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A HIGH-FREQUENCY SONAR FOR PROFILING SMALL-SCALE SUBAQUEOUS BEDFORMS

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ABSTRACT

A high resolution sonic profiler permits both laboratory and field studies of small-scale subaqueous bedforms. The device operates at a frequency of 4.5 mHz using a 2.5 cm diameter crystal. Operation at that frequency permits vertical accuracy of at least 1 mm. Compared to other small-scale profiling methods, the sonic technique profiles the bottom more accurately and more rapidly without disturbing the bedforms. These characteristics are vital in the wave dominated nearshore zones where oscillatory flow and low visibility for the most part have stymied detailed bedform studies.

In the laboratory the transducer is mounted directly to an instrument carriage. For fieldwork the transducer housing is mounted in a 2m long aluminum frame. The frame is situated and operated by scuba divers. Various field deployment schemes are possible, and the device has other field applications.

INTRODUCTION

Flow-generation and flow-modification of sedimentary structures are of widespread interest. Geologists, for example, use preserved bedforms to interpret ancient environments of deposition. Flow-generated bedforms are an integral part of the sand transport process and thus provide information on the movement of sand in rivers, lakes, and oceans. Bedforms play an important part in at least three aspects of sediment transport: 1. the migration of sand as bedload; 2. the suspension of material above the bed; 3. the modification of the bottom shear stress from the flat bed value.

Bedforms must therefore be quantitatively related to flow conditions before sediment transport can be fully understood.

This paper describes a high resolution sonic profiler developed at the Shore Processes Laboratory of the Scripps Institution of Oceanography. The unit was designed specifically to study small-scale subaqueous bedforms in both the field and the laboratory and is compact enough so that the entire unit can be encapsulated for remote underwater use.

Background

The detailed study of small-scale flow-generated bedforms requires specialized measurement techniques because the dynamic nature of the fluid-sediment system produces bedforms that are continually in motion. The ideal bed profiler must be able to sample the bedforms in a time span much shorter than the rate of bedform motion in order to insure dimensional accuracy. This applies to both undirectional flows, where continuous bedform migration occurs, and to oscillatory flows, where the ripple crest position undergoes transient movement with the phase of the oscillation.

The ideal profiler must also be able to overcome other environmental restraints. Visibility is often greatly restricted in the vicinity of the bed. This makes direct observations difficult and, in some cases, impossible. The bedforms are commonly so small in physical scale - heights on the order of a centimeter and lengths on the scale of a decimeter - that direct measurement under field conditions becomes very inaccurate. Finally, some areas of interest, notably ocean depths beyond the range of divers, require remote sampling methods.

Various techniques have been employed to measure small-scale subaqueous bedforms. Both direct and remote techniques have been tried with varying degrees of success. The most accurate of these either have limited application or require special instrumentation. Other methods circumvent these problems by accepting less accuracy.

Direct sampling methods illustrate the types of problems that arise in measuring subaqueous ripples. These methods are inexpensive and simple to use, buy they require relatively long employment times and/or modify the bedform during the measurement. Included in this category are pointer gages, plastic strips upon which the bedform dimensions are directly marked, and the preservation of a section of bed by box coring for later measurement (e.g., Inman, 1957; Newton, 1968).

Any of the above methods may have disturbed the structures during sampling. Only the box core method readily gives the three-dimensional bed configuration and often modification occurs before the actual measurements can be made.

Two types of remote methods have been employed to study small scale subaqueous bedforms. One of these, photography, is rapid and does not disturb the bed. In the field its value is limited because the profile view is unobtainable and because the water visibility is often too poor for good resolution. Photography is useful where the plan view is of interest, assuming that water clarity will permit detailed photographs. Stereophotography is a possibility in clear water but is probably not accurate enough for most purposes.

The other remote technique employs high frequency sound waves to obtain a profile of the bed. The fathometer is an example of this, but commercial models are unable to resolve small-scale structures. Richardson et al (1961) developed a sonic profiler capable of 3 mm resolution with a sample rate of

30 samples per second. They used this instrument in some of their excellent laboratory studies on current-generated bedforms. Ensuing units have been used in several field studies by U. S. Geological Survey personnel including the study of bedforms in the Rio Grande conveyance channel by Culbertson *et al* (1972). In these studies the transducer was mounted in the well of a small boat which was positioned on the river by cables. The units had range selection capability (2, 5, 10 and 15 ft. maximum ranges) with accuracy of ± 1% of full scale. Culbertson (oral communication) indicated that the small scale bedforms could be picked up on the 5 ft. range, although extraneous boat movements precluded detailed analyses of these features.

TECHNICAL DESCRIPTION

Oscillation ripples formed on beds of fine sand tend to have elevations of the order of a centimeter and lengths of the order of a decimeter (Figure 1). The sonar we have developed is capable of resolving features of this size to 1 mm. Such accuracy is possible because the wavelength of the sound in water at the chosen frequency (4.5 mHz) is on the order of a third of a millimeter. The wavelength L is given by the relation

$$L = C/f$$

where C is the speed of sound in water and f is its frequency.

This sonic profiler is similar in concept to the one developed by Richardson et al (1961) although it differs from theirs in several respects. Advances in electronic technology have resulted in higher resolution, higher sampling rates, and lower bulk for our unit. Different design criteria have resulted in different packaging and deployment configurations for the two units.

In our sonar a free-running 800Hz multivibrator is used to trigger a 100 μsecond one-shot multivibrator. The output of the one-shot multivibrator both turns on the timing circuit and drives the transmitter oscillator. The oscillator generates a 4.5 MHz signal which pulses the transducer, a 2.5 cm diameter Glenite piezoelectric ceramic wafer which acts as both transmitter and receiver. The pulse is 100 μseconds in duration and there are 800 pulses per second. After amplification the receiver signal stops the timing circuit and a voltage proportional to the round trip time of the pulse is recorded. The timing circuit is accurate to within 2%. Output at the crystal is 15 milliwatts per pulse, and either some percent of the energy must return to the crystal or a loss of signal occurs. Signal losses can be extreme over smooth surfaces unless the surfaces are oriented parallel to the crystal face. Orientation is not a problem over sand because the sand grains scatter the signal so that some energy returns to the receiver. Signal losses do occasionally occur in practice when there are large amounts of organic material below the transducer or high concentrations of sand-sized material suspended between the transducer and the bottom.

The transducer must be mounted from 10 to 75 cm from the sand bed. Return signals from closer than 10 cm are blocked out because the width of the transmitted pulse will interfere with the return signal. At distances greater than 75 cm the return is blocked by the next transmitted pulse. According to theory, the beam is columnar over these distances. This was never verified experimentally.

The transducer was separated from the electronics package by distances of 150-200 m. Operation with this separation was satisfactory, but there is a greater separation where the return signal will drop below detection level because of line losses. The sonar calibration is not noticeably affected by changes in the length of coaxial capable between the transducer and electronics package. Operation at great distances from the data recording site is possible by submerging the electronics package near the transducer and only cabling the output voltages.

The instrument operates on ± 15 volts direct current and draws 200 mamps on the positive voltage and 70 mamps on the negative voltage. It weighs 3 Kgm excluding the batteries. Battery weight could be as low as 2 Kgm using c-size nicad batteries. Such a battery pack would permit at least eight hours of continuous operation.

The accuracy of the sonar was determined experimentally in the laboratory by comparing the sonar profile with a pointer gage profile (Figure 2). This comparison indicates that the sonar reproduces bedform elevations and locations to at least 1mm. Resolution of the bedform flanks was not so good: They tend to be more rounded in the sonar profile. Because the study was concerned with ripple heights and wavelengths, nothing was done to correct flank rounding. Later studies, which are also concerned with ripple asymmetry, indicate that flank rounding does somewhat affect the horizontal location of the ripple trough when the ripples are small. This has been minimized by covering the crystal face with a lead shield into which a 10x25 mm window has been cut. The window is oriented with the short dimension perpendicular to the ripple crests. Laboratory tests show that this modification results in acceptable reproductions of the ripple profile (Table 1). The unit is extremely stable. During the four years of use at Scripps and the U. S. Geological Survey it did not change calibration.

Construction costs vary with the type of packaging required. We estimate that a basic unit could be constructed for under \$ 800. This cost includes about \$ 300 in parts with the remaining cost for labor (assembly & testing).

DEPLOYMENT

This unit has been used in both the field and laboratory. Component packaging and deployment were the same for all the studies; the only difference being in the mounting of the transducer housing. The basic system is shown in Figure 3. The transducer housing, which contains the crystal and a tuning coil, connects to the rest of the electronic circuitry by a waterproof coaxial cable. Although the entire unit could easily be encapsulated for underwater deployment, we choose to submerge only the transducer housing. The rest of the unit - circuitry, power supply, voltage regulator, and recording or transmission equipment - remains above water where it can be monitored and where flooding is precluded.

Laboratory deployment is very simple. The transducer housing is solidly suspended below water level from a cart while the rest of the unit is left on a work table (Figures 4 & 5). Transducer location is determined either by the variation in resistance of a multiturn poetentiometer mounted to a wheel of the cart, or by driving the cart at constant speed from a given starting point. Either arrangement permits rapid scanning along any selected length of tank.

For field deployment the sonar head is mounted in a 2 m long aluminum framework (Figure 6). The horizontal position of the transducer is determined by a ten-turn potentiometer attached to the drive gear. The frame is placed on the bottom by scuba divers who also operate the drive mechanism at selected intervals (Figure 7). Setting the frame on the bottom eliminates errors caused by vertical motion of the transducer. The frame design was chosen because it was easily transported underwater and relatively scour free. Visual observations during field experiments under various flow conditions indicates that the flow disturbance caused by the sonar track does not reach the sand bed. This arrangement permits rapid relocation and has worked quite well from piers, small boats and, in some circumstances, beaches. Current meters and pressure transducers are mounted directly to the frame to permit correlation between the scans and the waves.

SUMMARY

High resolution sonic bed profilers have much value in the study of small-scale subaqueous bedforms. These instruments sample rapidly, with significantly greater accuracy than mechanical methods. They minimize bed disturbance since they are removed from physical contact with the sediment surface. Although they can be affected by large amounts of suspended material, they are capable of operating under visibility conditions that would prohibit visual and photographic observations. Each electronics package can be assembled by an electronics technician from parts that cost around $300.

The sonar described in this paper incorporates solid-state electronic technology. Its physical compactness and low current, low voltage requirements permit both laboratory and field deployment even in the nearshore zone of the open ocean. While this unit is tuned to a frequency of 4.5 MHz, which results in an accuracy of at least 1 mm, tuning to other frequencies or reducing the sample rate and increasing the power would permit bedform studies over other transducer-bottom distances.

This paper describes only deployments of the transducer that provide (instantaneous) bed profiles. Other deployments can be used to study other subaqueous fluid-sediment processes. Studies are planned at the U. S. Geological Survey to examine short-term and long-term fluxuations in sand level (ripple migration and offshore beach profile changes, respectively) by mounting the transducer in a fixed position. With the addition of a motor to drive the head and the encapsulation of the entire electronics package, the frame described above could readily be used in depths beyond diving range.

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TABLE 1

Average asymmetry values for sonic scans of artificial ripples. The ripples were triangular in profile with heights of 1.5 cm, wavelengths of 10 cm and asymmetry values of 0.3, 0.4, 0.5 where the asymmetry is defined as the ratio of the shorter horizontal crest-to-trough distance to the wavelength.

Constructed Asymmetry	Sonic profile Asymmetry (without shield)	Sonic profile Asymmetry (with shield)
0.30	0.36	0.33
0.40	0.43	0.40
0.50	0.51	0.49

LIST OF FIGURES

Fig. 1. Typical sonar scan of a rippled bed in fine sand off the Scripps Institution of Oceanography Pier. Ripples are on the order of a centimeter in height and a decimeter in wavelength.

Fig. 2. Laboratory comparison of the sonar scan with a pointer gage profile. Note rounding of the flanks by the sonar.

Fig. 3. Electronics package and transducer for the sonar. Components in front of the scale were carried underwater while the components behind the scale remained above water.

Fig. 4. Transducer mounted to carriage in the wave tank of the Sedimentation Laboratory, U. S. Geological Survey, Denver, Colorado. Compare the ripple asymmetry shown against the plexiglass wall with the scan plotted in Figure 5. Upwave is to the left. The sand has a median diameter of 625 μm.

Fig. 5. Sequence of scans during a typical laboratory experiment. The last scan (3.5 minutes) correlates with the rippled bed of Figure 4. The arrow indicates the position of the transducer housing in Figure 4. The oscilliscope shows the transmit and return pluses after amplification.

Fig. 6. Underwater mounting for the sonar transducer. Pressure sensor is attached to an onshore leg.

Fig. 7. Fish-eye photograph of the sonar and mounting frame on site over a fine sand bed near the end of the Scripps Pier (photograph by Tom Harman).