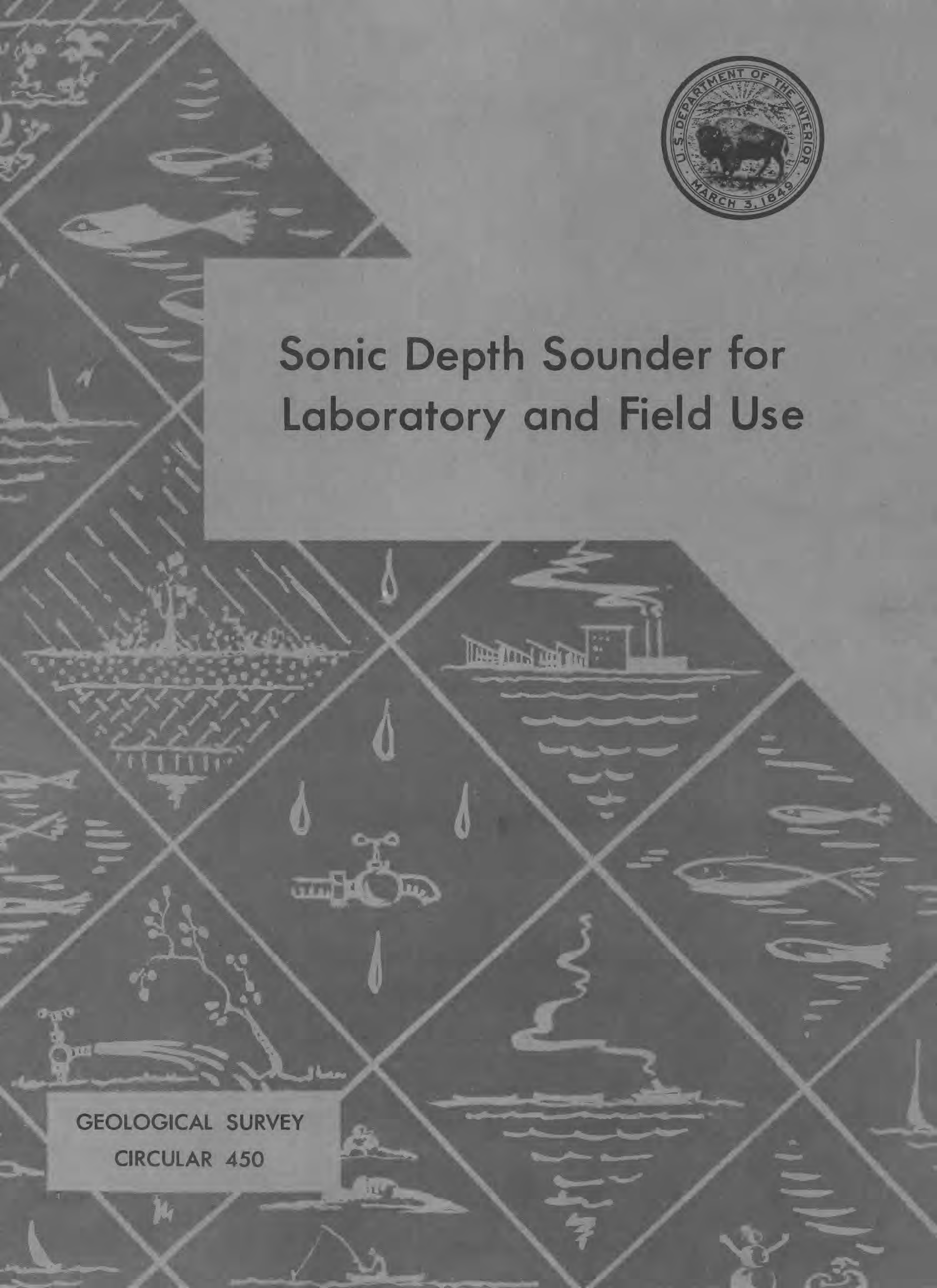

Sonic Depth Sounder for Laboratory and Field Use

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By E. V. Richardson, D. B. Simons, and G. J. Posakony

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CONTENTS

ILLUSTRATIONS

Sonic Depth Sounder for Laboratory and Field Use

By E. V. Richardson, D. B. Simons, and G. J. Posakony[1]

ABSTRACT

The laboratory investigation of roughness in alluvial channels has led to the development of a special electronic device capable of mapping the streambed configuration under dynamic conditions. This electronic device employs an ultrasonic pulse-echo principle, similar to that of a fathometer, that utilizes microsecond techniques to give high accuracy in shallow depths. This instrument is known as the sonic depth sounder and was designed to cover a depth range of 0 to 4 feet with an accuracy of ± 0.5 percent. The sonic depth sounder is capable of operation at frequencies of 500, 1,000 and 2,000 kilocycles. The ultrasonic beam generated at the transducer is designed to give a minimum-diameter interrogating signal over the extended depth range. The information obtained from a sonic depth sounder is recorded on a strip-chart recorder. This permanent record allows an analysis to be made of the streambed configuration under different dynamic conditions.

The model 1024 sonic depth sounder was designed principally as a research instrument to meet laboratory needs. As such, it is somewhat limited in its application as a field instrument on large streams and rivers. The principles employed in this instrument, however, have many potentials for field applications such as the indirect measurement of bed load when the bed roughness is ripples and (or) dunes, depth measurement, determination of bed configuration, and determination of depth of scour around bridge piers and abutments. For field application a modification of the present system into a battery-operated lightweight instrument designed to operate at a depth range of 0 to 30 feet is possible and desirable.

INTRODUCTION

In September 1956 the U.S. Geological Survey established a research project at Colorado State University to investigate roughness in alluvial channels (Simons and Richardson, 1960). In an alluvial channel the form of the bed can be a plane, ripples, dunes, transition, standing waves, or antidunes depending on flow and sediment characteristics as illustrated in figure 1 (Simons and others, 1961). A plane bed will have surface irregularities on the order of the grain size, whereas a dune bed is composed of approximately triangular-shaped elements which, in the flume, are 2 to 10 feet long and 0.2 to 1.0 foot high. A ripple bed is composed of similar triangular-shaped elements which are less than 2 feet long and are 0.02 to 0.20 foot high and may compose the major element of bed form or be superimposed on the back of dunes. Antidunes are sinusoidal undulations which, in the flume, have amplitudes from 0.05 to 0.3 foot and wavelengths from 3 to 10 feet. In the field the wavelength and amplitude of dunes and antidunes may be much greater depending on depth of flow.

In the laboratory investigation it soon became apparent that measurement of the bed configuration should be made under dynamic conditions. Measurements of bed form that are made after an experiment has been concluded and the flume has been drained can be inaccurate and misleading. Because of the softness of the bed, measurements made by mechanical probing during the experiment were also inaccurate. Some method of obtaining the bed configuration, both areally and as it changed with time at a point, had to be developed.

Sonic depth sounders proved the most logical type of instrument for measuring the bed configuration under dynamic conditions. However, commercial instruments, designed to operate at great depths relative to those in a laboratory flume, were not accurate enough. These commercial instruments have a minimum-depth range of about 60 feet and their accuracy is ± 0.5 percent of full scale. Since the propagated sound beam in most of these instruments is a cone which has a divergence of about 20°, the beam diameter at the bottom (or bed surface) is a function of depth. The normal frequency of most commercial instruments is 50 kilocycles and their pulse repetition rate is about 500 cycles per minute.

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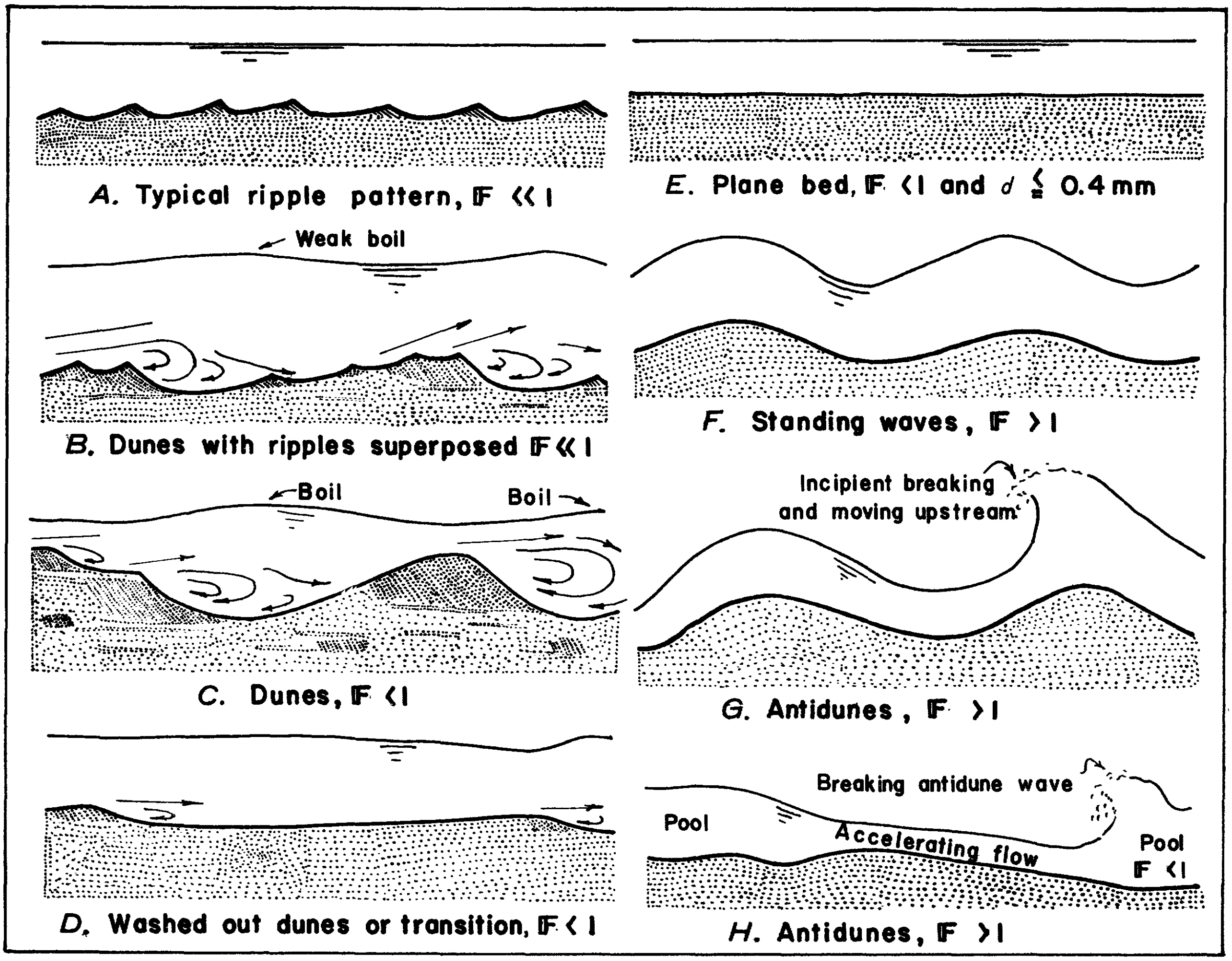

Figure 1.—Forms of bed roughness in alluvial channels.

In contrast, an instrument was needed which would operate in depths of water ranging from 0.3 to 2.0 feet with an accuracy of 0.01 foot. The effective area of the bed which would reflect the sound waves should not be any greater than 1 square inch and smaller if possible; as there would be large quantities of suspended sediment, methods of minimizing its effect had to be developed; and the instrument would have to define the downstream face of the dunes which makes an angle with the horizontal of 25° to 40°. These requirements for a useful depth sounder were very stringent. The desired accuracy (small reflection area) required the use of high-frequency sound waves. However, the higher the frequency of the waves, the shorter is their wavelength. Any sediment particle in suspension with a diameter equal to or greater than the wavelength of the sound energy will readily reflect some of the sound wave. This may, in some instances, help solve other problems but in this application it was a detriment. The steep downstream face of the dune did not present a problem because the granular surface of the streambed reflected enough acoustical energy in the plane of the transducer so that an amplifiable echo was always received.

In the development of the sonic depth sounder, the major accomplishments have included:

1. The design and development of transducers that have a nondiverging sound beam so as to define small changes in the streambed.
2. The development of a timing-circuit clock and a linear time-measuring circuit that can accurately (within 0.01 ft) determine the distance from the transducer face to the bed.

DESCRIPTION AND SPECIFICATIONS

The basic elements of the sonic depth sounder and their functions are:

A. Pulser to provide timed pulses of high voltage at a given frequency. Pulses operating at three frequencies - 500, 1,000, 2,000 kilocycles per second - are provided. Pulse-repetition rate is 400 cycles per second, the pulse duration is 1 microsecond, the pulse amplitude is 1,200 volts, and the duty cycle is 0.04 percent.

B. Transducers to convert the high-voltage pulses to acoustic energy. A lithium sulfate crystal was used in the transducer to make the conversion. This same crystal is used as a receiver to detect and change the echo from acoustical to electrical energy and feed it to the receiver. Crystals are frequency-sensitive so a transducer is provided for each frequency. However, a crystal tuned for one frequency (for example, 2,000 kilocycles) can be driven by pulses of a lower frequency (500 kilocycles) but the returning echo is weaker, requiring greater amplification. The transducers are designed, using conventional acoustic theory (O'Neal, 1949; Posakony and McMasters, 1960), to maintain a nondivergent sound beam. This sound beam has very little divergence from the central axis. The area of the bed from which the sound wave is reflected is a function of frequency and crystal diameter. The beam diameter of the transducers used ranged from half an inch at 2,000 kilocycles per second to 1-3/4 inches at 500 kilocycles per second. To maintain a nondiverging sound beam, the size of the transducer must vary with frequency. The lower the frequency, the larger must be the transducer. The 500 kilocycle transducer is 3 inches in diameter and the 2,000 kilocycle transducer is 1 inch in diameter (Heuter and Bolt, 1955). To maintain a nondiverging sound beam at a frequency of 60 kilocycles would require a transducer that has a diameter of about 18 inches.

C. Clock to provide a time base with which the other system modules are synchronized and which the linear time circuit uses as a base to compute the time between main pulse and echo.

D. Receiver to detect, shape, and amplify the small echo signals from the transducers for the linear-time-measuring circuit and display system. The receiver is provided with a variable gain so that amplification of the echo can be controlled. This is necessary to keep interference from suspended sediment to a minimum. Excessive amplification can cause spurious echoes from the suspended sediment. The linear-time-measuring circuit measures time from the initiating pulse to the first returning echo. Spurious echoes can cause the measurement of the wrong time interval. Amplification of the signal should be set at a level at which the echo from the bed surface is sufficient to trigger the linear-time-measuring circuit. By varying the gain and frequency, it was always possible to obtain excellent definition of the bed with little or no interference from suspended sediment.

E. Linear-time-measuring circuits which measure the time between the initial pulse and the echo from the bed. This time is then converted into voltage that is linearly proportional to the distance from the bed. This voltage actuates a strip-chart recorder. The linearity of the instrument is illustrated in figure 2. Here, the actual distance from the bed is compared with the strip-chart readings.

F. Visual display system, consisting of an oscilloscope where the initial pulse and returning echo are displayed on the time base, for monitoring the ultrasonic information.

The instrument is designed to operate at depths between 0.2 and 4 feet. Since the electronic responses of the transmitter-receiver system require a few microseconds to establish a quiescent level, the minimum depth is set at 0.2 foot. The maximum depth is limited to 4 feet to maintain the high accuracy of the linear-time-measuring circuit.

Physically, the pulse-repetition rate used limits the maximum depth of this instrument to 6 feet. That is, at depths in excess of 6 feet the echoes have not been received before another cycle starts. This 6 foot depth limit can be increased by decreasing the pulse rate, but at extended ranges time is more difficult to measure accurately. With this instrument deeper depths may be sounded by lowering the transducer, by rod or sounding weight, a predetermined distance below the water surface.

With the present unit the range scales are 0–1, 0–2, 0–3, and 0–4 feet. To define small irregularities on the order of 0.01 and 0.02 feet, an expanded scale is provided for range of 0–4 feet. This expanded scale takes the

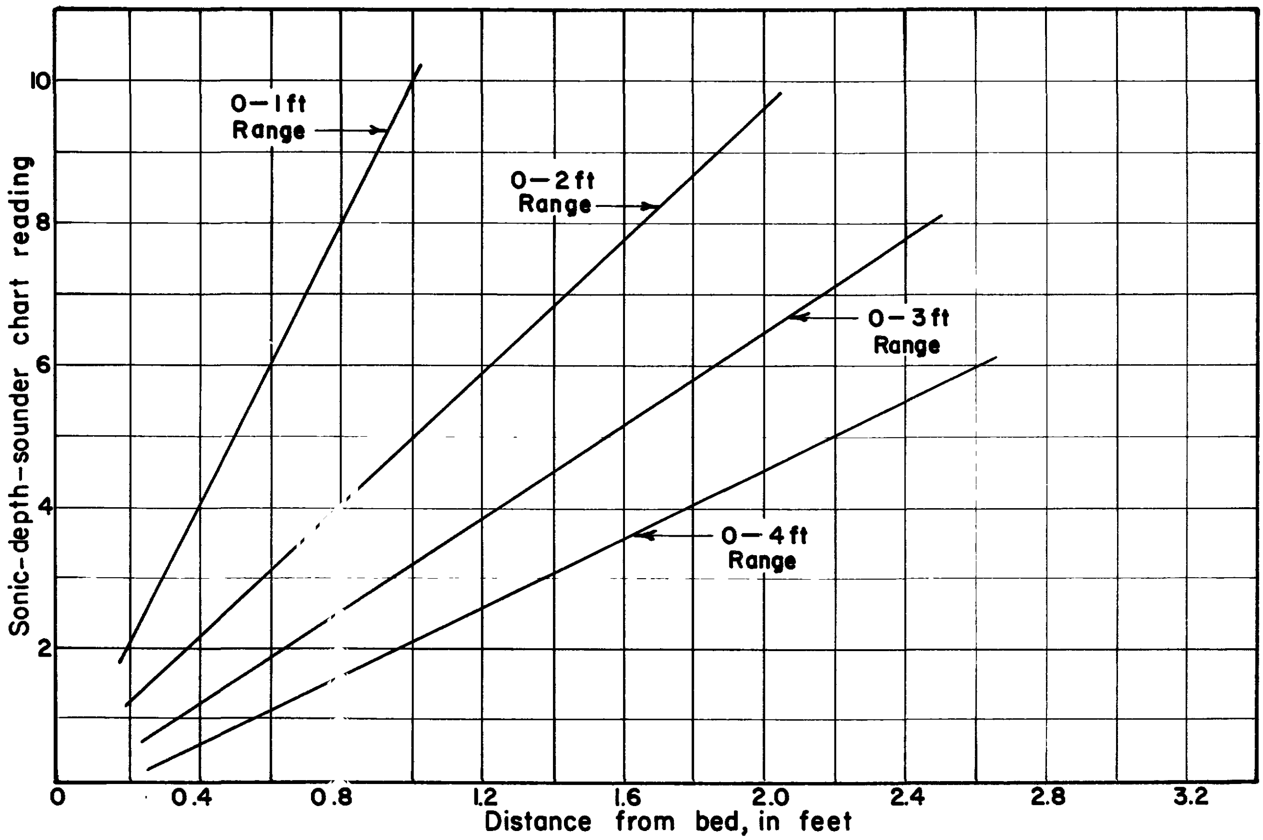

Figure 2.—Linearity of the sonic depth sounder.

last 1 or 2 feet on the 0–4 scale and expands it to a scale of 0–1 or 0–2 feet.

Accuracy of the instrument is better than 1 percent of full scale. Its accuracy ranges from 0.01 foot for the ranges of 0–1 and 0–2 feet to 0.02 foot for those of 0–3 and 0–4 feet.

The controls for the instrument are a range selector, expanded range selector, frequency selector, variable gain, and variable damping. The variable-damping selector places capacitors across the output terminals to the strip-chart recorder to further decrease any effect of suspended sediment.

In addition two calibration controls, zero and range, are incorporated in the instrument. These controls are to adjust signal output to the strip-chart recorder so that their zeros coincide, and true change in depth will be reflected by a corresponding movement of the pen for each of the ranges selected. In 1 year's operation there has been no change in the range control since the initial calibration. However, the zero has drifted because of voltage fluctuations in the power supplied to the instrument. This can be corrected by an external voltage regulator.

The instrument operates on 120 volts, 60 cycles alternating current, and requires 500 watts power. It is 28 inches long, 18 inches high, and 16 inches wide and weighs about 140 pounds.

Two types of recorders have been used satisfactorily with the instrument. One was a Texas Instrument milliamp recorder which operates on the current output. The other was a Leeds and Northrup null-balance recorder which operates by voltage differences. Using these recorders, the instrument has given excellent performance with very little maintenance and, as stated before, has required no change in the range calibration.

OPERATION

In the laboratory, two methods have been used to measure depth and bed configuration with this instrument. One method is to take three or more profiles of bed configuration along a 70-to 100 foot reach of the flume bed. The other method is to set the transducer at a point in the cross section and record the changes in bed configuration with time.

To obtain the bed configuration as it varied with distance the transducer was mounted on the instrument cart, which was supported by rails along the flume walls, a known distance below the water surface and moved downstream at about 1 foot per second. The sonic depth sounder can operate at even higher traverse speed but the recorders available have response times and chart speeds which are too slow. With the faster recorders now available, traverse velocities of at least 5 feet per second should be possible.

DATA OBTAINED

In figure 3 a typical trace of a dune bed configuration obtained by longitudinally traversing the flume is presented. Note that the dunes, although not to proper scale, appear as if they were. This results from selecting a chart speed based upon traverse speed. It is important in the interpretation of the profiles that dunes or ripples are in a suitable scale ratio of length to height. To accomplish this, recorders with high response and fast chart speeds are needed or the traverse must be made at too slow a speed to obtain a suitable scale ratio of dune length to height.

The variation of the bed at a point as a function of time is illustrated in figure 4. This record graphically illustrates the changes of the bed with time. The depth of flow can vary 200 or 300 percent of the average depth in the interval of a few minutes.

With the ability to evaluate the velocity and amplitude of tranquil-flow sand waves, a theoretical expression for bed-load transport was developed (Simons, D. B., Richardson, E. V., and Haushild, W. L., written communication, 1961). This equation for total load is

$$q_b = (1-\lambda)\ V_s\ h/2$$

in which

q_b = volume rate of bed-load transport per foot of width per unit of time

λ = porosity of sand bed

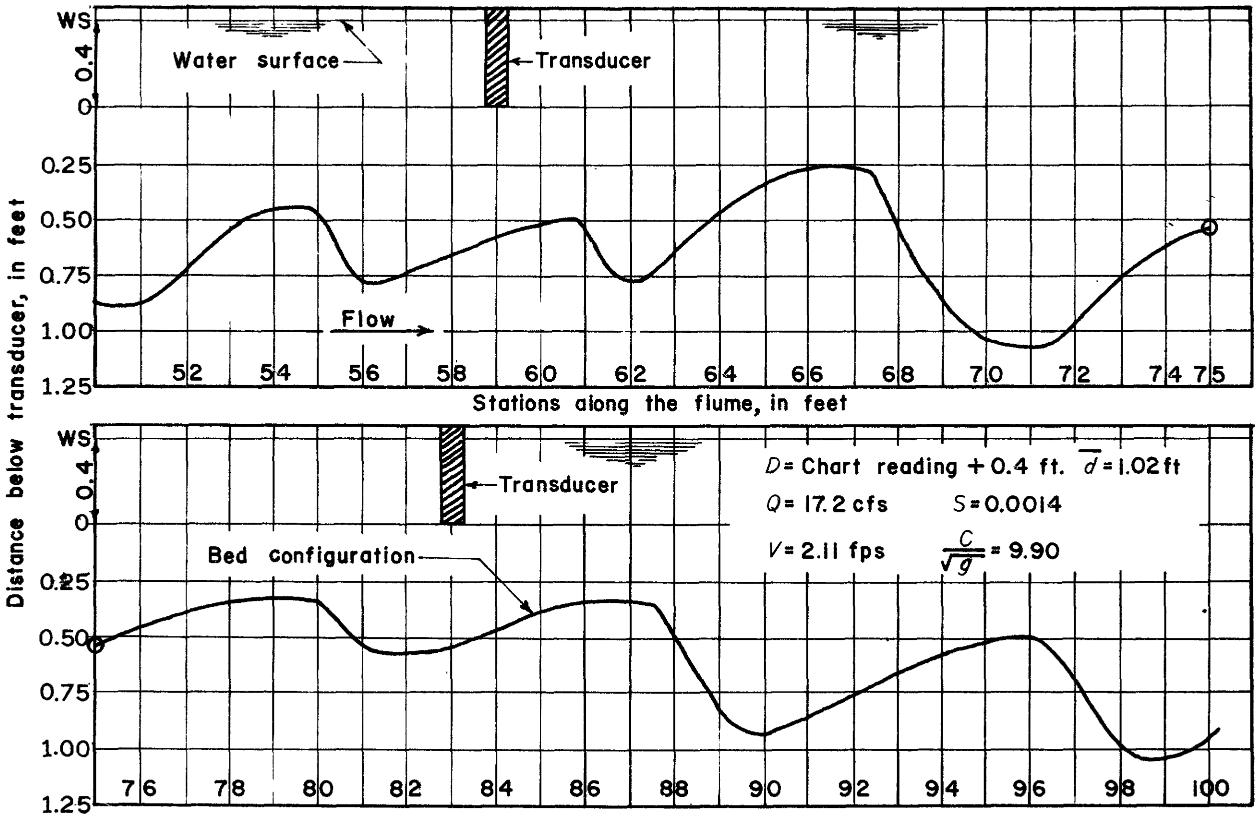

Figure 3.—Variation in elevation of an alluvial bed with distance.

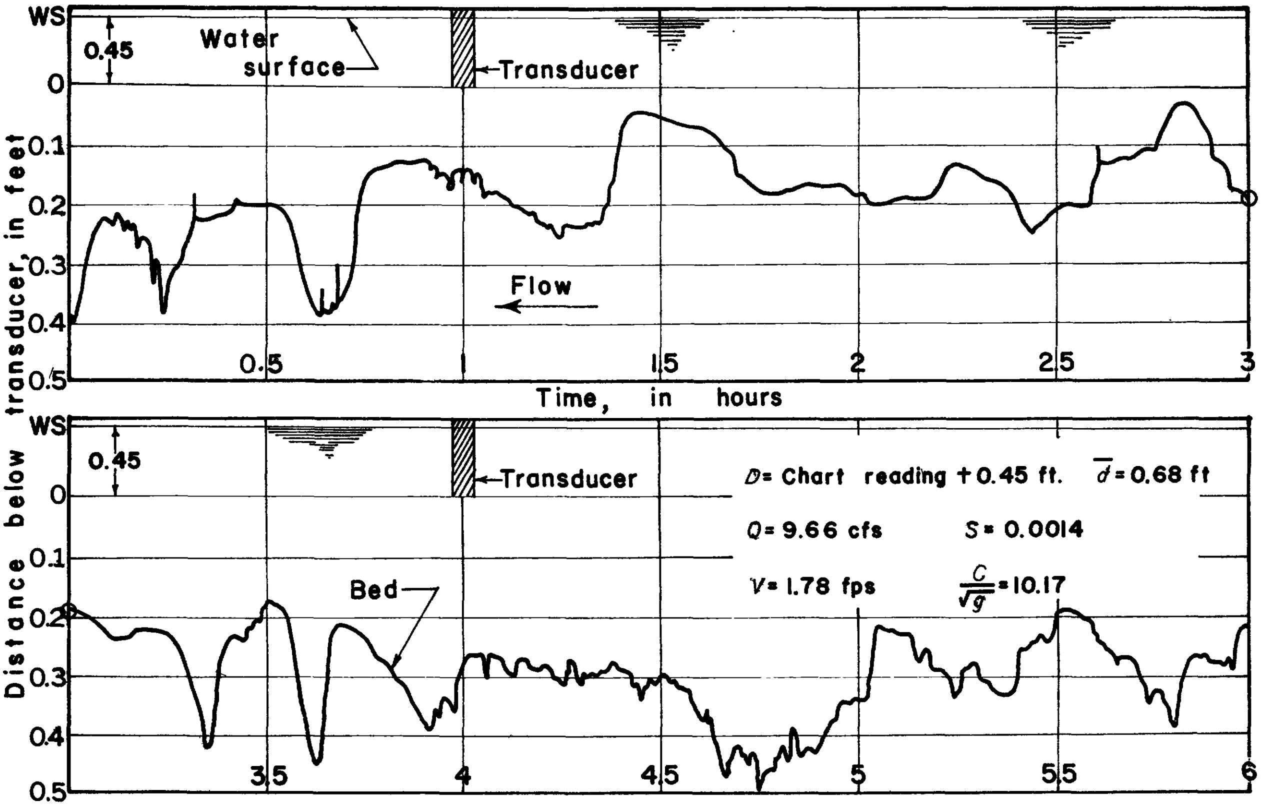

Figure 4. —Variation in elevation of an alluvial bed with time.

V_s = velocity of the sand waves in the direction of flow

h = average amplitude of sand waves

The sediment load computed by this equation is very closely related to total bed-material load under flume conditions because of relatively shallow depths. However, as demonstrated by Hubbell and others (written communication, 1960) the computed bed load correlates very well with actual bed load under field conditions.

As stated earlier, the form of the bed in an alluvial stream is variable and is a function of flow and the characteristics of the bed material. The bed surface may be plane without bed-material movement, or it may consist of ripples, dunes, a plane surface with bed-material movement, standing waves, or antidunes depending on depth of flow, slope, size and distribution of bed material, and a few other minor variables such as temperature and seepage forces. The sonic depth sounder, by giving a trace of the bed, will indicate which bed form exists. This is important because resistance to flow and sediment transport are intimately related to the form of the bed roughness. Knowledge of the bed form will greatly increase the accuracy of prediction of both flow-resistance coefficients and total bed-material load.

SONIC DEPTH SOUNDER FOR FIELD USE

The sonic depth sounder was primarily designed for laboratory use, however, it shows potential in many field applications. With a bed roughness consisting of ripples and (or) dunes, using this or a similar instrument, the velocity, length, and height of the sand waves can be determined and from these data the bed load can be estimated by applying the total-bed-load equation above.

In streams where the bed degrades, or it is believed that it does, this instrument used with the standard water-surface recorder will give a record of the depth of flow as it changes with time. With some modifications, the sonic depth sounder will record actual depth of flow. In most alluvial channels the depth-discharge rating curve is more stable than the stage-discharge relation. In addition, the sonic depth sounder will define the form of bed roughness as it changes with stage. Very little is known about this change where the instrument is used in the field.

In an alluvial channel one of the most difficult and largest sources of error is in the determination of depth when making a discharge measurement. In the tranquil-flow regime with dunes the bed is exceedingly soft and a sounding weight may penetrate 1 foot or more. In the rapid-flow regime the high-velocity flow deflects the sounding weight downstream, also effecting depth measurement. In measuring flood flow, especially on the smaller streams, debris and rapidly changing stage are always a problem. Using the sonic depth sounder for determining depth and making velocity determinations just below the water surface would mitigate the effect of debris and rapidly changing stage. This procedure should result in more accurate flood-discharge measurements.

The instrument has been used as a scour meter in the laboratory in experiments to determine depth of scour around bridge piers. With some modification, especially to increase maximum depth and decrease cost, a portable scour meter for field use could be developed. Thus, it should be possible to obtain records of depth of scour on the prototype where there is a serious lack of data.

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