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# Institute of Oceanography
# Old Dominion University
# Norfolk, Virginia

Technical Report No. 4

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## Laboratory and Field Evaluation of an Underwater Sand Height Gage

by

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and

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Prepared for the
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*A TECHNICAL REPORT*


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# LABORATORY AND FIELD EVALUATION OF AN UNDERWATER SAND HEIGHT GAGE

By Donald J. P. Swift[1] and Dennis G. McGrath[2]

## SUMMARY

Under the National Aeronautics and Space Administration master contract agreement NAS1-9434, Task Order No. 21, Old Dominion University researchers undertook this investigation to evaluate an underwater sand height gage. This instrument consisted of two transducers, one screened and one unscreened.

Laboratory experimentation included static and dynamic tests with three test sands--fine, medium, and coarse. Field tests were conducted at Rudee Inlet, Virginia Beach, Virginia.

Test results showed a linear response to up to 10 inches of sand loading. Deviation observed in identical tests appeared to be due to variation in the density of sand. Density differences reflected varying packing styles which, in turn, were a consequence of grain size and flow regime. Further evaluations of the sand height gage reflect this instrument's potential.

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## INTRODUCTION

This investigation was undertaken by Old Dominion University researchers for the National Aeronautics and Space Administration under master contract agreement NAS1-9434, Task Order No. 21. Its purpose was to determine the practicality of an underwater sand height gage for measurement of rates and amounts of sand accretion and erosion in the course of coastal engineering studies.

A significant portion of growing national concern with the quality of marine coastal environment is associated with the preservation of open coast. Utilization of the Atlantic, Gulf, and West Coast beaches has kept pace with the exponential rate of urbanization of these areas, and so has the concern of federal and regional authorities for beach preservation.

Beaches are the most dynamic of marine environments. Beaches and shore faces, or beach submarine extensions, are not stable surfaces, but surfaces which aggrade and erode in response to the changing energy level associated with the coastal wave climate. Net alongshore transport rates on open coasts range from 10,000 to 1,000,000 cubic yards of sand per year, and a single storm may strip a beach back 50 yards in a matter of hours. Sand is usually returned over a period of months by the fair-weather wave regime; yet, most coasts exhibit a net long-term deficit in their sand budgets due to the slow rise of sea level--a rate of some inches per century.

Engineers concerned with monitoring and controlling this sand flux are faced with an awesome logistic task. Instrumenting and observing the zone of breaking waves is in many respects more complex than equivalent procedures in deep-water oceanography. One of the simplest yet most difficult parameters is the rate of erosion or accretion of sand bottoms. At present, direct observation by divers is the only feasible method for small-scale changes--a weather-dependent operation with a low efficiency in terms of money and man hours.

## INSTRUMENTATION

The sand height gage represents a first attempt to develop an *in situ* sensing technique for this sand-flux parameter. It consists of two stainless-steel, flush-diaphragm, wire-strain gage transducers mounted in a brass adapter (fig. 1). The transducers used were Statham Instruments Model PM 131 TC, with 0.5-inch diaphragms and a pressure range of ±5 psid. The gage has been temperature-compensated to yield less than 1 percent of full-scale change in sensitivity for a temperature range of 0° to 100° F. The maximum nonlinearity of the transducers is less than 0.75 percent. One transducer diaphragm was covered with a 40-mesh brass screen so that the gage would sense only hydrostatic pressure. The other transducer was left unscreened to sense both the total and hydrostatic pressures.

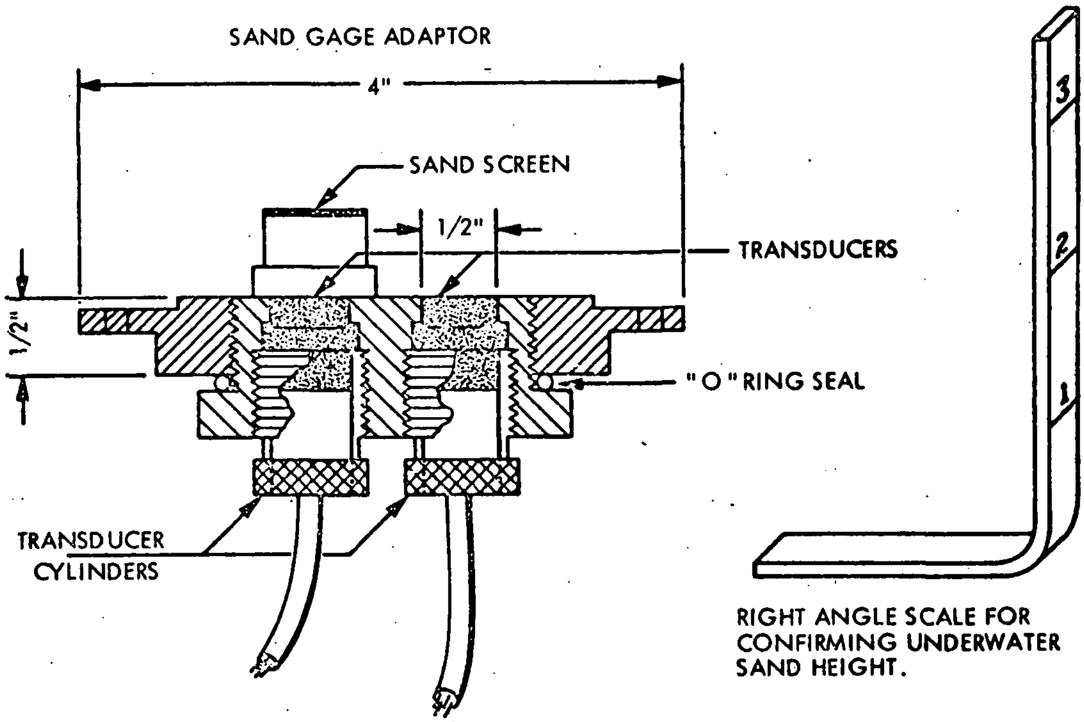


*Figure 1.- The sand gage sensing head.*

In performing field tests the adapter housing was modified to achieve greater stability. The transducers were mounted in a stainless-steel cylinder with one side port for both leads. The cylinder was attached to a 1-foot-square stainless-steel plate (fig. 2). The remaining instrumentation included a regulated power supply, a balance-control unit, and a Honeywell Electronic 19, 2-channel, strip-chart recorder (fig. 3).

*Figure 2.- Sensing head with screen.*

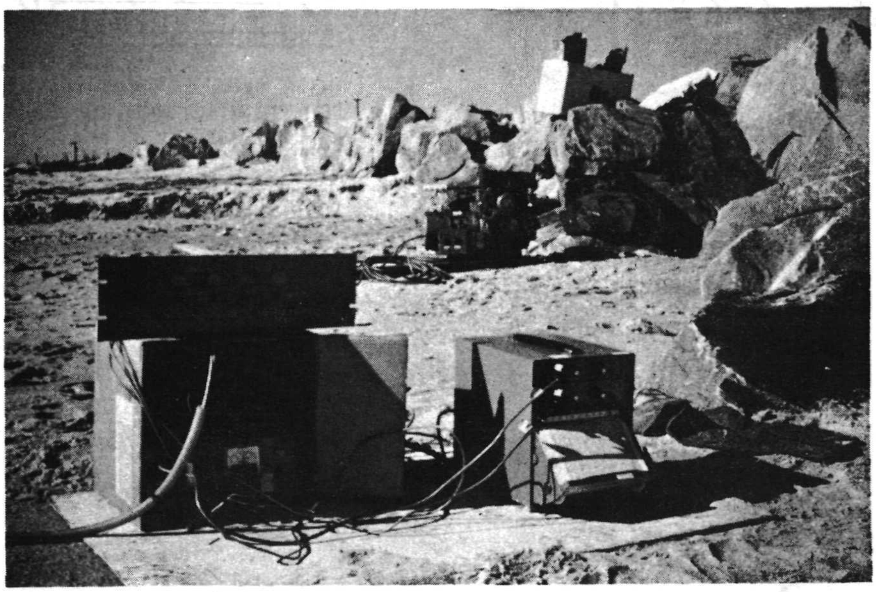

*Figure 3.- Recorder and power plant at Rudee Inlet, Virginia Beach, Virginia.*

Laboratory test tanks included a tank of marine plywood, 3 by 3 by 4 feet, with a fiberglass interior and a recirculating flume (fig. 4). The flume's observation section was 16 inches long by 18 inches high, by 22 inches wide. An outboard-motor propeller and an electric motor provided surface velocities of 1 to 2 feet per second.

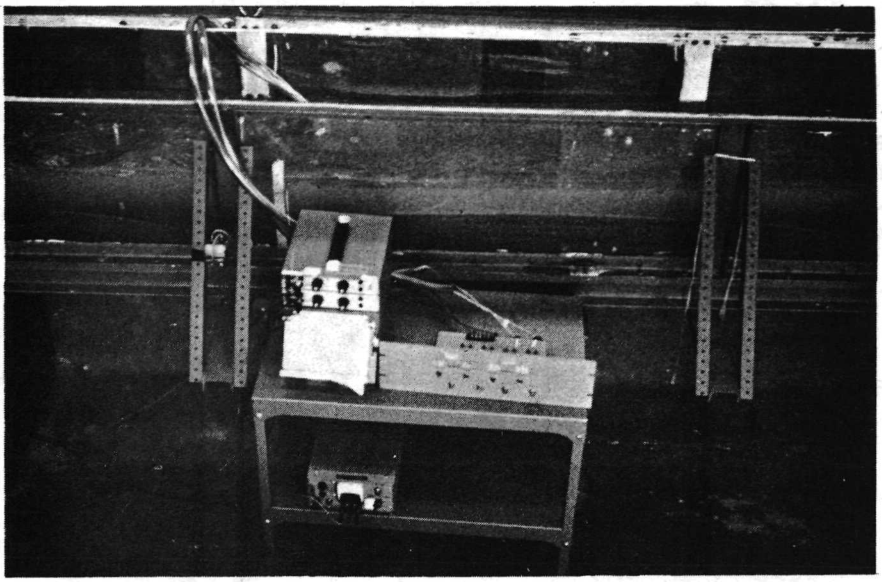

*Figure 4.- The recirculating flume.*

## PROCEDURES

In order to evaluate the gage, coarse, medium, and fine test sands were selected (fig. 5). Static and dynamic laboratory tests were performed, during which sand and water heights were measured at 1-inch intervals together with corresponding gage deflections.

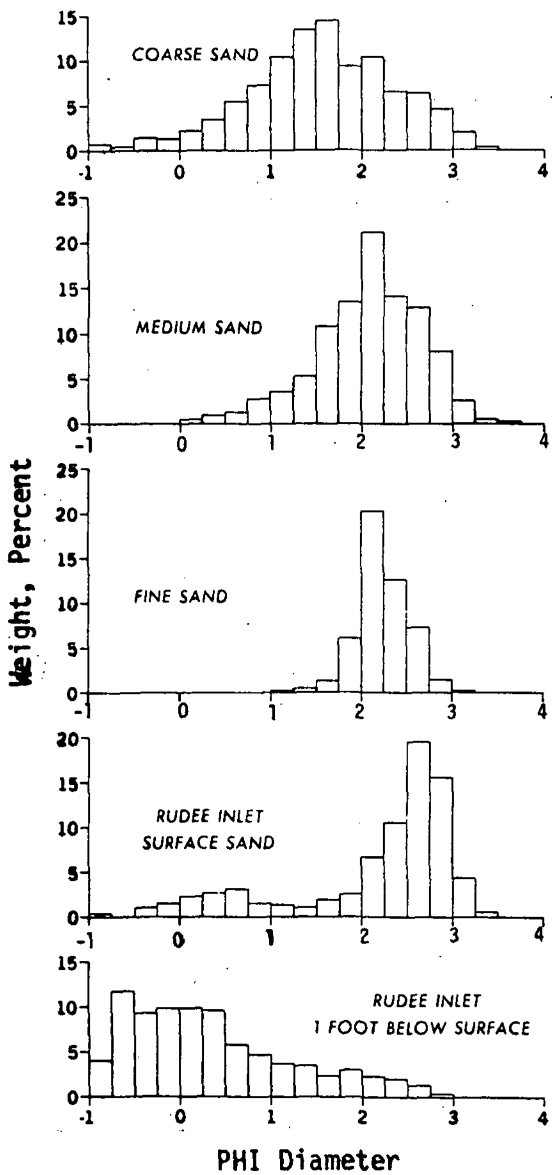


*Figure 5.- Size frequency distributions of test sands. The PHI grain diameter is the negative log of the diameter in millimeters to the base 2.*

In the static tests, the gage was mounted flush with the bottom of the static tank and was covered with 24 inches of water. The gage was loaded 3 times with fine- and coarse-grained sands by gently sprinkling sand onto the transducer in the test box, until the sand level reached 24 inches.

In dynamic tests, the gage was mounted flush with the flume floor. Medium- and coarse-grained sand types were sedimented onto the gage as a current-induced bed load. Because of the geometry of the flume, total flume loadings were limited to 6 inches.

Four field tests were conducted under behavioristic circumstances at Rudee Inlet, Virginia Beach, Virginia (fig. 6), where a sand-entrapment area has been created next to the beach on the upcurrent side of the inlet. The entrapment area is designed as a staging area for the littoral sand drift, where it can be pumped across the inlet.

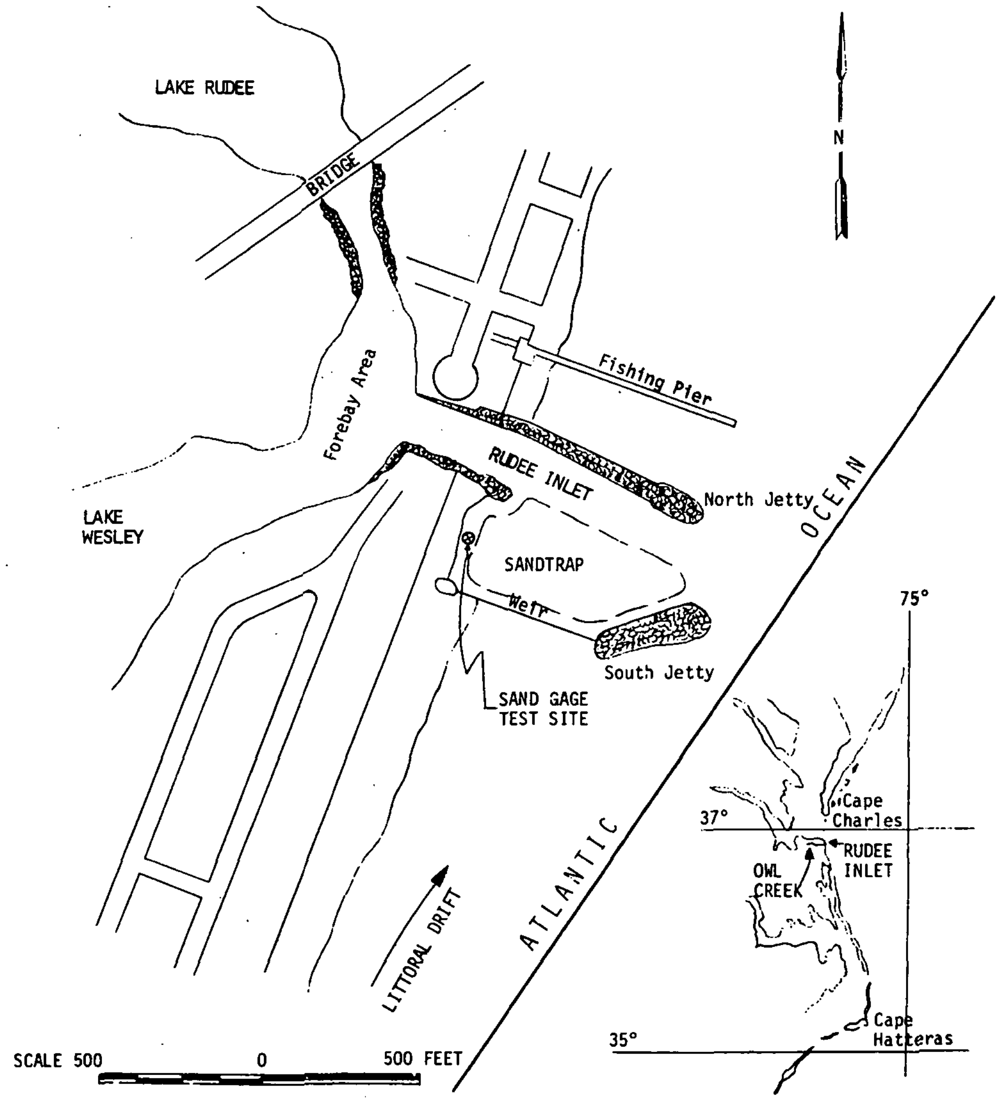


*Figure 6.- Rudee Inlet, Virginia Beach, Virginia.*

RESULTS

Static Laboratory Tests

Results of static loading tests with fine and coarse sands (fig. 7a & 7b below; and 8, p. 9) showed that, between 0 and 10 inches of sand, the gage registered a linear response to the loading of sand.

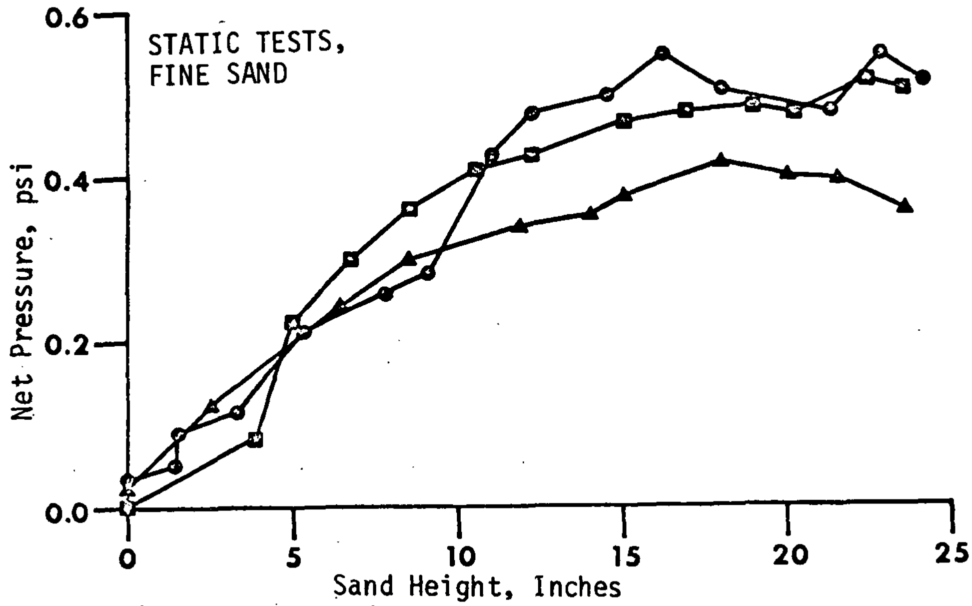


*Figure 7a.- Results of static tests, fine sand.*

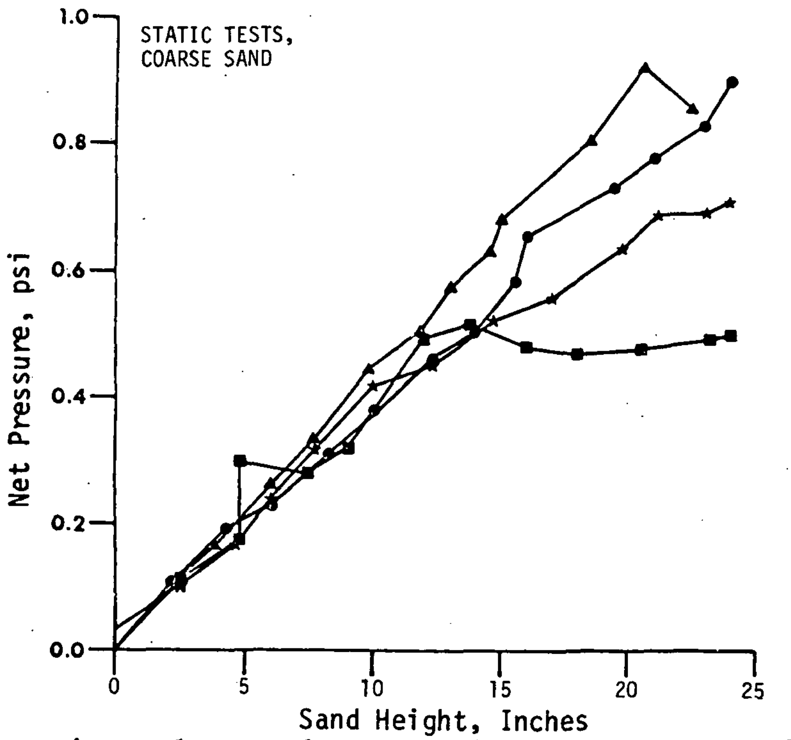


*Figure 7b.- Results of static tests, coarse sand.*

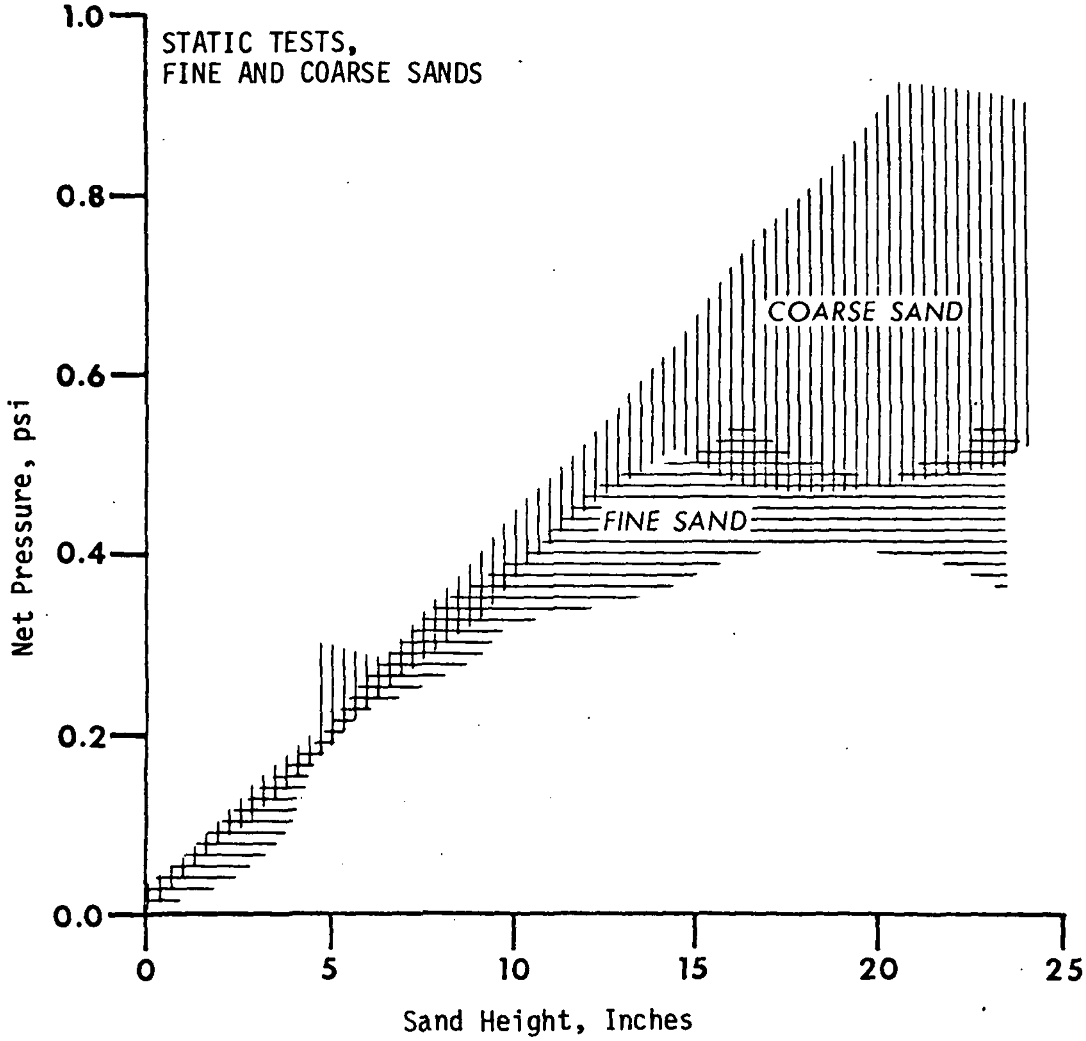


*Figure 8.- Comparison of static tests.*

Reproducibility for this section of the curves was ±25 percent for fine sand and +10 percent for coarse sand. The major source of error was probably the variable packing of the sand. Sand sprinkled into water accumulated in open packing and its porosity approached 48 percent, the value for perfect spheres. Such sand was unstable and a tap on the static tank was sufficient to collapse it into a tighter packing.

Sand behavior changes with increased loading. Heretofore, it has behaved as viscous fluid and, respectively, the gages have sensed hydrostatic pressure due to weight of water and total hydrostatic pressure. When a critical loading was reached (10 in. for fine sand), the sand layer began to behave as a semisolid. Grains interlocked and pressure was transmitted away from the gage to the walls of the tank.

The result was that curves flattened out and further loading was not recorded as an increased differential between the two gages. A feedback may occur so that further loading may increase the locking effect, and the pressure differential actually may decrease. This behavior will be referred to as the bridging effect.

The nonlinear response appeared in only one of four coarse sand tests, possibly due to a collapse into tighter packing. Presumably, all runs would bridge at some higher sand height. The low bridging threshold seen in static tests was an artifact caused by testing in a tank with walls. In nature, a free bridging effect would probably occur when the sand height, for a given grain size in a sheet of effective infinite extent, is sufficient to result in solid behavior.

## Dynamic Laboratory Tests

During dynamic loading tests, medium- and coarse-grained sands were run three times, each at three current velocities (fig. 9a, below; 9b & 9c, p. 11; 9d, 9e, & 9f, p. 12; and 10a and 10b, p. 13). Surface-current velocities were ranged approximately between 1 and 2 feet per second. Effects of these velocities on the medium- and coarse-grained sands were dependent on the geometry of the flume, and it was more useful to restate the respective velocity fields in terms of the flow regime. Flow regimes may be defined in terms of water depth, velocity gradient, bottom shear stress, dimensionless numbers; or, qualitatively, in terms of characteristic bed configurations. The low-, medium-, and high-velocity runs for the medium-grained sand tests occurred in the lower, middle, and upper parts of the lower flow regime--a regime characterized by migrating sand ripples. A somewhat higher velocity was used during the high-velocity run for coarse sand, with the result that the transition to the upper flow regime was attained, in which ripples flattened out and a plane bed appeared.

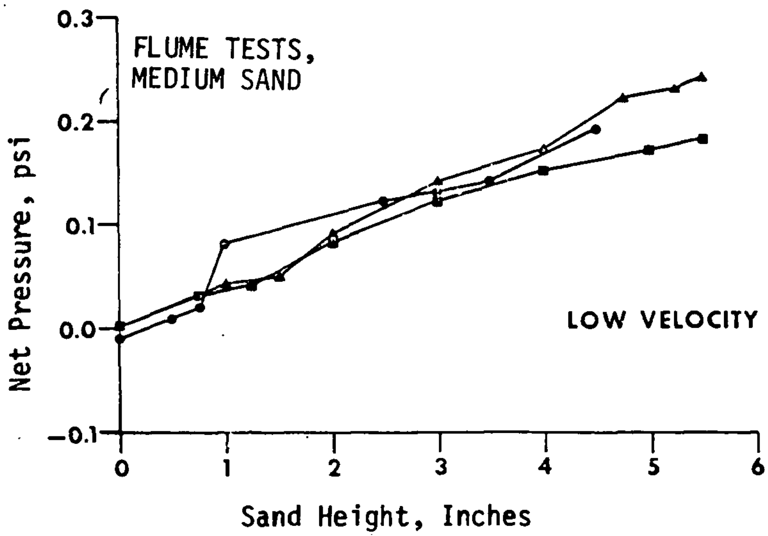


*Figure 9a.- Results of flume tests, medium sand, low velocity.*

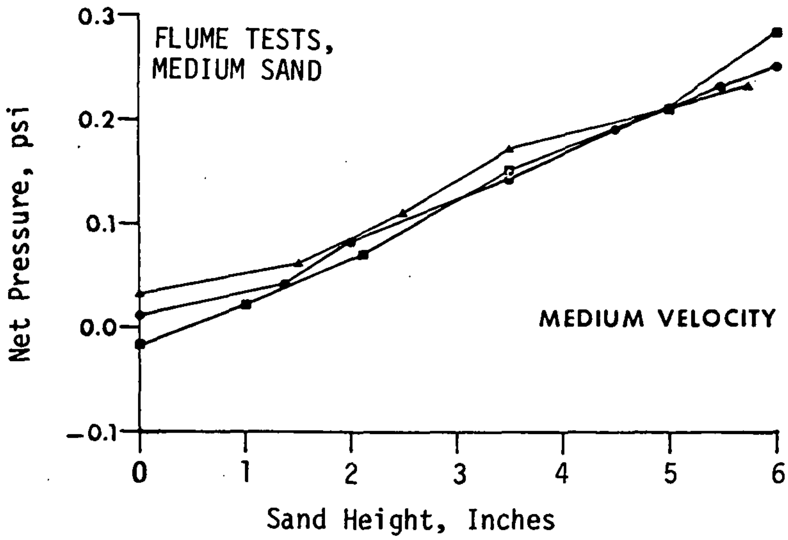


*Figure 9b.- Results of flume tests, medium sand, medium velocity.*

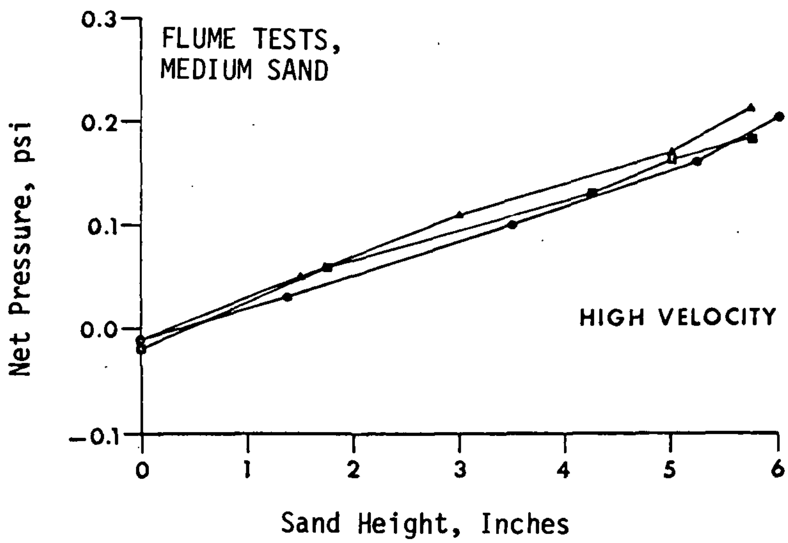


*Figure 9c.- Results of flume tests, medium sand, high velocity.*

Due to the geometry of the flume, it was not possible to load the transducers with more than 6 inches of sand. Consequently, all tests were conducted with sand heights that in static tests had resulted in a semiviscous behavior of the sand and a linear response of pressure to sand height. Responses were also linear in the flume test.

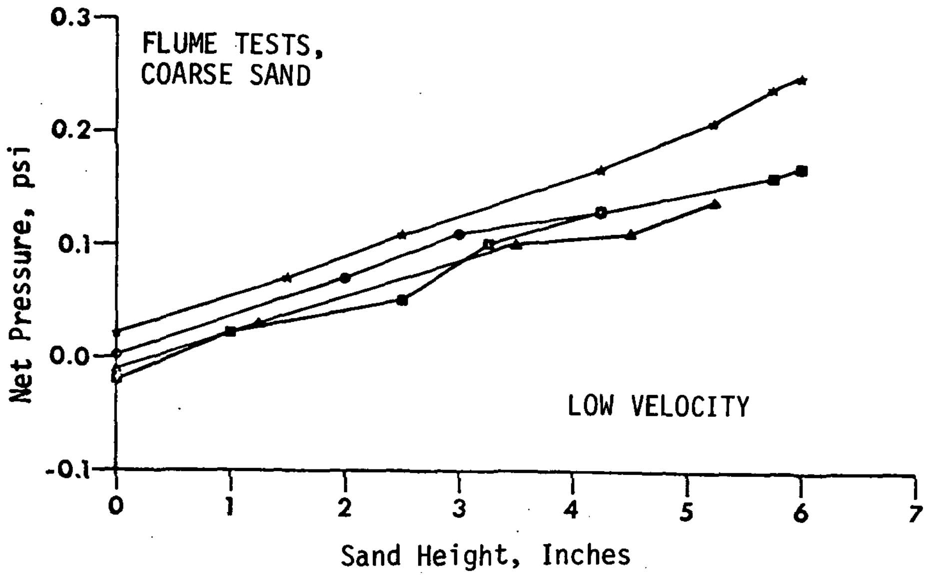


*Figure 9d.- Results of flume tests, coarse sand, low velocity.*

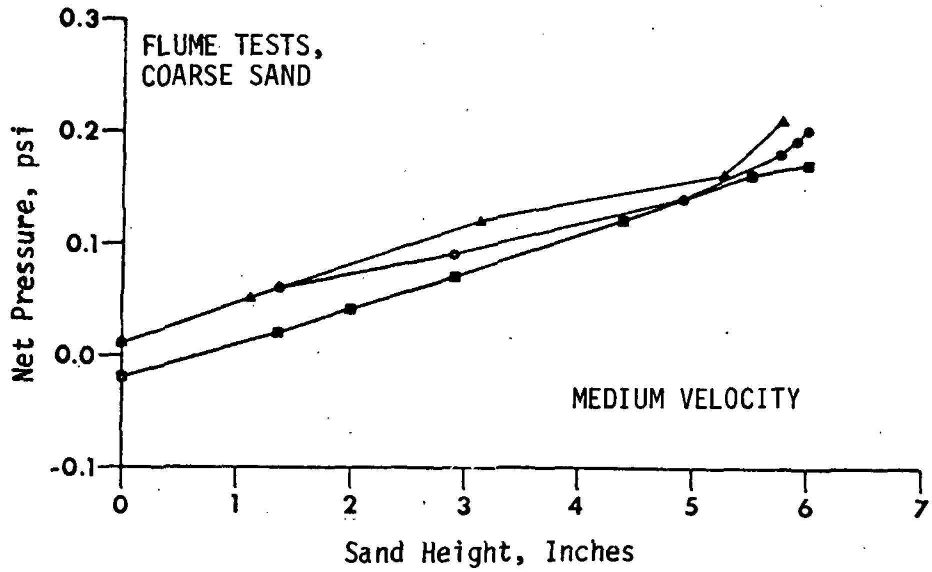


*Figure 9e.- Results of flume tests, coarse sand, medium velocity.*

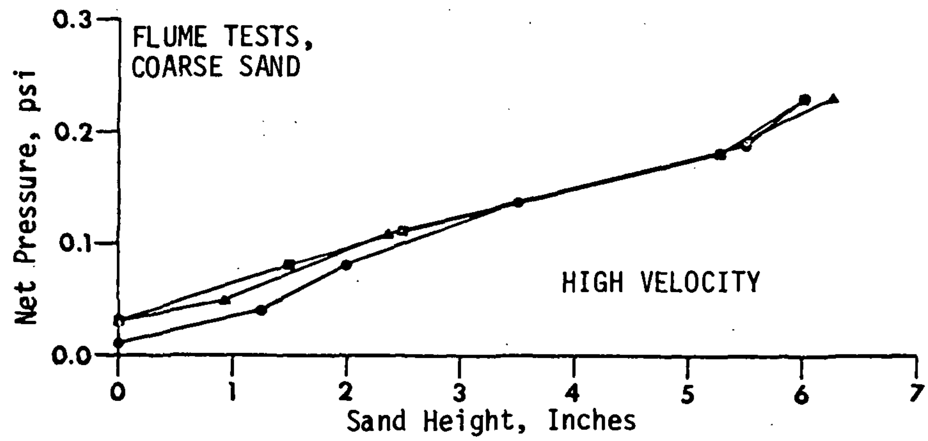


*Figure 9f.- Results of flume tests, coarse sand, high velocity.*

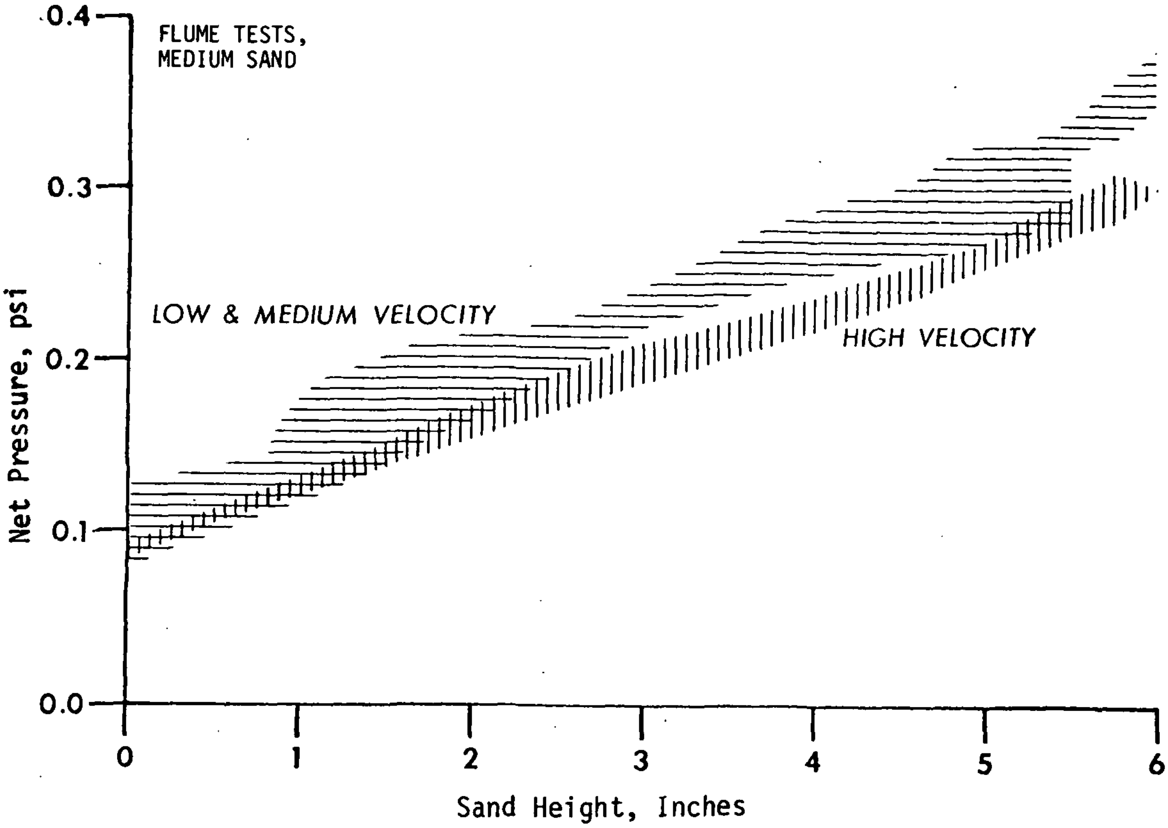


*Figure 10a.- Flume tests, medium sand; low, medium, and high velocities.*

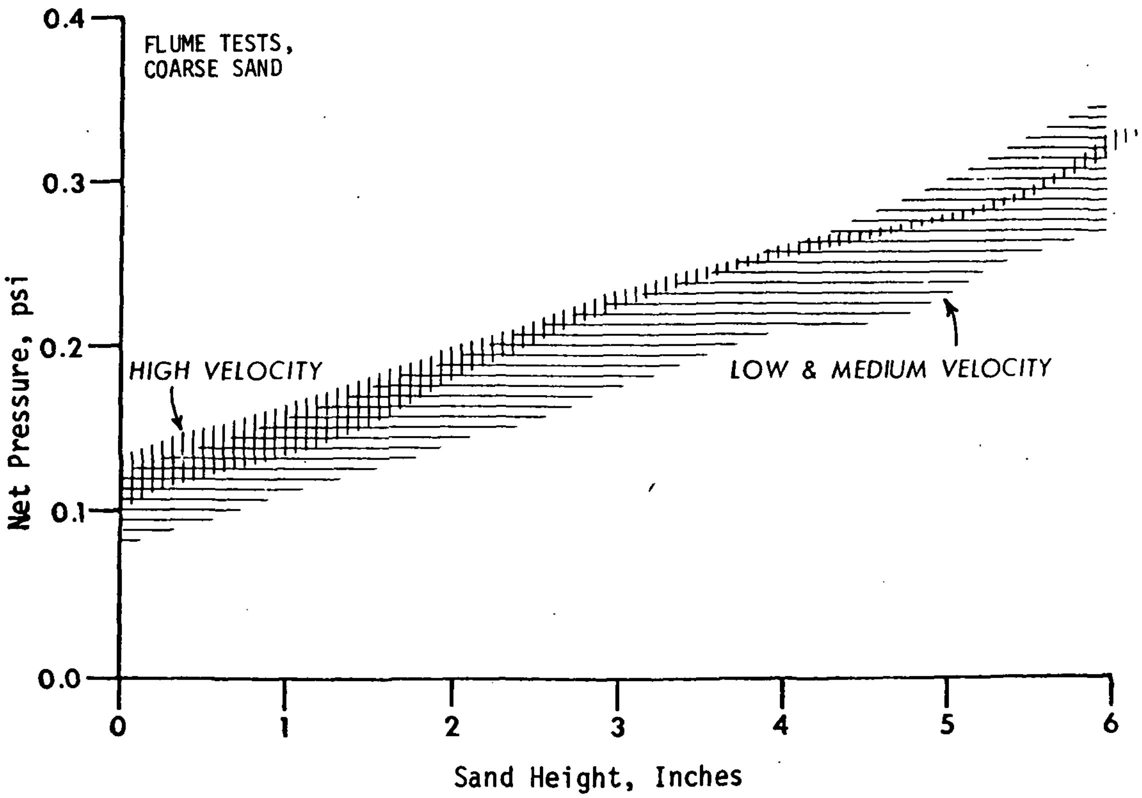


*Figure 10b.- Flume tests, coarse sand; low, medium, and high velocities.*

Flume tests of medium sand at low and medium velocities did not differ significantly from each other, although all runs showed that sedimented sand exerted approximately 30-percent more pressure at any given sand height than did sprinkled sand. This was a consequence of a changed mode of deposition. Sand deposited by moving current ripples was deposited as alternations of upcurrent strata, whose grains were driven in at full velocity, and lee-slope strata which had tumbled over the crest (fig. 11). The former, in close packing, were absent in the static-test strata which were, therefore, less dense.

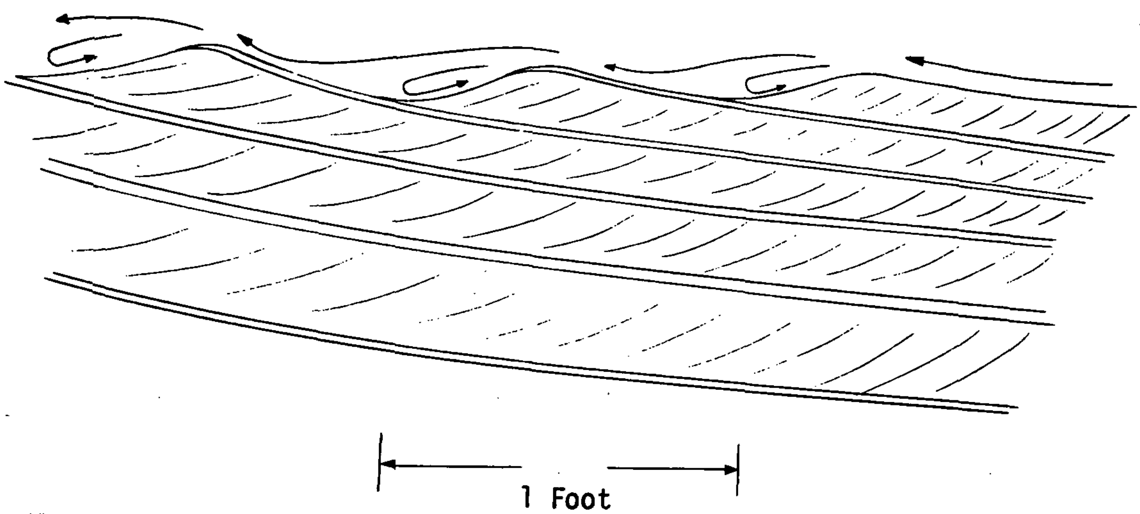


*Figure 11.- Sketch indicating stratification produced by sand ripples. Arrows show flow lines. Lee-slope strata are in relatively open packing. Ratio of lee-slope strata to upcurrent-slope strata increases through lower flow regime due to destruction of latter by lee vortex; then, decreases as transition to plane bed begins at Froude number of approximately 1.*

The high-velocity flume test from medium-grained sand exhibited approximately 0.02-psi less pressure than the low-velocity runs; hence, sand deposited during this run was in somewhat looser packing. Variation among the 3 runs was also less. Visual observations suggested that, in the upper portion of the lower flow regime, scour in the lee of the ripples tended to destroy the upcurrent beds of the preceding ripple, and that the ratio of packed upcurrent beds to loose downcurrent beds was lower. Therefore, mean density was higher and variability was less.

Flume tests with coarse sand revealed a variation in pressure with sand height that was not significantly different from that of sprinkled sand; unlike medium sand, coarse sand did not pack markedly better when current-deposited than when sprinkled. The reason is probably to be sought in differing settling behavior of different sand grades. Finer sand more nearly settles according to Stokes law, in which viscous forces are important and its impact is cushioned by a viscous boundary layer, which is thick relative to grain diameter. Hence, settled fine sand can be more openwork than settled coarse sand. Within fine sand tests, high velocity runs appeared to have been more uniform and to have resulted in slightly denser sand. Apparently, this run was of sufficiently high velocity to have approached the transition to the upper flow regime, with reduced flow separation over ripple crests. This resulted in the planing off of ripples and a reduction in the ratio of lee-slope to upcurrent-slope strata.

## Field Tests

Field loading tests at Rudee Inlet were conducted near the beach within range of the 100-foot cable between the gage and the recorder. To obtain maximum accretion, a hole was dug in the sand several feet above water level at low tide. As the tide advanced, the gage was gradually buried. Sand- and water-height readings were taken at 5-minute intervals. Maximum sand heights varied between 2 and 11 inches in field tests.

Two of the four field tests were unsuccessful (fig. 12). In the first test, a shell containing an air bubble fell over the transducer early in the experiment, resulting in zero to negative sand pressures. In the third test, insufficient sand sedimented onto the transducer. The remaining two curves correspond closely. Both exhibit reversals, apparently due to sand washing off the gage.

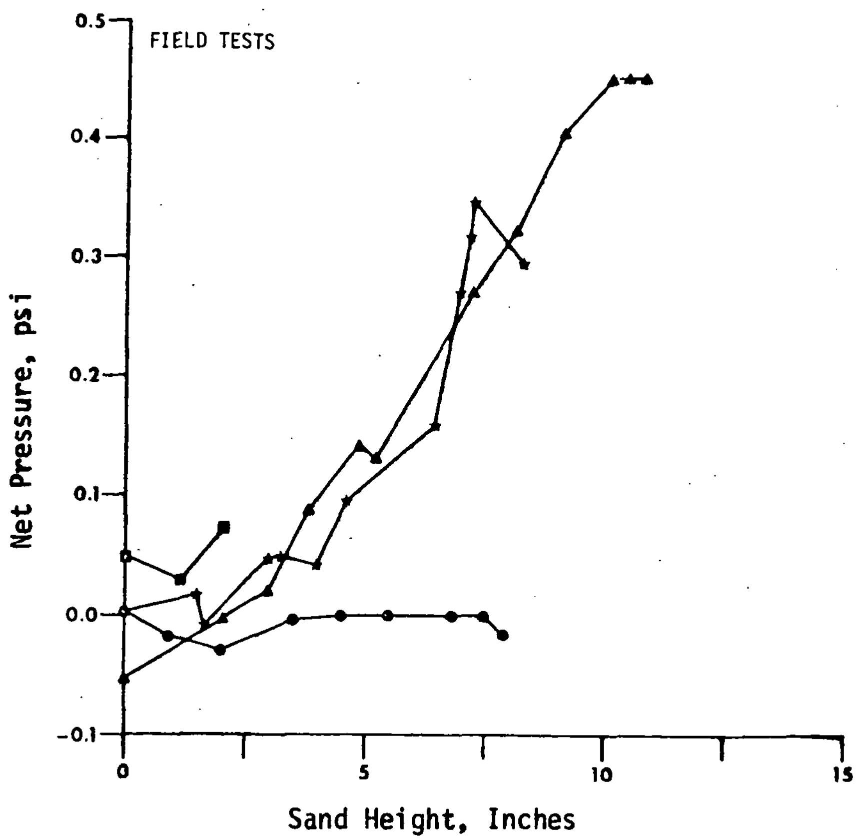


*Figure 12.- Results of beach tests.*

## CONCLUSIONS

The sand height gage as constituted at present responded in linear fashion to up to 10 inches of sand loading. Errors ranged from 25 percent for fine sand sprinkled into a box to as low as 1 percent for coarse sand sedimented by current in the transition to high flow regime. When loaded beyond 10 inches in a static tank, the gage's response was nonlinear due to the semisolid behavior of the sand. Instrument and operator variance appeared to account for only a small portion of the observed variation. Most of the variation appeared to be due to real variations in the density of the sand. These reflected differing packing styles which, in turn, are the consequence of

(1) Grain size

Finer sand is less permeable due to a greater ratio of pore width to viscous boundary layer. Therefore, it resists close packing more than coarse sand. The degree of packing also varies directly with the standard deviation of the size frequency distribution of sand, and fine sands are usually better sorted (fig. 5).

(2) Flow regime

In the lower flow regime where sands move as migrating ripples, the ratio of loosely packed lee-slope strata to closely packed upcurrent-slope strata passes through a maximum with increasing velocity, and sand density passes through a corresponding minimum. The effect on gage readings is slight compared to that of grain size.

In general, pressure recorded for a given height of sand increased with grain size and current velocity, and variation decreased. On most natural beaches, with medium to coarse sand and currents whose peak velocities exceed 1 foot per second, reproducibility with the instrument tested would be within ±5 percent if the instrument were calibrated for grain size. This would be an acceptable value.

In its current form of construction, the gage displays restricted characteristics as an underwater sand measuring device.

(1) Instrument's advantages:

(a) It is more sensitive to smaller changes (0.1-1.0 ft) than echo sounders.

(b) It is a remote sensing system which could be developed into a remote recording system.

(2) Instrument's major limitations:

(a) It cannot respond accurately to more than 1 foot of sedimentation.

(b) It must be emplaced at the beginning of a cycle of sedimentation and erosion, and it cannot measure erosion unless buried first.

(c) It requires a cable run back to shore since a remote recorder has not been developed yet.

(d) Unlike an echo sounder, it is a point sensor; an array must be used for an areal study.

In its present state of development, the sand height gage seems destined to become a specialized research instrument. In view of the bridging problem, it will be more efficient and cheaper for engineers with service-type problems to survey nearshore shoaling by means of echo sounders, sea sleds, or divers. However, researchers investigating nearshore sedimentary processes would have a real use for a device which could remotely sense very small changes in depth. It is very possible that the bridging threshold depends, not only on size and packing characteristics of sand, but also on the configuration of the gage itself. Therefore, further development might result in an instrument for more general use.