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IMPROVED EQUIPMENT FOR A PULSE METHOD OF SOUND VELOCITY MEASURE--ETC(U)

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IMPROVED EQUIPMENT FOR A PULSE METHOD OF SOUND VELOCITY MEASUREMENT IN WATER, ROCK, AND SEDIMENT.

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IMPROVED EQUIPMENT FOR A PULSE METHOD OF SOUND VELOCITY MEASUREMENT IN WATER, ROCK, AND SEDIMENT

by

S. Howard Abernethy

PREFACE

The Marine Environment Division at NEL has been using a pulse-technique method for measuring sound velocity in various materials since 1960 (Shumway and Abernethy, 1961). This memorandum describes the modifications made to the original equipment and notes the use of newer, associated electronic components. These modifications have significantly improved the accuracy of measurements of sound path-length and travel-time through the samples. Much of the material in the original report has been revised. The revised material is included in this memorandum to make it of maximum benefit to those persons who do not have the original version. It is believed this information will be useful in this form to others at NEL and a few persons and activities outside NEL. This memorandum should not be construed as a report, as its only function is to present general information on the measuring techniques used in studies of sound velocity in sea-floor sediments, which is a continuing project.

The writer appreciates the discussions, comments, and aid in the preparation and writing of this memorandum (and development of the equipment) as follows: C.E. Terry and E.C. Henry: handwheel, screw, and associated readout of the path length; H.P. Bucker, Jr., frequency within pulses; E.L. Hamilton: calibrations and accuracy discussions in relation to the equipment, and comments on the handling of samples, E.C. Buffington: critical reading; R.O. Mizer: discussions of time measurement.

INTRODUCTION

The pulse technique is the most frequently used laboratory method for measuring the speed of compressional (and shear) elastic waves in rock, sediment, and other samples. The method became easily possible during and after World War II because of developments in electronics, especially in pulse circuitry and oscilloscopes. Three recent papers have especially good résumés of the technique, its variations, and development through the years, and include numerous references to actual measurements (Birch, 1960; Auberger and Rinehart, 1961; McSkimin, 1961). The resonance method is less frequently used than the pulse technique, but affords the opportunity to operate at lower frequencies (Shumway, 1960, operated at 24-40 kc/sec) and to measure attenuation in samples of reasonable size.

GENERAL DISCUSSION OF METHOD

The pulse technique is basically simple: the travel time of compressional, elastic waves is measured over a known path-length. These waves are generated by a voltage pulse which excites vibrations in a barium titanate ceramic transducer. These mechanical vibrations travel through the sample and are converted in the receiving transducer to electrical signals which are amplified and displayed, together with the outgoing signal, on the face of an oscilloscope.

The time delay, or travel time of the sound wave through the sample, is noted on an oscilloscope dial after the operator picks, by eye, the first deviation from the horizontal of the outgoing and incoming wave, as displayed on the oscilloscope face. The equipment components used in the NEL version are diagrammatically shown in Figure 1. In Appendix "A", the equipment is described further, together with some detailed descriptions and comments on the equipment, samples, and procedures of measurement. The purpose of this technical memorandum is to note the changes made to the original equipment (Shumway and Abernethy, 1961, Figure 2), partly illustrated in Figure 2, and to note changes in the purchasable ("shelf-item") components.

The basic philosophy in using this type of equipment is to measure sound speed on actual samples from the sea floor which are as little disturbed as possible, and are fully saturated. The first criterion is met (as well as feasible) by cutting sections from the liner used in sampling. The second requirement is met by keeping samples under sea water until they can be measured, or by immediate measurements as a core comes aboard.

The pulse-technique equipment being used at NEL offers the following advantages over the resonant method and some of the other variations of the pulse method. The equipment is portable and can be taken aboard ship, kept in a locker, and can be set up for measurements in a relatively small space. A transverse cut can be made through the plastic liner of a core tube, and sound velocity can be measured without further disturbance to the sediment (such as by extrusion). The other properties of this discrete sample can then be determined (e. g., density, porosity, grain size, and mineralogy). Sound speed can be measured with a sample under water, and distilled - or sea-water sound velocities can be measured. Rock and hardened sediment samples can be shaped and measured, under water, for sound speed (e. g., a rock sample taken by the bathyscaph ARCHIMEDE in the Puerto Rico Trench). The lucite water chamber is a considerable aid in certain laboratory studies involving porosity changes in saturated sands, under water, and consequent changes in sound speed. However, other devices using the pulse technique may be better for the specific purposes for which they were designed. For example, pulse measuring equipment can be combined with various loading devices so that sound speed versus pressure can be studied (Laughton, 1957), and the Navy Oceanographic Office has recently acquired a device which will measure sound velocities through a core liner without cutting or disturbing the sediment.

The pulse technique uses high frequency sound. In general, the frequencies actually present within the pulses depend on the resonant vibrations of the barium titanate disks, which in turn depend on their thickness and radius (see Shaw, 1956, for a detailed discussion of these matters). Ordinarily, the frequencies can be varied by different designs of the transducers, and frequencies in the range of 100 kc/s to several Mc/s have been used by various investigators (Shaw, 1956). The transducers presently being used in the NEL equipment vibrate at about 200 kc/s.

The accuracies of measurement are always of critical interest in any device such as the one described here. The equipment has been calibrated in two ways. The first method, by Shumway and Abernethy, involved the uses of a series of lucite rods, one inch in diameter, and of varying lengths between 0.5 and 8 inches. Travel times through the various rods as a function of length produced a linear relationship which terminated at a zero travel time for a zero length, and which had a slope representing a sound speed of 8890 ft/s. It should be noted that transmission of sound through long, thin rods or bars may be at a "bar" velocity, and not at a true velocity of the material concerned. Birch (1960) recommends (in rock cylinders, or bars) that the ratio of length to diameter be 4 or 5, or less, in order to avoid measuring a bar velocity.*

* Bar velocity $= \sqrt{\frac{E}{\rho}}$; "True" velocity $= \sqrt{\frac{K + 4/3\,\mu}{\rho}}$

Where, E = Young's Modulus, ρ = density, K = incompressibility, and μ = shear modulus.

The method of calibration in current use involves measurements of absolute sound speed in distilled water at known temperatures. Assuming the tables for the speed of sound in distilled water are correct, the differences between measured and tabulated values can be determined at various path lengths, and correction factors determined. Multiple calibrations using distilled water at known temperatures indicate overall accuracy of measurements, including all errors of equipment and the human eye and hand, is ± 5 ft/sec. Since an average sound speed in clayey sediment is around 5000 ft/s, the accuracy is around 0.1 percent. In reporting sound speeds in meters per second, the policy is to round the measurement to the nearest one meter per second, with a stated accuracy of ± 2m/sec. In view of the variations of sound speed in sediments, both laterally and vertically, because of changes in mineralogy, density, and porosity, the accuracy of this system is thought to be well within tolerable limits.

In the measurement of sound speed through a substance encased in another substance of higher sound speed, there is always a chance that sound is traveling through the higher-speed material along part of its path. The lucite liners which ordinarily contain the sediment samples transmit sound at much higher speeds than does the sediment which, for clays, usually has a speed within 2 percent of that in water. Experiments indicate that there is no transmission through the lucite with the lengths and diameters concerned. This was determined by immersing empty, 2- to 5-inch lengths of 2-inch and 2 1/2-inch diameter lucite liners (those commonly used) in water, placing them so that the transducers were centered on the longitudinal axis, and measuring the velocity of sound between the transducers; the velocity was always that of the water alone.

The original equipment described by Shumway and Abernethy in TM-517 included equipment for applying pressure along the line of the transmission of the compressional wave. This pressure equipment was taken off and the remainder of the device improved in three significant ways: (1) time is now read by using a Tektronix 545A Oscilloscope, (2) the path length is measured by using a dial gage which can be read to the nearest 0.001 of an inch, and (3) a better pulse generator is being used. These improvements are described in more detail below.

PATH LENGTH MODIFICATION

The original press used with the compressional wave measuring equipment was operated hydraulically and the indicating scale read-out was accurate only to about ± 0.01 inches. Time and use proved the hydraulic pressure system unnecessary for most usage and the error in scale read-out was greater than desirable.

The hydraulic piston was replaced by a machined, stainless-steel screw (B) using 10 threads per inch with a 10 inch diameter wheel (A) for easy turning to gain required adjustments of sound path length (Figure 2). It is noteworthy here to point out that one revolution of the hand wheel moves the transducer 1/10 inch. The hand wheel screw is coupled to the transducer rod by a thrust bearing. This bearing allows the screw to raise or lower the transducer rod without the rod itself rotating, since the transducer is connected to the electronic equipment through a BNC connector and cannot turn. The rod and screw are housed in a stainless steel cylinder (C) with a monel threaded collar, and the rod contains one-inch brass collar-bushings spaced every 3 inches on center with a diameter 0.010 inch greater than the rod itself, to minimize friction with the cylinder.

The cylinderis mill slotted (D) 0.250 inch wide and 8 inches in length to accomodate the greatest travel needed. A pin is mounted 2-1/2 inches below the thrust bearing in the transducer rod, extending through the slot just discussed, for the purpose of aligning the transducer as well as serving as a coupling to the indicating dial micrometer.

The indicator read-out is accomplished by using a 5/16 inch diameter stainless steel rod (E) 7 inches in length moving vertically in the coupling to the guide pin in the milled slot. The rod is drilled at one-inch intervals in 6 places just deep enough to accomodate the pointed locking screws for accuracy. This allows samples between the transducers to be from zero to 8 inches long. A dial micrometer (Starret No. 25-441, zero to one inch) (F) is coupled to the lower end of the indicator rod and the tip bears on a machined seat imbedded in the upper frame plate (G) of the press.

This read-out system is quite simple for the operator, requiring only that a rough measurement of the sample length be known. The indicator rod is set in the appropriate length range by the set screws, the screw handle wheel is turned down to make good acoustic coupling, and the indicator dial can be read to 0.001 inch accuracy.

The water jacket (H) mentioned in NEL TM-517 was modified by an additional removable side that is shorter than the full length side in order to accomodate 3 to 4 inch samples without having to remove and replace the side for each test being conducted.

OTHER MODIFICATIONS

After the press was modified to improve path length read-out to an accuracy of 0.001 inch, a comparable improvement in velocity-time measurement was required. The Dumont 256-D oscilloscope used in the original setup was slow in rise time as well as lacking in a fast enough horizontal sweep speed. The Dumont 256-D was replaced with a Tektronix 545 A, dual trace scope with the CA type plug-in unit. Any of the Tektronix scopes with sweep delay can be used, however the dual trace series are most desirable.

By using a newer pulse generator (Hewlett-Packard Model 212A) with a phasing control or pulse delay, the pulse can be started well behind the trigger and the start of the pulse can be easily observed on "A" channel of the two traces while the received or delayed pulse through the sample is displayed on "B" channel. With "B" trace intensified by "A", the leading edge of the two pulses is used as the point of measurement using the intensified portion movable with the Delay-Time dial. The Hewlett-Packard Model 212A is better for the present usage than the one originally used because of greater latitude of pulse shape, both in length and amplitude. Of even greater importance is the delay feature, which is a must in the present application. This pulse generator has been used by Birch (1960), Auberger and Rinehart (1961), and others.

APPENDIX A

DESCRIPTION OF EQUIPMENT

The main components of the equipment are shown in Figure 1. The Pulse Generator is the Hewlett Packard, Model 212A. Typical settings of this generator for measuring the velocity of sound in deep-sea clay are: Pulse Rate: 50 cps; Pulse Length: 10 micro seconds; Attenuation: 0; Sync Selector: X 10; Polarity and Sync Out at "positive", and Amplitude at about 75.

For a description of the Tektronix 545A oscilloscope, one can go to the manufacturer's catalogue. Some convenient settings, however, might be worthy of note and are listed with some comments below.

A Hewlett-Packard 450A Amplifier is used to amplify the signal from the receiving transducer. Water and high-porosity clays usually require (for optimum wave-form) an amplification of 20 db; sands usually require 40 db amplification.

The transducers consist of disks of barium titanate 20.6 mm in diameter and about 6 mm thick. These are mounted in a cast plastic which fills the conical cavities in the stainless steel mounts (Figure 3). These conical cavities serve as horns to minimize possible troublesome sound radiation from the back surface of the transducers.

PROCEDURE FOR MEASURING SOUND VELOCITY (TIME-DELAY) THROUGH A SAMPLE

I. Assemble the various components as shown in Figure 1.

II. Set controls on the scope (Tektronix 545A) as follows.

A. Time Base "A" (main sweep)

1. Triggering mode - - - - - - Any position but AC auto.
2. Stability - - - - - - - - - - - Full clockwise.
3. Triggering level - - - - - - Full clockwise.
4. Time/cm - - - - - - - - - - 0.2 microsecond.
5. Variable - - - - - - - - - - Full clockwise.

B. Time Base "B" (delaying sweep).

1. Time/cm or delay time - - 10 microseconds.
2. Sweep length - - - - - - - - 10 cm (full clockwise).
3. Stability - - - - - - - - - - - Stable sweep.
4. Triggering level - - - - - - Stable sweep.
5. Triggering mode and slope - Ext. positive.

C. Horizontal Display - - - - - - - "B" intensified by "A".

1. 5X Magnifier - - - - - - - - "On"

D. TYPE 53/54C PLUG-IN UNIT

1. Volts/cm either channel - - Desired amplitude (see comments below).
2. Mode - - - - - - - - - - - - Chopped or alternate.
3. Switches at: AC, Normal Polarity.

E. Set all other controls for normal operation.

F. Amplitude Calibrator: "off"

III. Make the measurement as follows:

A. Adjust the Pulse Position on the pulse generator so that P1 (Figure 1) will be 2 to 3 microseconds behind t_s; set other controls as desired (see previous suggestions).

B. Adjust the Delay-Time dial (oscilloscope) to visually align the intensity marker with the start of the leading edge of P1 ("A" channel), then read the Delay-Time Multiplier dial.

C. Adjust the Delay-Time dial to visually align the intensity marker to coincide with the start of the leading edge of P_2 ("B") channel). Read the Delay-Time dial.

D. Subtract the first reading of the Delay-Time dial from the second reading to obtain travel time.

IV. Comments.

A. Figure 1 assumes that any delay contributed by the two transducers is small enough to be considered negligible.

B. The measurement accuracy may be affected by either impedance mismatch or the poor frequency response of the two transducers.

C. After familiarization with the test set-up has been established, the overall accuracy of the test method should be checked by using a sample of known velocity or distilled water as previously discussed.

D. For some measurements, Hamilton has found it convenient to turn the Focus and Astigmatism controls left to about the 7 o'clock position so that the wave form on the face of the oscilloscope forms a broader line and deviations from the horizontal can be more easily picked.

E. Sediment Sample.

1. The present equipment can measure samples between 1 and 8 inches in height, but convenient sizes for this equipment are between 3 and 4 inches. The cut section of the core can be made with a saw, but a special cutting device which gives a smooth, even cut, normal to the longitudinal axis is better for later computations of volume (if density computations are desired). Also, an even cut across the liner at the bottom of the sample allows the liner to bear evenly on the base around the lower transducer and thus be more "water proof".

2. The lower transducer housing should be ringed by a doughnut-shaped "shim" so that when a sample is placed over the lower transducer, the barium titanate disk indents the sediment very slightly. This shim also allows a sample to be moved sideways without serious disturbance.

3. If a clay sediment sample is 100 percent saturated at the time of measurement, and is within a lucite liner with an even out across the bottom, there is usually no need to seal the bottom of the liner in order to retain water during the measurements; there is little water loss from the relatively impermeable clay. A wet sand, however, will drain rather quickly and it is recommended that a plastic, waterproof material such as a non-hardening, electricians sealing compound, or florists plastic "clay", be used to form a ring on the base around the transducer into which the lower end of the cut liner can be impressed; additional putty can be placed around the transducer housing to seal that area. With these cautions and procedures, it is usually possible to make measurements quickly enough so that the sediment remains saturated without filling the lucite chamber and running the measurements under water.

4. A small amount of sea water (from an eyedropper) should be placed on the upper surface of the cut sediment sample in order to have an excess of water on the sample to allow for

some small drainage which might take place, and to insure proper contact between the transducer and the sediment.

5. The upper transducer is moved down until the barium titanate surface barely indents the sediment. If too much pressure is placed on the sediment there is a chance of a false "pressure induced" reading, especially in sand.

6. After the measurements have been made, it is important that the temperature of the sediment be taken immediately so that corrections can be made to sound speed (Hamilton, 1963, 1965). This has been efficiently done by inserting a calibrated, small-diameter thermometer into the center of the sample.

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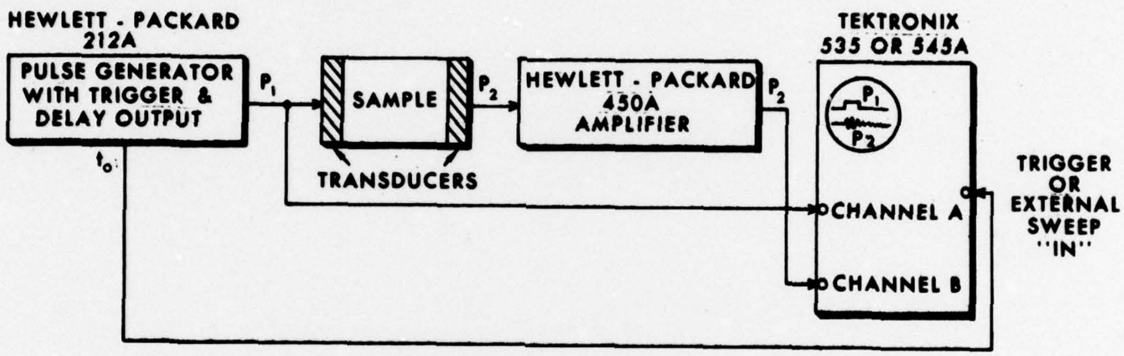

FIGURE 1. DIAGRAM SHOWING COMPONENTS IN THE NEL PULSE-TECHNIQUE, SOUND-VELOCITY MEASURING EQUIPMENT

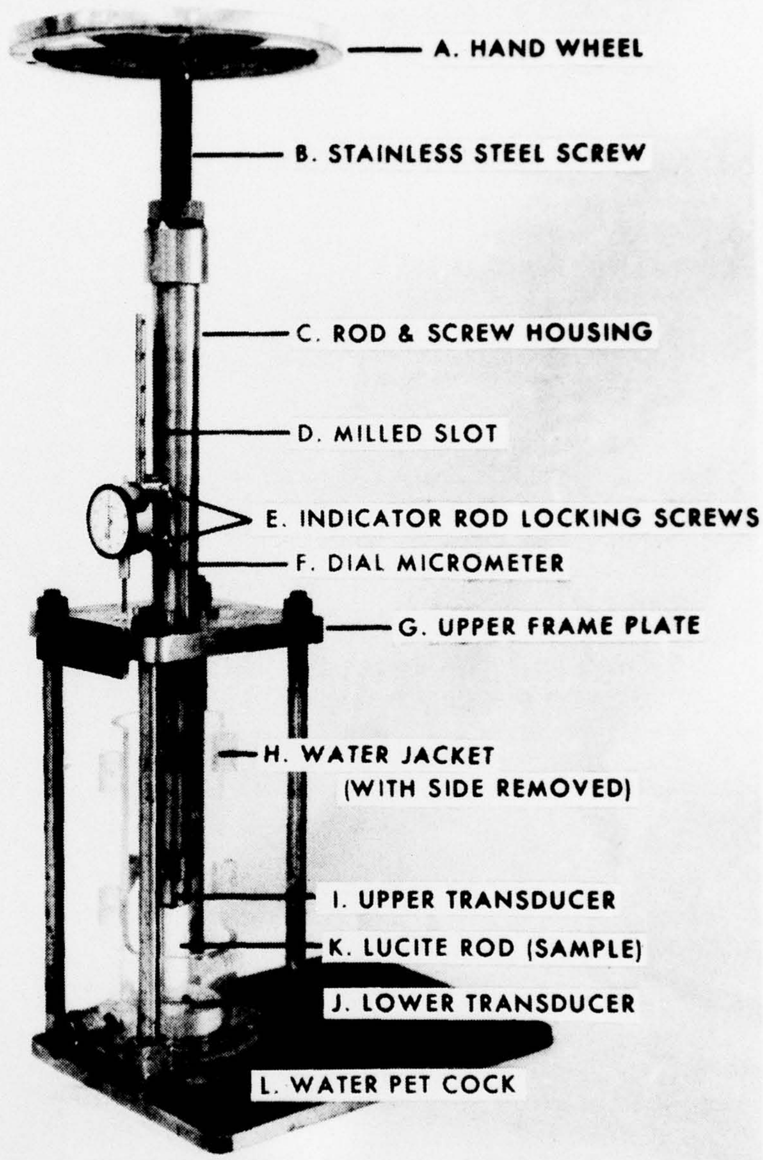

FIGURE 2. PULSE-TECHNIQUE, SOUND-VELOCITY MEASURING EQUIPMENT
(WITHOUT PURCHASABLE, ''SHELF'' ITEMS: SEE FIGURE 1.)

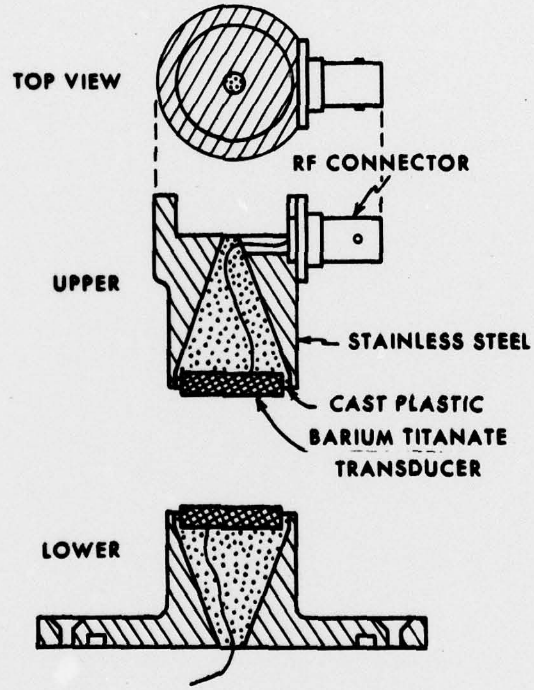

FIGURE 3. TRANSDUCERS AND MOUNTS