3-1987

# Response Characteristics of a Short Range, High resolution, Digital Sonar Altimeter

Malcolm O. Green

John D. Boon III
*Virginia Institute of Marine Science*

# RESPONSE CHARACTERISTICS OF A SHORT RANGE, HIGH RESOLUTION, DIGITAL SONAR ALTIMETER

by

Malcolm O. Green and John D. Boon III

Virginia Institute of Marine Science
School of Marine Science, College of William and Mary
Gloucester Point, VA 23062



March, 1987

Report to the the U.S. Army Corps of Engineers, Waterways Experiment Station. Funding was provided by the Waterways Experiment Station, Grant No. DACW3986 M3677.

ABSTRACT

The Datasonics Model ASA-920 digital sonar altimeter (DSA) is a compact, high frequency (1 MHz), short range (0.5 to 5 m) underwater sonar device originally designed as an altimeter for submersibles. Wright et al. (1986) have used the DSA successfully to measure changes in relative bed elevation at a point on the shoreface prior to and during a storm. Fixed to a rigid mounting on the seabed, the DSA produces a digital output that is proportional to the transducer elevation above the bed. The purpose of this report is to describe the response characteristics of the DSA.

The maximum theoretical resolution of the DSA is 1.5 mm; tests using a flat steel plate and a flat sand bed as the target showed that the DSA is capable of resolving differences in elevations of at least 5 mm. Because the acoustic pulse emitted by the transducer has a finite width, the DSA is fundamentally incapable of delineating undulating sand beds when the bed slope, taken over the beamwidth, is significant. This limits the instrument's use over a bed of wave-generated ripples; in general, the altimeter does not "see" into the troughs of ripples when its height above the bed is more than eight times the ripple wavelength. The instrument stability is good: over 12 operating hours (14 days of burst sampling), the indicated elevation drifted by 3 mm. The acoustic pulse is susceptible to interference by suspended particulate matter. During storm conditions in 8 m water depth on the shoreface, two kinds of problem occurred: pulse scattering that caused a loss of echo detection, manifest as spikes in the record; and premature echoes that obscured the actual bed surface.

## INTRODUCTION

The innovative use of high resolution sonar altimeters has advanced coastal processes research in at least three areas: subaqueous bedform geometry and kinematics; benthic boundary layer dynamics; and inner shelf sedimentation.

Dingler and Clifton (1984) described the change in wave ripple size that occurred over a tidal cycle on a low-energy tidal flat and attributed the change to a concomitant variation in the wave character. Detailed bed profiles were made with a high frequency sonar altimeter (Dingler et al., 1977) mounted in a movable carriage suspended on a frame that was placed on the bed. The altimeter neither disturbed the bed during the measurement process (an advantage over pointer gages, combs and greased cards) nor did it require good visibility to operate (unlike photography). A high resolution (1 mm) was achieved and the elevation could be sampled rapidly enough (64 Hz) to provide a detailed two-dimensional bed profile.

The friction velocity, $U_*$, can be estimated from the benthic boundary layer vertical velocity profile by use of the law of the wall (e.g. Dyer, 1986). The velocity profile is measured by vertically-stacked current meters; Cacchione and Drake (1982) estimated that a vertical positioning error of 1 cm for each current meter would cause a maximum fractional error in $U_*$ of 15%. Grant et al. (1983) used a sonar altimeter to monitor the height of a current meter array above the bed over the duration of the deployment. The altimeter data were used in conjunction with other information (side-scan sonar images, photographs) to estimate the average bed level and therefore the uncertainty in the current meter elevations and the velocity profiles were shifted within this range of uncertainty to achieve the best fit of the velocity profiles to the law of the wall. In this way, confidence in the estimates of bed shear stress was maximized.

Wright et al. (1986) used a sonar altimeter to measure sedimentation and erosion at a point on a southern Mid-Atlantic Bight shoreface (8 m depth) prior to and during a storm. The bed, as indicated by divers, was covered with wave-generated ripples of length 10 to 20 cm and height 1 to 3 cm. The altimeter was mounted on a stable platform supported by pipes driven into the seabed and data acquisition was controlled by a self-contained data logger.

The purpose of this report is to describe the operational characteristics of the high resolution, "off-the-shelf", digital sonar altimeter that was used by Wright et al. (1986). The instrument accuracy and precision over the following three targets is determined: 1. flat steel plate; 2. flat sand bed; 3. rippled sand bed typical of the shoreface deployment. The long-term stability of the instrument is demonstrated and the response of the instrument to particulate matter suspended in its line-of-sight is investigated.

## INSTRUMENT DESCRIPTION

The Model ASA-920 Digital Sonar Altimeter (DSA) is a short range (0.5 to 5 m), high resolution altimeter manufactured by Datasonics, Inc., Cataumet, MA. The instrument in its standard configuration is equipped with a 200 kHz transducer; for applications requiring very high resolution a 1 MHz version is available. The time between transmission of a high frequency (1 MHz) acoustic pulse and receipt of a target echo is measured by a solid state timer and converted to a digital number proportional to the distance between the transducer and the target. The receiver incorporates both an automatic gain control which keeps the gain at just the level required to detect the target, and a time-varying gain which allows the detection of a close target by eliminating amplifier saturation and transducer ring. The transducer is encapsulated in urethane and, together with batteries and logic boards, is mounted in a compact cylindrical aluminum pressure housing. The cylinder is 13 cm diameter by 66 cm long and the complete package weighs approximately 6 kg when submerged. Sixteen alkaline D-cells supply 50 ma current; the operating life is rated at 60 hours.

The DSA transmits digital signals through a 10 m armoured cable and a parallel interface to a Sea-Data Model 635-9 Directional Wave Recorder. Standard versions of the Model ASA-920 convert each digital measurement to an analog voltage before transmission to a data logger. The latter reconverts the data back to digital form before recording, a process affecting power requirements and data precision. The Model 635-9 data logger was modified at the Sea-Data factory to receive the DSA input in its original digital form in the channel that is normally reserved for a digital compass. The data logger, operating in a burst mode, switches the DSA on at the start of a burst and writes one sample of the digital output from the DSA to tape for every 8 samples of pressure and u and v components of velocity. The DSA is switched off at the end of the burst by the data logger.

## INSTRUMENT ACCURACY AND PRECISION

A calibration was performed to establish the response of the instrument. The calibration was repeated for various target types. For each target, the calibration was repeated to establish the instrument precision.

A calibration was carried out with the DSA mounted vertically in a frame which was positioned over a flume containing standing fresh water (depth 120 cm). The DSA was aimed at the center of a target resting on the floor of the flume. The DSA could be positioned at any of ten fixed elevations between 30 cm and 90 cm above the target. For tests of instrument resolution, a slight modification of the frame allowed positioning of the DSA at virtually any elevation within the same range. The "true elevation" (E) of the DSA above the target was established with the use of a surveyor's auto-level and graduated staff; the staff was read to the nearest 0.001 feet (0.3 mm). The digital output of the DSA (T) was read from a computer interfaced to the DSA through the Sea-Data data logger that is used to control the DSA during a deployment. The same 12-bit digital data word recorded on tape in the field was thus used in the calibration. A calibration consists of mounting the DSA in each slot of the mounting frame in sequence and recording T and E. A calibration curve is obtained by finding the best-fit straight line between E (the dependent variable) and T/4095 (independent variable; 4095 is the full-scale 12-bit data word).

Target = Flat Steel Plate

The DSA was mounted in the flume and the flume bed (flat steel) was used as the target. The calibration was performed moving the instrument from the lowermost to the uppermost slot in the mounting frame. The calibration curve is presented in Figure 1. Over the range investigated, 35 to 85 cm above the target, the response of the instrument was highly linear, yielding a coefficient of variation ($R^2$) of 0.999. The precision was perfect: moving the instrument in the reverse sequence gave an identical calibration curve.

Assuming that the speed of sound in water is 1500 m/s, then the wavelength of the 1 MHz acoustic pulse is 1.5 mm. Based on the calibration curve in Figure 1, a change of one unit in the digital output of the DSA represents a change in elevation of approximately 1.5 mm. Therefore, the maximum resolution possible using a 12-bit data word is approximately 1.5 mm. To test the instrument resolution, the calibration was repeated, this time changing the DSA elevation by minimum increments of 5 mm over a range of 50 to 60 cm above the target. The results are shown in Figure 2: the instrument is clearly capable of resolving differences in elevation of at least 5 mm. Again, the precision was perfect.

Target = Flat Sand Bed

The calibration procedure was repeated with a flat sand bed as the target. A bucket containing a smoothed surface of quartz sand (mean grain size 0.10 mm) was placed on the flume bed underneath the DSA. The results of the calibration are shown in Figure 3. The calibration curve obtained in this way had an almost identical slope to the curve obtained from the test with the steel plate target, but displaced downwards by approximately 1.2 cm. This is consistent with two hypotheses: 1. the acoustic pulse was penetrating the sand bed a constant distance before being reflected, and, 2. a systematic error occurred in the measurement of the true elevation of the DSA above the target. The latter seems likely; it was difficult to perfectly smooth the sand bed and hence the DSA may have been "seeing" a local irregularity in the sand surface. A repeat of the calibration resulted in a slightly different systematic deviation, which further supports the latter hypothesis. Thus, essentially only differences in elevation rather than absolute values of instrument height can be measured with high accuracy due to the uncertainty in the instrument datum, i.e. the location of the focal point (origin) of the sonic beam within the transducer.

Target = Rippled Sand Bed

A natural sand bed under waves is rarely flat; usually the sand surface is molded into rhythmic bedforms (ripples) by the wave orbital velocities. A number of artificial bedforms of various size were used to investigate the way the DSA "sees" an undulating sand surface. The artificial ripples were constructed by forming sheet aluminum (30 cm wide) into the desired shape and stapling the formed sheet to a heavy perspex baseboard. The aluminum was sprayed with glue and dry sand (mean grain size 0.14 mm) was sprinkled on the setting glue. The excess sand was shaken off and the process repeated until a layer of sand 3 mm thick was built up. The sand was deemed necessary to duplicate the complex acoustic reflection and absorption that must occur with a real sand bed.

The baseboard with artificial ripple attached was placed on the flume bed and the DSA was mounted 40 cm above the bed on a track that allowed the DSA to be moved in precisely measured increments along a line normal to the ripple crest. For each artificial ripple, the DSA was moved in its track in 1 cm increments and at each stop the digital output from the DSA was recorded and converted to an elevation above the bed; from this was drawn the "indicated ripple profile".

Figure 4 shows the indicated and actual profiles of a symmetrical ripple of 20 cm length and height (trough to crest) of 2 cm, which is representative of the ripples observed by Wright et al. (1986). The steepness (0.1) is within the range generally displayed by wave-generated ripples in non-cohesive quartz sands (Nielsen, 1981).

The DSA accurately delineated the ripple crests, but failed to delineate the ripple trough. The results can be explained by assuming that the acoustic pulse emitted by the DSA has a finite width. The "effective beamwidth" was determined by mounting the DSA at a known elevation above a target and sliding a plate inwards towards the point directly underneath the DSA until the digital output jumped, indicating that the plate was being "seen" by the DSA (see Figure 5). The effective beamwidth determined in this way was 3 degrees to either side of the vertical. The bed profile that should be "seen" by the DSA is then easily calculated by assuming that the beam is conical and that each part of the conical beam is reflected back to the transducer from the ripple: the profile calculated in this way is compared to the indicated profile in Figure 4. The two profiles are similar, lending support to the (simplistic) interpretation of a finite beamwidth. The DSA therefore is fundamentally unreliable when the bed slope, taken over the beamwidth, is significant. This limits the instrument's capability to determining the "average" or approximate relative bed elevation when the bed is covered with relatively short wave-generated ripples. As a general rule, applicable to small amplitude ripples, placing the transducer at a height above the bed that is more than eight times the ripple wavelength guarantees that the crest level of the ripple field will be sensed as though depressions below this level do not exist.

## INSTRUMENT STABILITY

The DSA was mounted vertically in a 150 cm diameter tank of standing freshwater approximately 100 cm deep. The target was a flat sand surface that was contained in a small bucket placed on the floor of the tank. The nominal elevation of the DSA above the target was 50 cm. The DSA had an unobstructed view of the target. The DSA was connected to the Sea-Data data logger and the logger was set to operate at a duty cycle that is representative of an actual deployment: sampling rate of 1 Hz; 512 samples per burst; burst interval 4 hours.

The test continued uninterrupted for 14 days which represented an approximate operating time of 12 hours. The digital output of the DSA increased by a total of 2 units over the duration of the test. The change occurred progressively and corresponds to a change in indicated elevation of approximately +0.30 cm.

## INSTRUMENT SENSITIVITY TO SUSPENDED PARTICULATE MATTER

In the field, the acoustic pulse is vulnerable to scattering by bubbles and suspended particulate matter. Nevertheless, the instrument's use in the field has been successful because the deviations from the true target elevation are intermittent and (usually) evident when they occur, thus making their detection and removal possible.

Data were collected over a 10 day period on the mid-shoreface (8 m depth) in the southern Mid-Atlantic Bight; the details can be found in Wright et al. (1986). The sediment at the site was a fine sand (mean diameter 0.125 mm) with a silt and clay content of 2%. The DSA was mounted initially 50 cm above the bed. The digital output was sampled every 8 s over each 34 minute duration burst. A burst was begun every 4 hours.

During the first 6 days of the deployment the waves were low and the burst-averaged suspended sediment concentration at 14 cm above the bed never exceeded 900 mg/l. The DSA output remained stable over this period.

A shift of the wind to the northeast presaged an increase in wind speed and a building of surface waves. During the storm, burst-averaged suspended sediment concentrations reached 4000 mg/l at 14 cm above the bed. The DSA output deteriorated during this period. Two kinds of problem occurred: a loss of echo detection caused presumably by scattering of the acoustic pulse by suspended particulate matter (sediment and organic detritus); and premature echoes. The former were easily identified as spikes in the record and were simply deleted, the latter were more difficult to isolate since they occurred periodically and tended to obscure any hard baseline that may have represented the actual bed surface. During times of intense sediment resuspension, the physical meaning of the "bed surface" itself is not at all clear; once the storm abated the DSA output became stable again and the bed surface once more became discernible.

Data were collected over a 10 day period on the mid-shoreface (8 m depth) in the southern Mid-Atlantic Bight; the details can be found in Wright et al. (1986). The sediment at the site was a fine sand (mean diameter 0.125 mm) with a silt and clay content of 2%. The DSA was mounted initially 50 cm above the bed. The digital output was sampled every 8 s over each 34 minute duration burst. A burst was begun every 4 hours.

During the first 6 days of the deployment the waves were low and the burst-averaged suspended sediment concentration at 14 cm above the bed never exceeded 900 mg/l. The DSA output remained stable over this period.

A shift of the wind to the northeast presaged an increase in wind speed and a building of surface waves. During the storm, burst-averaged suspended sediment concentrations reached 4000 mg/l at 14 cm above the bed. The DSA output deteriorated during this period. Two kinds of problem occurred: a loss of echo detection caused presumably by scattering of the acoustic pulse by suspended particulate matter (sediment and organic detritus); and premature echoes. The former were easily identified as spikes in the record and were simply deleted, the latter were more difficult to isolate since they occurred periodically and tended to obscure any hard baseline that may have represented the actual bed surface. During times of intense sediment resuspension, the physical meaning of the "bed surface" itself is not at all clear; once the storm abated the DSA output became stable again and the bed surface once more became discernible.

## CONCLUSIONS

The Datasonics Model ASA-920 digital sonar altimeter is a highly accurate, precise and stable sonar that can be used to measure changes in relative seabed elevation. Because the acoustic pulse emitted by the DSA has a finite width, the instrument is unreliable when the bed slope, measured over the beamwidth, is significant. Therefore attention needs to be paid to the likely range of bedform steepness when interpreting the instrument output. In general, the altimeter does not "see" small amplitude ripples when its height above the bed is more than eight times the ripple wavelength. Particulate matter suspended in the instrument line-of-sight can cause both loss of echo detection and premature echoes. The former are manifest as spikes in the record and are simply removed; the latter obscure the true bed surface.

## REFERENCES


Cacchione, D.A. and Drake, D.E., 1982. Measurements of storm-generated bottom stresses on the continental shelf. J. Geophys. Res., 87:1952-1960.

Dingler, J.R. and Clifton, H.E., 1984. Tidal-cycle changes in oscillation ripples on the inner part of an estuarine sand flat. Mar. Geol., 60:219-233.

Dingler, J.R., Boylls, J.C. and Lowe, R.L., 1977. A high-frequency sonar for profiling small-scale subaqueous bedforms. Mar. Geol., 24:279-288.

Dyer, K.R., 1986. Coastal and Estuarine Sediment Dynamics. Wiley-Interscience, London, 342 pp.

Grant, W.D., Williams, A.J., Glenn, S.M., Cacchione, D.A. and Drake, D.E., 1983. High frequency bottom stress variability and its prediction in the CODE region. WHOI Technical Report 83-19, Woods Hole Oceanogr. Inst., Woods Hole, Mass., 71 pp.

Nielsen, P., 1981. Dynamics and geometry of wave-generated ripples. J. Geophys. Res., 86:6467-6472.

Wright, L.D., Boon, J.D., Green, M.O. and List, J.H., 1986. Response of the mid shoreface of the Southern Mid-Atlantic Bight to a "northeaster". Geo-Marine Letters, 6:153-160.

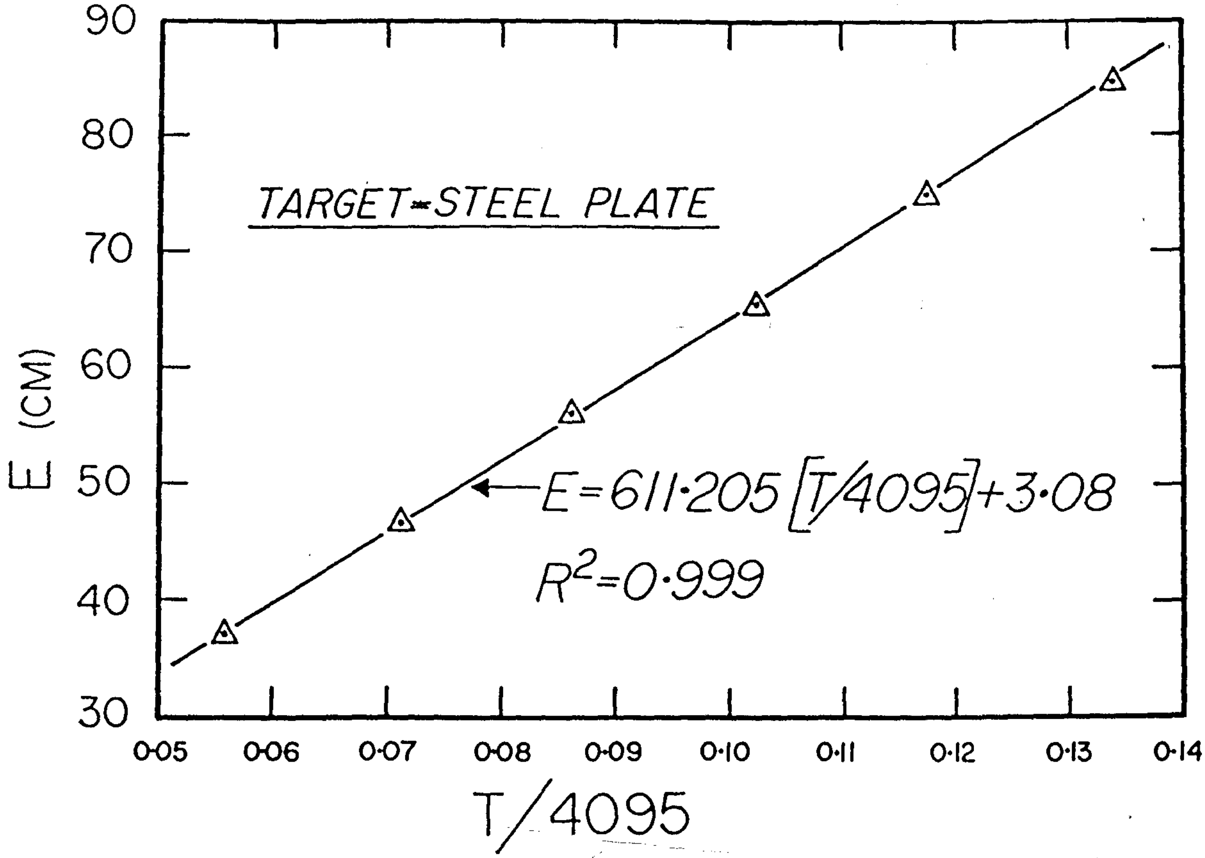


Figure 1. Calibration curve; steel plate target.

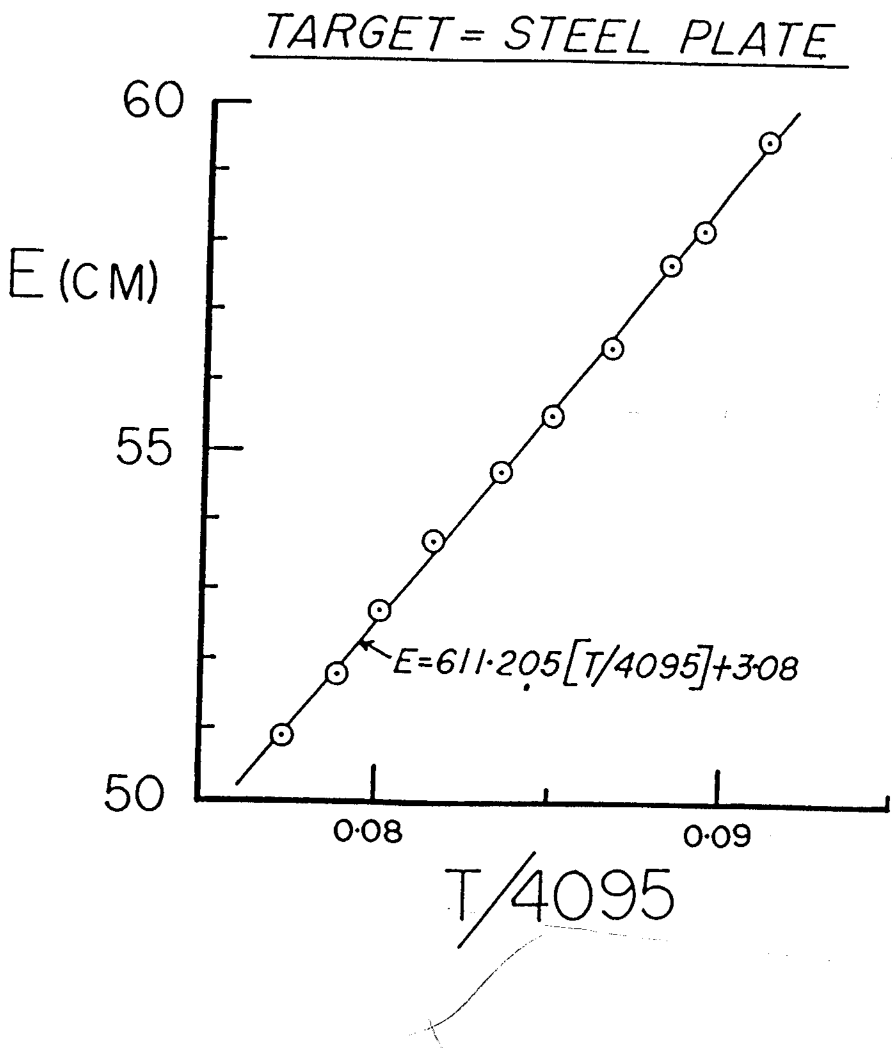


Figure 2. Calibration curve; steel plate target. The DSA is capable of resolving differences in elevation of at least 5 mm.

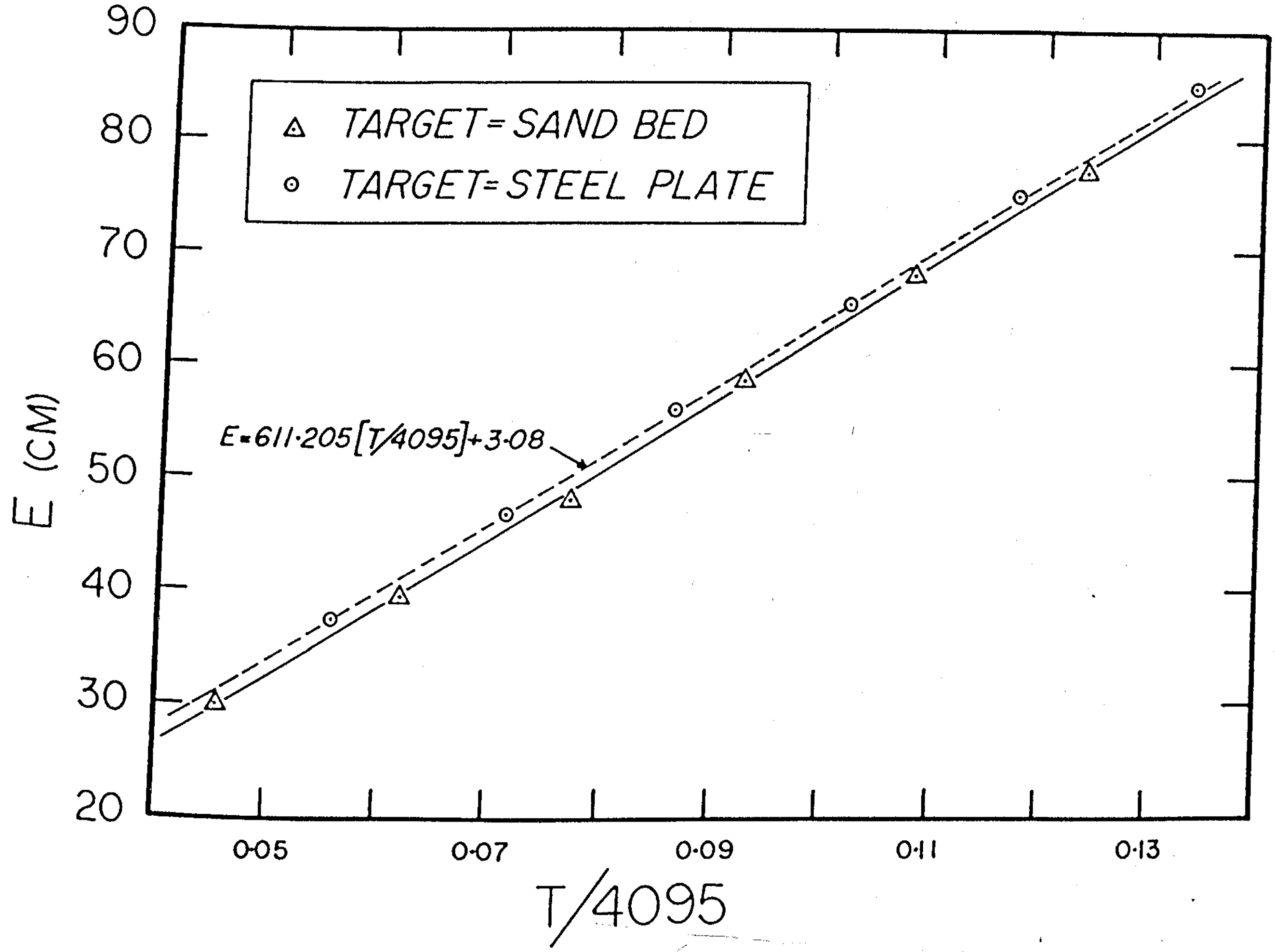


Figure 3. Calibration curve; flat sand bed target.

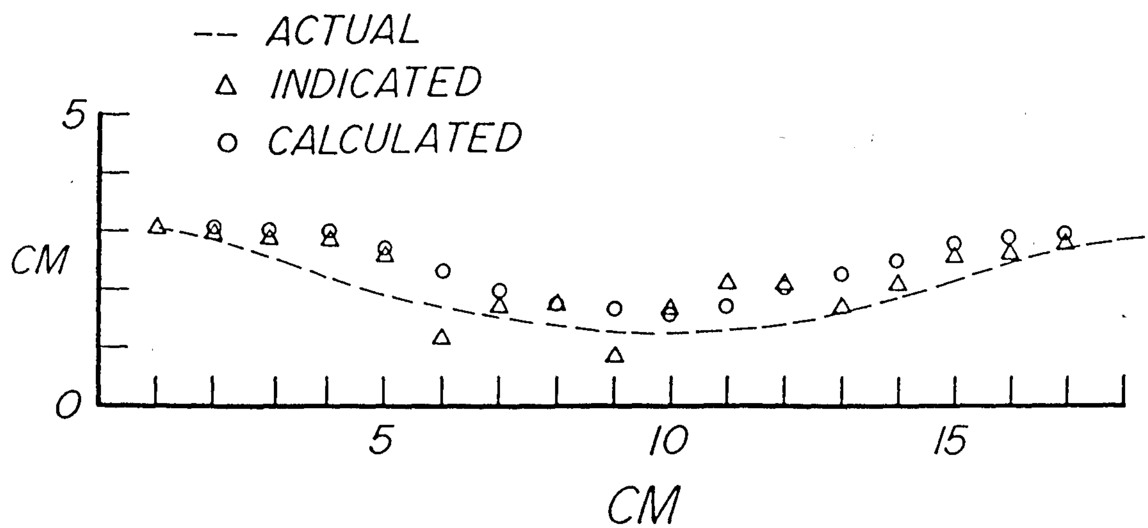


**Figure 4.** Test of the DSA's ability to delineate a rippled sand bed. The dashed line is the actual ripple profile; the triangles represent the profile indicated by the DSA. The circles represent the profile the DSA would "see" assuming the effective beamwidth of the DSA is 3 degrees.

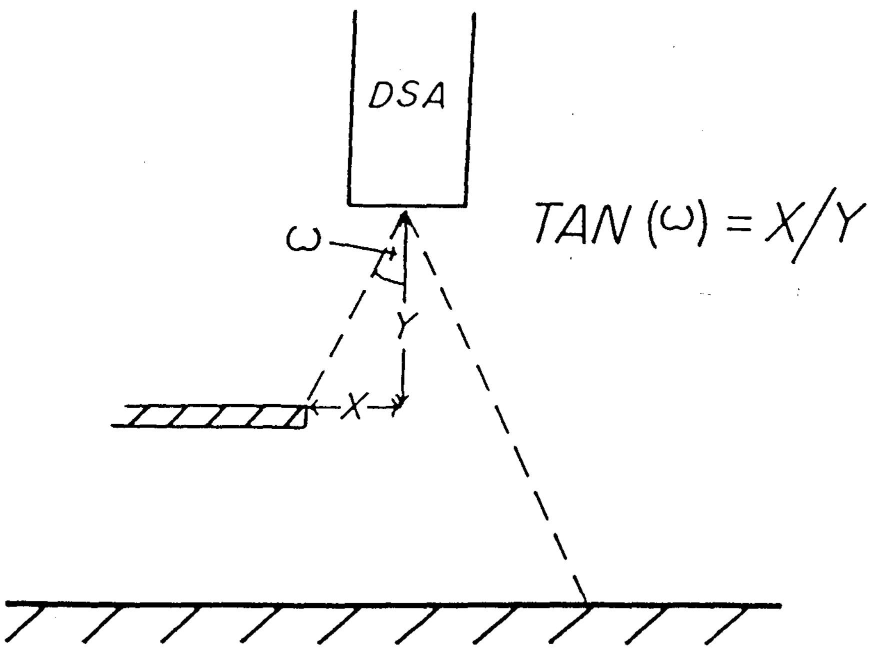


Figure 5. The experimental determination of the effective beamwidth. When the digital output jumps, the plate is in the line-of-sight of the DSA and the beamwidth is calculated.