizable signals were transmitted and received both at the WES and Pre-GONDOLA I test sites, steps were taken to fabricate an improved packer assembly that would provide more positive physical contact within the borehole. Photograph 1 shows the prototype packer in the expanded state, which reaches a maximum of about 8 in. In principle, the newly designed packer operates like a scissor jack. A double-acting air cylinder attached to the scissor arms of the assembly provides the means for extending or collapsing the friction contact mechanism. The friction contact portion of the packer consists of two slightly curved face plates that are approximately 4 in. wide by 12 in. long. In practice, the packer assembly is attached directly to an N acme size drill rod and lowered to a predetermined depth in a borehole. Two flexible air lines attached to the packer air cylinder are guided into the hole as the assembly is lowered. Upon reaching the designated depth, the air cylinder is activated by a portable air compressor regulated for

a pressure of 150 psi. The rod stability is then tested, and a retaining rope fastened to the drill rod protruding about 3 ft from the borehole. A small electrodynamic vibrator (50-lb force) is then threaded directly to the drill rod.

13. The tests utilized the improved packer and two triaxial pickups placed separately in 5-1/2-in.-diam boreholes. The three boreholes were located in line 50 ft apart. Both transducer arrays and the packer were secured at a depth 32 ft below ground surface. Before the tests started, two additional triaxial transducer arrays were buried flush with the ground surface approximately 6 in. from the borings housing the other transducers. It should be noted that the pickups in the borings were secured by a double leaf spring arrangement, which, when released, forces the pickup housing against the borehole wall nearest the signal source.

14. As a result of these tests, the following tentative observations were made:

a. The basic prototype design of the packer is sound.

b. The prototype suffered slight damage in the scissor arms during use.

c. Signal transmission through loess is feasible to distances of at least 100 ft and likely further.

d. Pulsed signals are necessary for the establishment of wave arrival times.

e. Phase velocity can be determined.

f. Apparent correlation between surface vibratory data and the vibropacker system exists.

15. The following recommendations were also made:

- a. A larger, structurally stronger version of the basic packer design should be fabricated.
- b. Further testing should be done over a wide range of packer and transducer depths.
- c. Data acquisition should include magnetic tape and bandpass filters.
- d. Additional comparisons between surface vibratory and vibro-packer techniques should be made.

16. Upon inspecting the equipment after the December 1966 study, it was seen that the packer design was basically sound but would have to be strengthened to withstand the force it was exerting on the wall. To further refine the method of orienting the transducer, an air-actuated piston was developed to aid in transducer placement (photograph 2). With the aid of alignment spikes on the connecting air pipe and a transit, the transducers were properly oriented within the borehole as each section of pipe was added. These equipment changes were used in the April 1967 study.

Technique Development

Equipment

17. After consulting several manufacturers, it was established that technology had not sufficiently developed to produce an in-hole vibrator that could be fitted into a 5-1/2-in.-diam borehole and that could withstand the pressures associated with operation at depths to several hundred feet. Knowing this, a technique was developed using an existing vibrator with the energy being transferred from the surface through drill rods to a packer located at some depth.

18. At shallow depths, the packer could support the static weight of the drill rods and vibrator. For greater depths, a new technique was devised whereby the static weight of the system was transferred to the borehole casing by using a piece of strong, flexible rubber fitting around the drill rod and supported by the casing. The static-weight transfer of the system was used to avoid exceeding the strength capability of the packer and/or the material subjected to tests.

19. While investigating possible energy sources, an acoustic suspension loudspeaker system was tried. The speaker was cushioned with foam rubber and placed over a borehole facing down into the hole. Previous tests have confirmed that a borehole will resonate at certain frequencies in accordance with the physical laws of closed pipes. Resonance frequencies of closed pipes (boreholes) are functions of pipe length. If numerous test frequencies are desired, it has been found that borings can be filled with water or plugged to predetermined depths to influence resonance frequencies.

Test procedure

20. The test procedure adopted for this program entailed the use of multiple borings located in a straight line. Borehole depths and spacing were somewhat arbitrary in the earlier feasibility studies. During the latter phase of testing, however, borings were made into limestone so that the performance of the vibropacker could be evaluated both in rock and cohesive materials.

21. To avoid losing the packer in soils subject to caving in, the signal source borehole was cased to within 5 ft of the depth to be tested, thus allowing the packer, when positioned in the borehole, to be

in direct contact with the soil mass just below the casing. Obviously, tests were run at the greatest depths first. The packer and casing were withdrawn together, maintaining the 5-ft differential as shallower zones were investigated.

22. To monitor the signal, transducers were placed in boreholes that were known distances away from the energy source. The transducers were positioned at the same depth as the packer; thus the straight-line distance divided by the signal time arrivals yields the phase velocity of the induced wave. Orienting the triaxial transducers at shallow depths was done visually. Using fuse wire to compress the retaining springs, the transducer was lowered freely to the desired depth in the hole. Then the fuse wire was ignited, thus releasing two springs to hold the pickup securely against the sidewall. An air-actuated transducer placement piston was used at lower depths or at depths below the water table (photograph 2). With alignment spikes attached to the connecting air pipe, the transducers could be oriented at any depth. When air pressure was applied, the piston pushed the transducer out of the container, thereby releasing the springs to hold it against the wall. Transducers were also placed at the surface beside the receiver holes to detect stray signal or noise occurring there.

23. To determine the signal frequency for best results with either the vibrator or the loudspeaker, a frequency sweep was conducted from 15 to 1000 Hz, and the frequencies producing greater amplitudes were used. The signals received by the pickups were normally recorded on an oscillograph and monitored on an oscilloscope. Manual reduction of these data

was simplified by causing an interruption in the signal source. A tone-burst generator was used to gate the signal emitted from the vibrator or the speaker so that wave arrivals could be more readily identified. One difficulty with the manual correlation technique involved phase matching of signals whose amplitude builds up or increases to a constant level as a function of time (this is most prevelant with the loudspeaker signal source). To overcome this problem, it was decided that the data should be recorded on magnetic tape for automatic data processing with an analog correlator. To prepare the data for the correlator, bandpass filters were included in the system, and frequency sweeps were run instead of the tone bursts because slow frequency sweeps allow the correlator a longer time span in which to determine the time arrival of a specific frequency at each transducer.

Test Results

First WES packer design

24. WES, May 1966. The brief study made at the WES in May 1966 served to initiate the WES borehole packer system concept. No data were recorded, but visual monitoring of an oscilloscope indicated that signals could be transmitted through loess by both the vibropacker source and the acoustically coupled loudspeaker system. These signals were received 40 ft from the source.

25. Pre-GONDOLA I. The next study in October 1966 at the Pre-GONDOLA I test site resulted in the first data measurements by the WES in rock material. The results indicated signal transmission through rock

materials is feasible with both the vibropacker and acoustical sources. Signals were received from distances of 40 ft with the vibropacker and up to 150 ft using the acoustical device. Wave shapes and amplitudes recorded in various borings denoted that the vertical particle velocities were predominant as compared to radial and transverse velocities. This indicates that the transmitted wave is shear type in nature.

Prototype vibropacker system

26. WES, December 1966. A study was conducted at the WES using the new positive-contact packer system concept shown in photograph 1. Various depths of packer-transducer placement were tried; however, the boring which housed the packer rapidly deteriorated and caved below 35 ft. Therefore, since casing was present for 22 ft from ground surface and cavities existed for several feet beneath the casing, only one packer position (32 ft) was used as shown in plate 2.

27. Numerous oscillograms were made of frequency sweeps and various individual frequencies. Several predominant amplitudes were noted at specific frequencies. Plate 4 shows data recorded from all four transducers as a result of a 38-Hz gated signal. By tracing the vertical transducer recording at the 32-ft-depth in hole 2 on a transparent sheet and overlaying and matching the characteristics of this wave on the signal recorded by the vertical transducer in hole 3, it was possible to correlate the two signals manually and, thus, to determine the phase velocity of the induced wave. A similar example of a 200-Hz gated pulse is shown in plate 5. Knowing that the distance between boreholes 2 and 3

was 50 ft and that the time lag between transducers was about 87 msec at 38 Hz, a velocity of 575 fps was determined. Likewise, the time lag determined between transducers at 200 Hz was about 78 msec, thus showing a slightly higher velocity of 640 fps.

28. During April 1966, conventional surface vibratory tests were conducted for another investigation in the near vicinity of the boreholes used for packer evaluation. The test data showed a slight trend of shear (or Rayleigh) wave velocity increasing with depth. At a depth of 31 ft, the average velocity was about 610 fps as shown in plate 6. For comparative purposes, the velocities determined with the packer at 38 and 200 Hz were plotted at a depth of 32 ft.

29. WES, April 1967. A final study was conducted at the WES test site incorporating a new air-actuated piston for placing the transducer and an analog correlator for reducing the data. The boreholes were drilled into limestone and cased (see plate 3). With elimination of the danger of the hole caving in, transducers were oriented successively at the following depths: 128, 121, 111, 91, 51, 31, and 11 ft. A test was run at each of these depths with the packer and the pickups located at corresponding depths. It should be noted that the pickups were held against the casing by springs, but the casing was withdrawn 5 ft above the depth of the packer prior to each test so that the packer would be in direct contact with the soil as previously described in test techniques.

30. A portion of the data from the vibropacker tests is presented in table 1 and plotted in plate 7. The data in plate 7 are plotted for frequencies between 27 and 345 Hz except for the tests conducted in the

limestone at a depth of 128 ft. In this thin layer, the lower frequencies (25 and 32 Hz) produced flexing* of the limestone and, therefore, an erroneous low velocity. In some cases, the data were very difficult to interpret. At a depth of 111 ft, a shift of one phase cycle can result in a radical velocity difference as indicated by the questioned point. Although this data point would appear to be more nearly compatible with previous data, manual correlation would not normally interpretate it to be at this point. Also presented for comparison are on-the-surface vibratory data and laboratory tests performed at comparable in situ confining pressures in the WES dynamic test apparatus on boring samples from the immediate area. It is apparent that the surface vibratory and the laboratory data are somewhat lower than that obtained with the packer.

31. The crosshole vibratory velocities increase gradually from 745 fps at 11 ft to 1510 fps at 111 ft. The surface vibratory velocities (Rayleigh) increased from approximately 500 fps at 11 ft to 876 fps at 111 ft. At 128 ft, low-frequency excitation of the thin limestone layer by the vibropacker apparently induced oscillations in a flexural mode;* however, high-frequency pulsed signals were of excellent quality and gave reasonable values of about 5000 fps shear wave velocity. The crosshole velocities are slightly greater than the surface values, but they show good correlation down to approximately 60 ft. From 60 to 120 ft, the crosshole values increase at a greater rate than the surface data. No surface vibratory velocity data in the limestone are available for

*Kolsky, H., Stress Waves in Solids, Dover Publications, 1963.

comparison; however, laboratory tests on the limestone specimen yielded a shear wave velocity of 4000 fps and a compression wave velocity of 10,000 fps.

32. As a supplement to these tests, hammer blows applied to the side of the drill rod were utilized for a compression wave source. The compressional velocities were 1050 fps from 0 to 11 ft, 5500 fps from 31 ft to limestone, and 10,000 fps for limestone. Plate 8 shows refraction seismic data for another investigation obtained along the line of boreholes prior to drilling. It will be noted that agreement between data shown in plate 8 and data shown in table 1 is quite good. Magnetic tapes recorded during this test series were subjected to automatic analysis with the correlator. It was found that the tapes were not recorded in a manner so as to be entirely compatible; however, wave arrival times at certain frequencies could be determined.

Acoustical tests

33. Also, a speaker was used as an acoustically coupled shear wave source. With the speaker aimed down into the hole, the resonating borehole produced good wave shapes, but the amplitude buildup was too slow to produce reliable data that could be manually correlated. No data were recorded on tape during this test to use with the analog correlator.

PART III: DISCUSSION AND CONCLUSIONS AND RECOMMENDATIONS

Discussion

34. As a result of the preceding studies, several tentative observations were made. For manual reduction of wave arrival times, pulsed signals are necessary to distinguish the arrival of a particular frequency peak at each pickup. Data reduction is still sometimes difficult for higher frequencies, which closely correspond to noise level frequencies, even when the signals are pulsed. This is partly due to the time required for the buildup of the source amplitude to readable amplitudes with each pulse at the receiver. Data recorded on magnetic tape in the April 1967 studies at WES were used with a correlator, which by nature is a signal-to-noise discriminator. These tapes were not entirely compatible, and for that reason, no data per se are presented in this report. It was determined that an analog correlator could be used for reduction of these wave arrival times. This would require that all data be taken on tape and that band-pass filters be used to filter out high noise levels in the area. Also for best results with the correlator, frequency sweeps should be run instead of pulsed signals so the correlator will have a reference frequency to select as the signal arrived at the pickups.

35. As a result of the tests conducted throughout this study, it became apparent that a good correlation exists between surface vibratory velocity data and data from the vibropacker system. The vibropacker data seem to be slightly higher, but the accuracy of the attempt at manual reduction of these data must be considered. Limited data prevent a more

positive conclusion. Another potential of the borehole packer is its use as a controlled energy source for shear wave propagation and signal attenuation studies. The data taken in limestone showed excellent results for data accumulated at a depth of 128 ft. The quality of the results seems to indicate that tests at even greater depths can be achieved and that relatively high frequencies can be used for accurate velocity determinations.

36. The two other supplemental tests, a speaker shear wave source and hammer-blow compression wave source, seem to be effective with certain limitations. The speaker produces good signals by resonating the borehole, but this method is limited to the open depth of the borehole. The amplitude buildup time for a pulsed speaker system is too protracted to manually reduce the data, but the correlator could possibly compensate for this with a steady frequency sweep. The hammer-blow compression wave data correlated well with refraction seismic data from the same area. This represents an inexpensive and reliable way to include a crosshole test series while other data are being taken in the same boreholes.

Conclusions and Recommendations

37. The feasibility study and critical evaluation of a vibropacker system as a controlled frequency and energy source confirmed its practicality. The vibropacker and associated test techniques show that the tool is indeed capable of propagating both shear and compression waves in crosshole fashion at extended depths to distances greater than 100 ft. It is recommended that additional tests be conducted at various test sites for the purpose of

gathering data pertinent to signal attenuation as a function of both frequency and distance. Other supplemental tests, such as acoustically coupled energy sources, have merit and should be considered in future testing.

Table 1

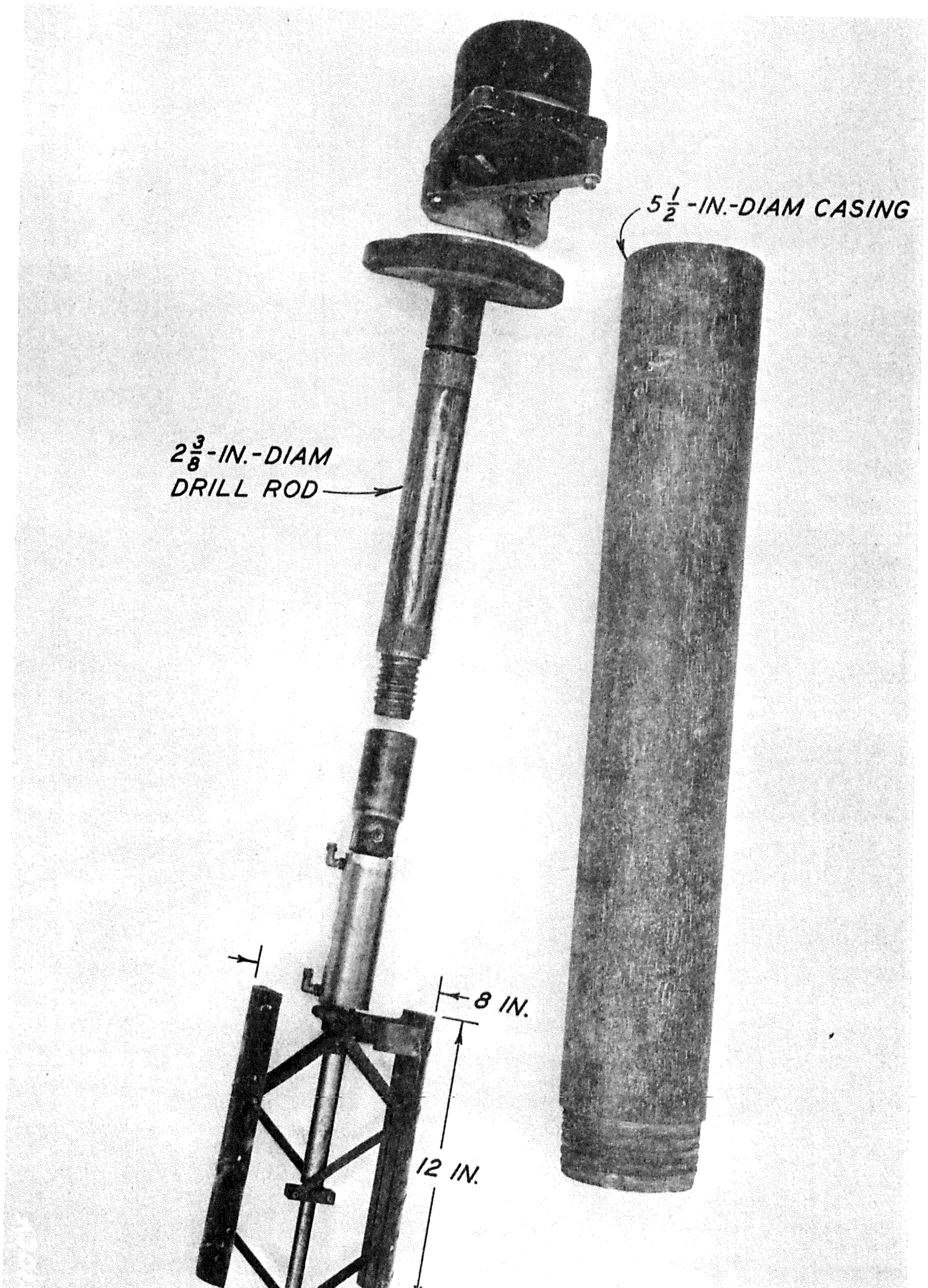
Typical Data from April 1967 Tests

Depth ft	Frequency Hz	Shear Wave Velocity fps	Compression Wave Velocity* fps
11	36	735	1,050
	140	745	
31	45	782	5,500
	105	714	
	252	695	
	345	657	
51	27	833	5,500
	138	782	
	152	782	
91	30	1,470	5,500
	600	2,000**	
	900	2,500**	
111	27	1,510	5,500
	31	710	
	31	1,390	
	910	5,560**	
	950	5,560**	
121	121	4,160	5,500
	184	4,550	
	242	4,160	
128	25	1,560†	10,000
	32	3,130†	
	230	4,550	

* Hammer blows were struck on the drill rod.

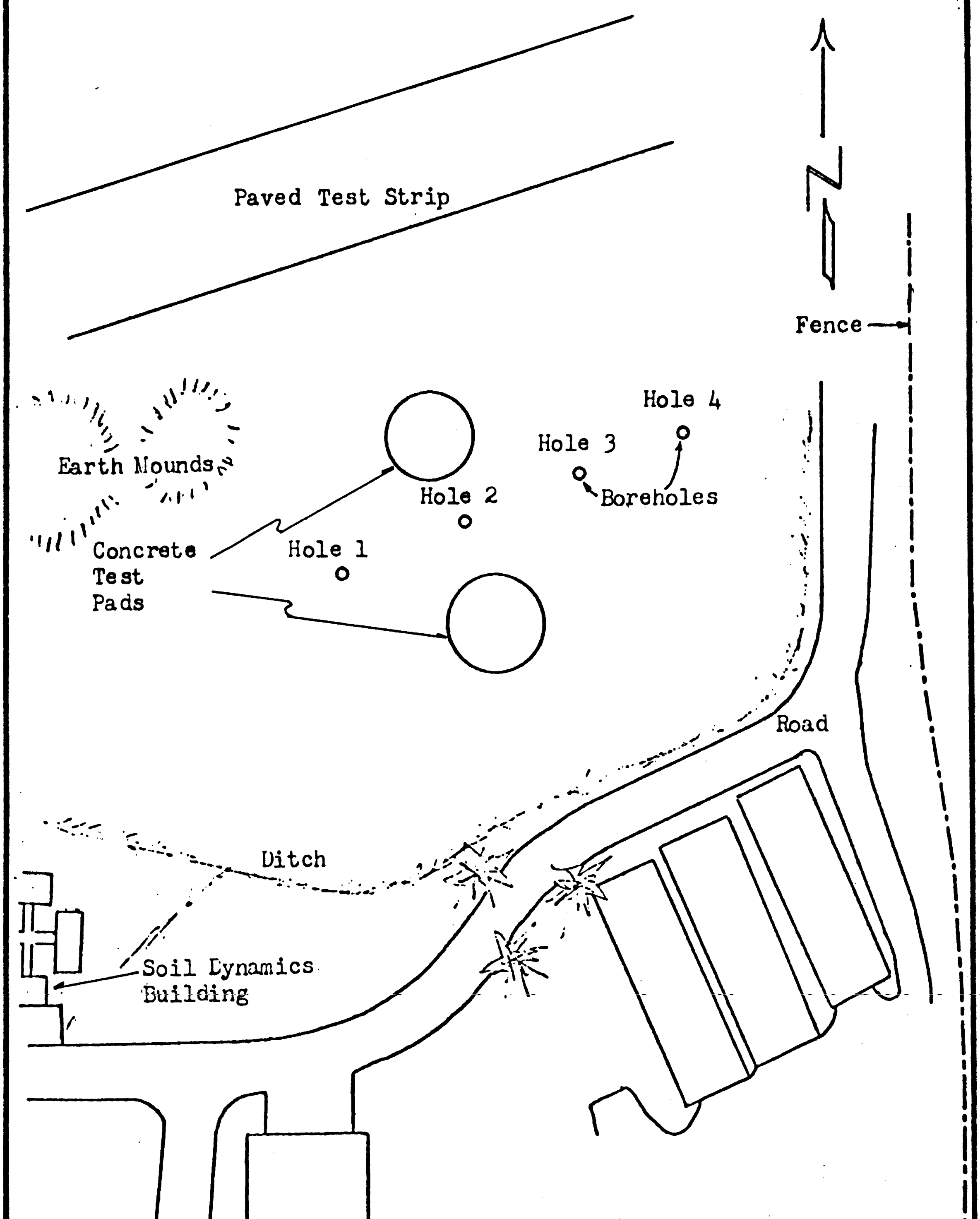
** Data were difficult to interpret and are not shown in plate 7.

† Probable velocity of limestone flexural mode.



Photograph 1. Improved packer assembly

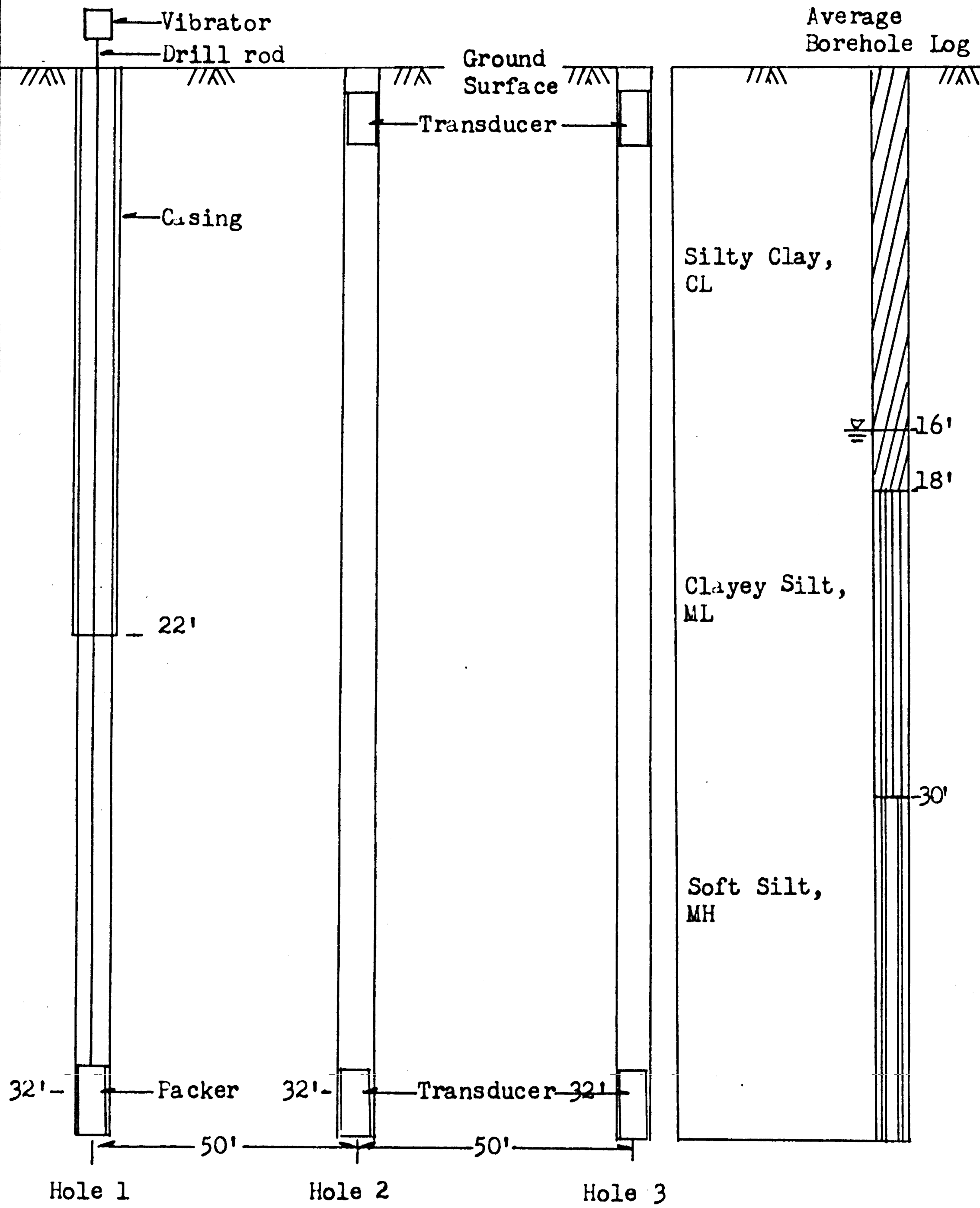
Photograph 2. Air-actuated piston used to aid in pickup placement



Not to Scale

GENERAL LAYOUT OF
WES TEST AREA

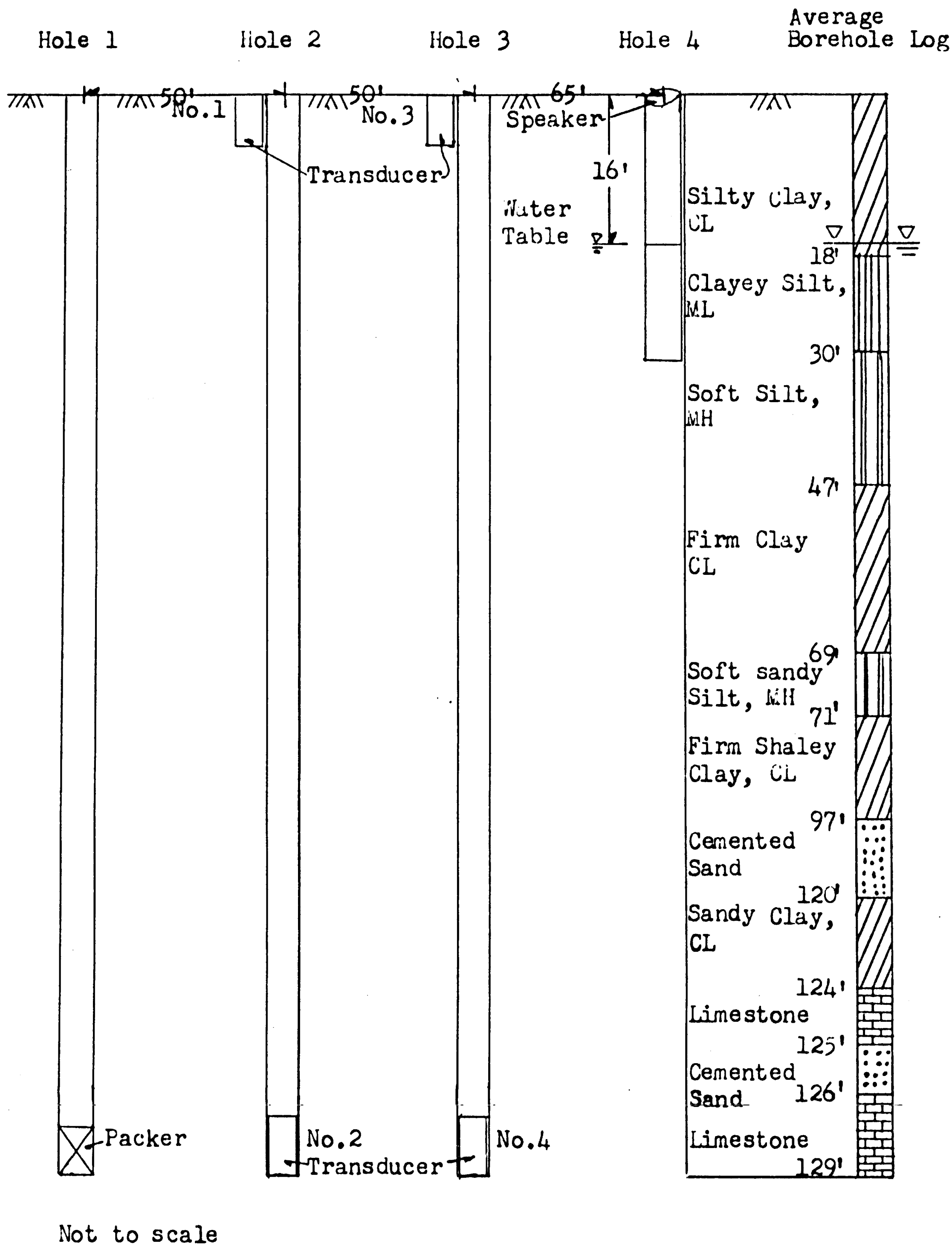
PLATE 1



Note: 5-1/2-in.-diam boreholes
Drawing not to scale

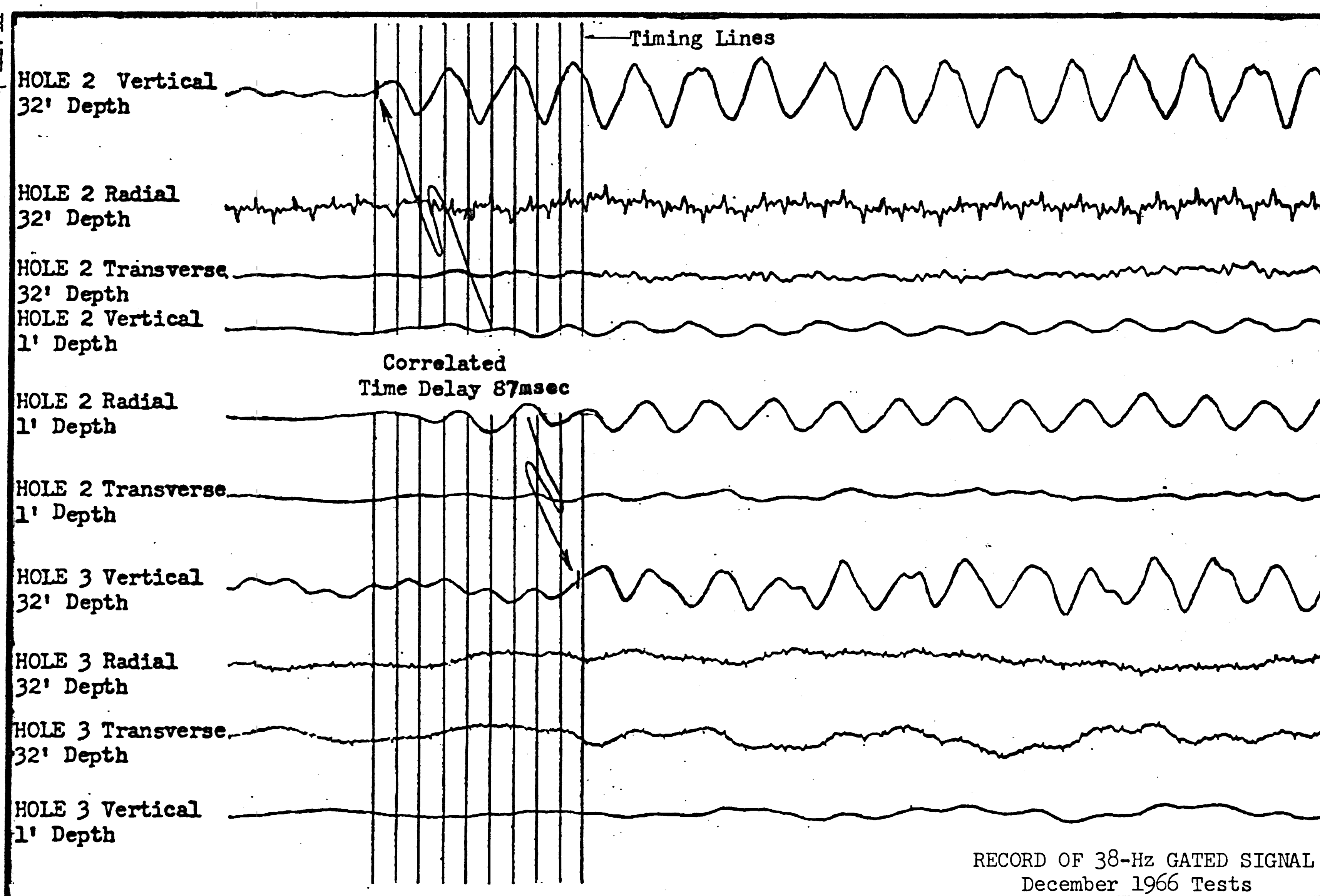
TEST LAYOUT
December 1966 Study

PLATE 2

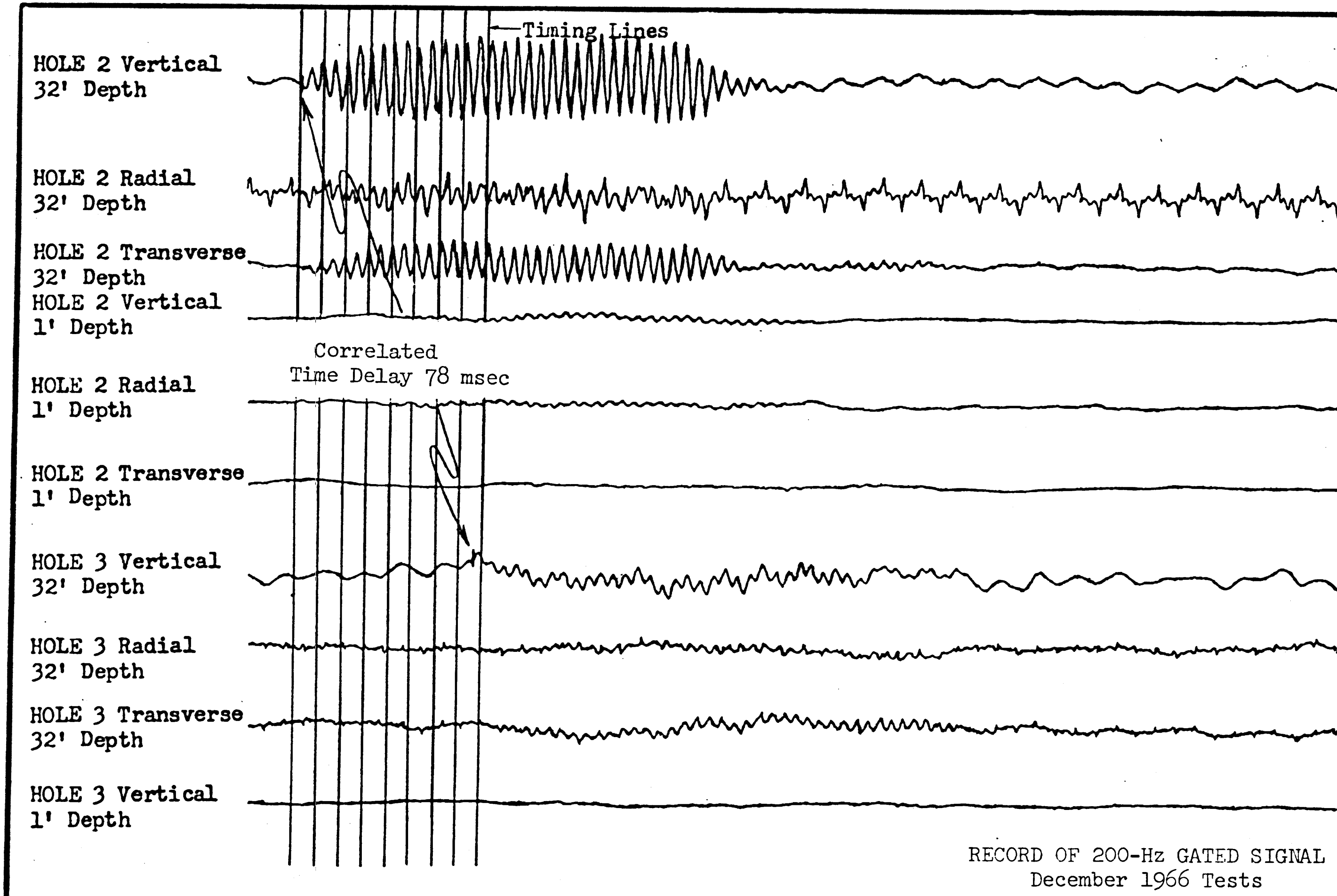


TEST LAYOUT FOR APRIL 1967 STUDY

PLATE 4

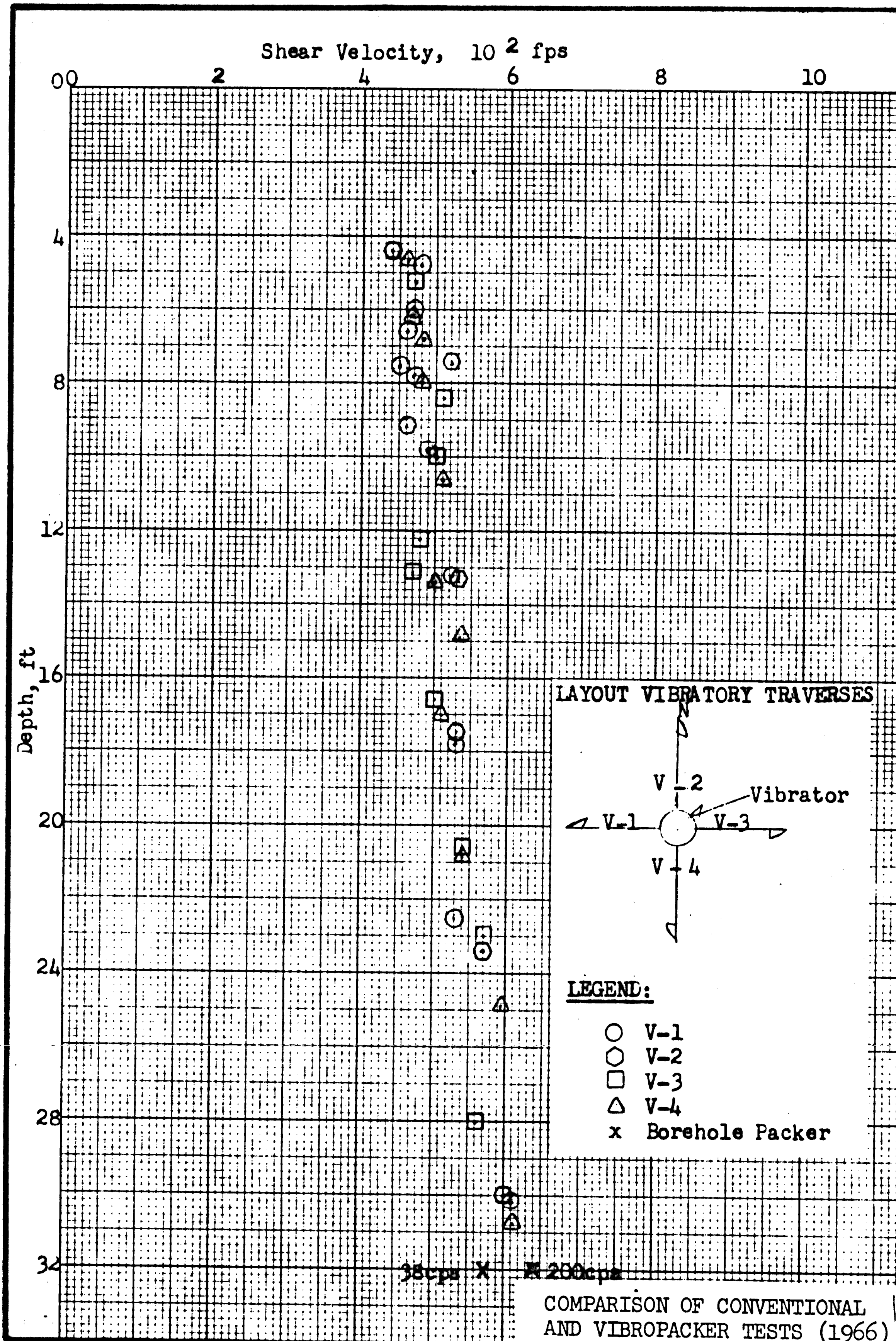


RECORD OF 38-Hz GATED SIGNAL
December 1966 Tests



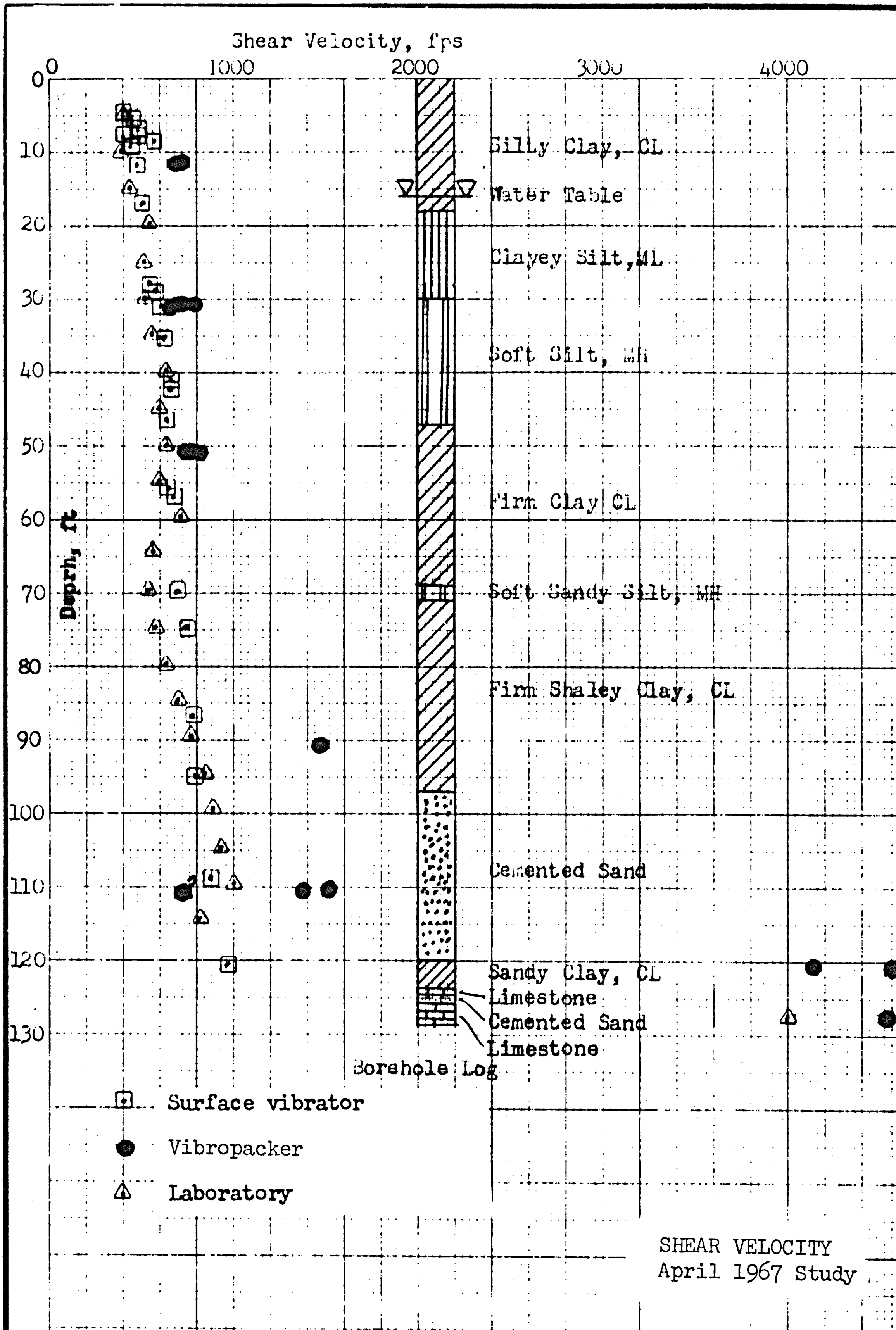
RECORD OF 200-Hz GATED SIGNAL
December 1966 Tests

PLATE 5

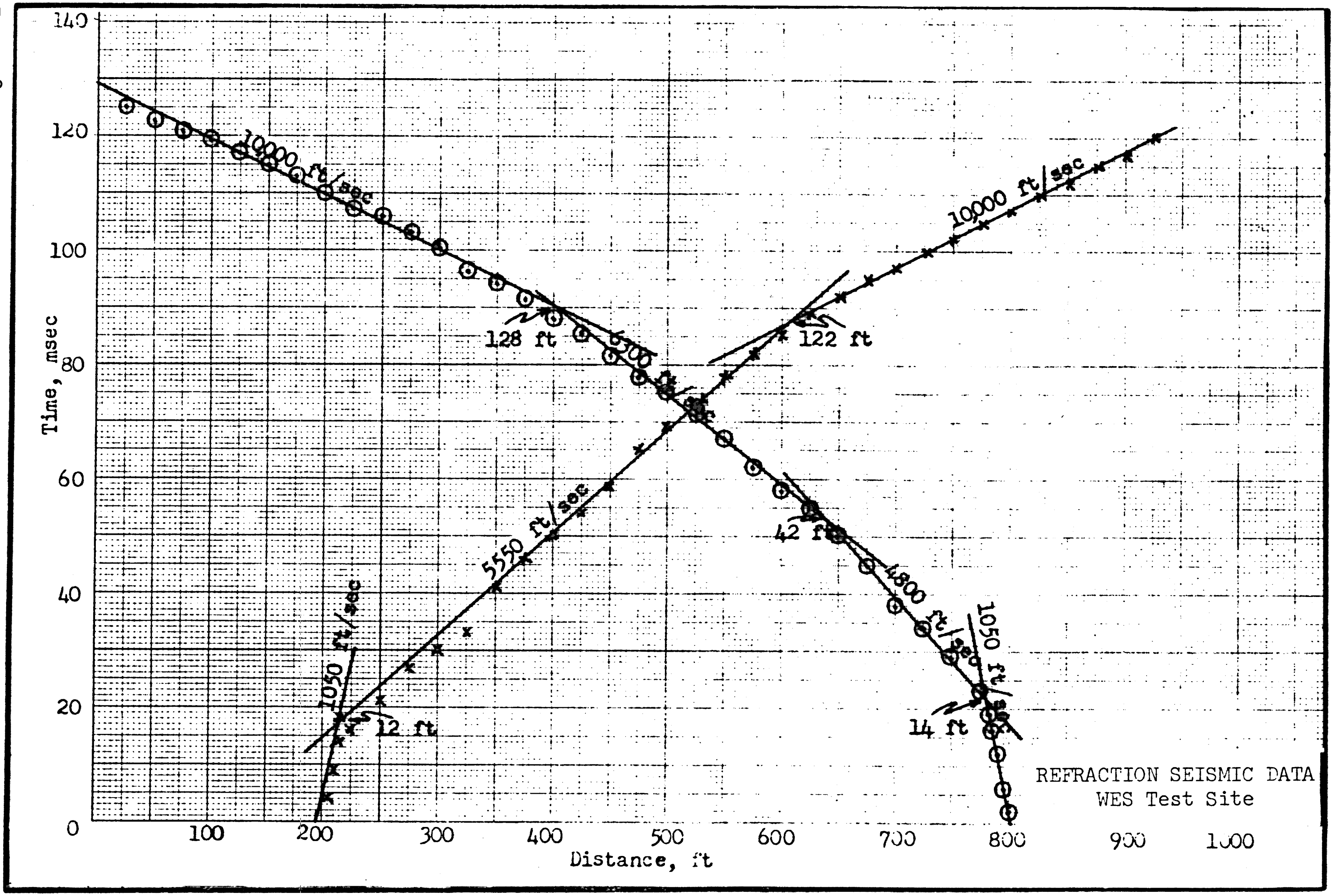


COMPARISON OF CONVENTIONAL AND VIBROPACKER TESTS (1966)

PLATE 6



SHEAR VELOCITY
April 1967 Study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4800 ft/sec
1050 ft/sec
1050 ft/sec
12 ft
14 ft
REFRACTION SEISMIC DATA
WES Test Site

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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DEVELOPMENT OF A VIBROPACKER SYSTEM FOR INDUCING POLARIZED SHEAR WAVES AND COMPRESSION WAVES AT DEPTHS

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13. ABSTRACT

This report describes the development of the U. S. Army Engineer Waterways Experiment Station (WES) borehole vibropacker system and a technique for applying the apparatus for generation of vertically polarized shear waves at any predetermined point within an existing borehole. Methods of receiver and transducer placement and orientation are also discussed. In addition, techniques of data acquisition and interpretation are presented along with comparisons of data from in situ surface vibrations and laboratory dynamic shear test data. When comparing shear and compression wave velocities, it was found that a good correlation exists between the three comparable test methods: the vibropacker system, surface vibrations, and laboratory testing. As a result of this feasibility study, it was determined that the vibropacker system will prove to be a useful tool for the determination of shear and compression wave velocities.

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