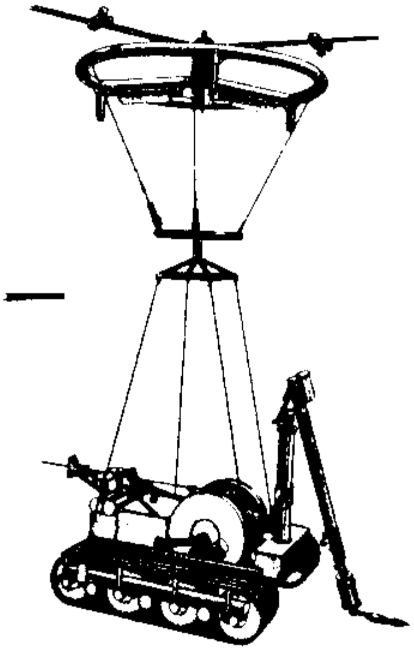
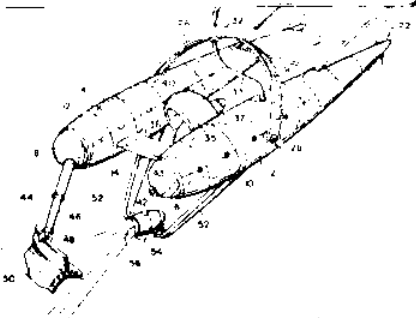


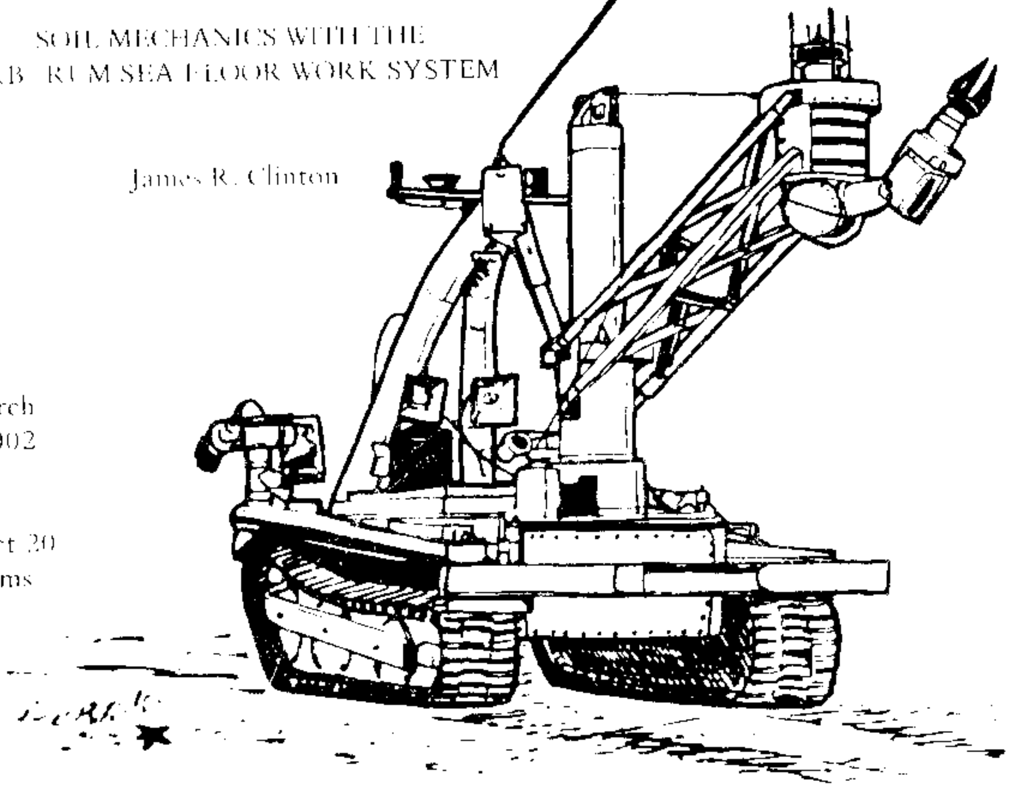


MARINE PHYSICAL LABORATORY
of the Scripps Institution of Oceanography
San Diego, California 92152

SEA FLOOR TECHNOLOGY
REPORT No. 4

SOIL MECHANICS WITH THE ORB-RUM SEA FLOOR WORK SYSTEM

James R. Clinton



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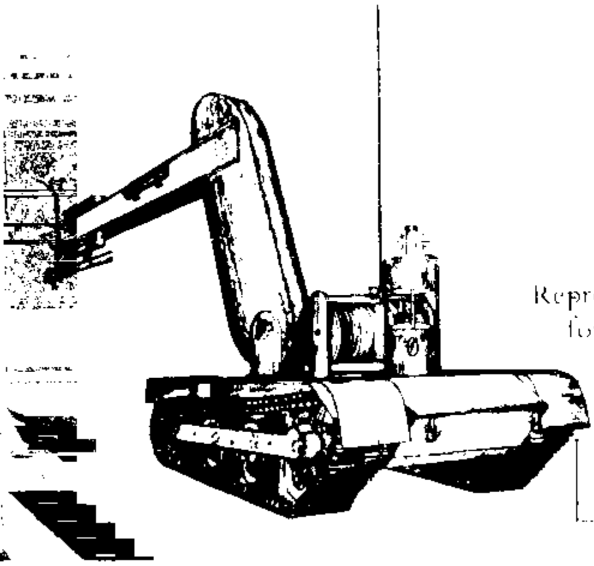

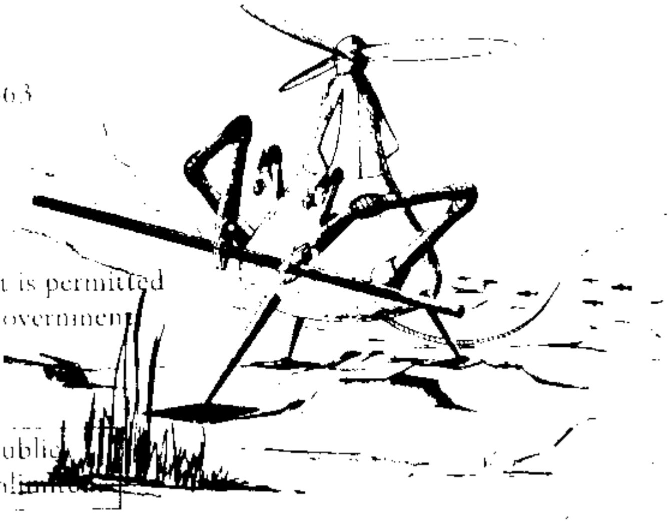

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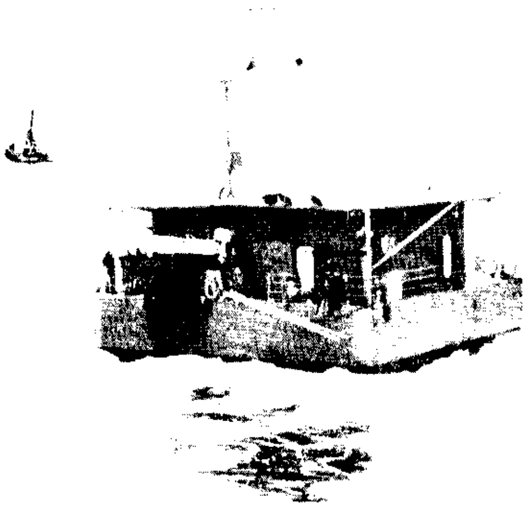

"ORB" Oceanographic Research Buoy

ORB, a 45-foot square vessel displacing approximately 180 tons, was developed by the Marine Physical Laboratory to serve projects at the laboratory which require the launch, retrieval, implantation or handling of large equipments or systems in the open ocean. Among these are:

1. "RUM" (remote underwater manipulator); remotely controlled, bottom crawling vehicle.
2. "Benthic Laboratory"; an electronic control and data transmission center, remotely operated and maintained on the sea floor.
3. Acoustic transducers and hydrophone arrays.

In contrast to FLIP, ORB is designed to follow the motion of the sea surface as closely as possible, in order to simplify the task of placing and retrieving large objects in the ocean. The vessel has a center well of 15- by 20-foot area which can be opened to permit equipment to be lowered through it. Loads up to 12 tons are safely handled with a system that includes a number of automatic control features, and can be lowered to a maximum depth of 10,000 feet. The supporting cable also serves simultaneously to transmit as much as 30 kilowatts of power to the remote equipment, and to return from it a variety of data, including television video signals.

ORB is 24 feet high from keel to helicopter deck. It has no means of self-propulsion and must be towed to and from operating areas. The vessel is equipped with diesel generating sets to provide 90 kilowatts of electrical power. ORB's equipment also includes a normal amount of navigation aids, communication and safety equipment. It carries fuel and water for a stay of up to 45 days while moored on station. Personnel rotation at sea where necessary may be accomplished by either small boat or helicopter.

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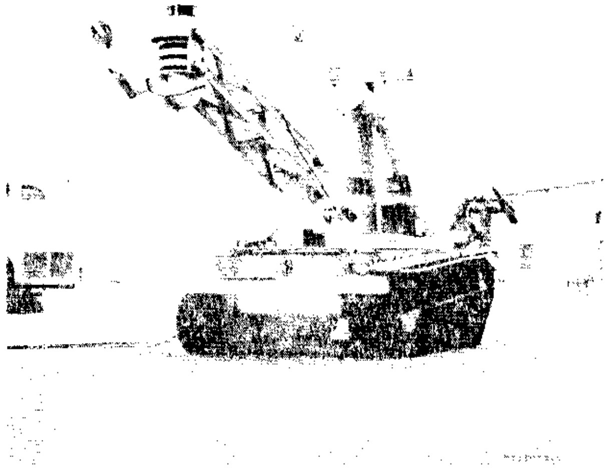

"RUM" Remote Underwater Manipulator

RUM is a remotely controlled, tracked sea floor work vehicle which has been developed under the sponsorship of the Office of Naval Research at the Marine Physical Laboratory for use as a research tool in sea floor technology experiments.

The hull, tracks and suspension system of the RUM vehicle are those of an "ONTOS," a surplus Marine Corps tracked rifle.

All power, telemetry for control and instrumentation, sonar, navigation aids and television are transmitted over the single coaxial umbilical cable connecting the RUM to ORB.

The vehicle is propelled by two independently controlled reversible 7-1/2 horsepower direct current motors, one driving each track. Other equipment includes two television cameras, eight 500 watt lights, a scanning sonar, depth sounder, magnetic compass, an acoustic transponder navigation system and numerous other kinds of instrumentation to monitor operational conditions.

All of the electrical and electronic components with the exception of the TV cameras and lights are immersed in oil and operate at ambient pressures of up to 5000 psi.

The manipulator is capable of working off of either side or to the rear of the vehicle and is capable of exerting 50 pounds of force in any direction at full arms length. In addition the manipulator boom is equipped with a hook capable of lifting loads of up to 1000 pounds and moving them about on the ocean floor. The manipulator boom swings in an arc of about 300° around a king post located at the rear center of the vehicle. The boom is raised and lowered by a motor-driven wire rope topping lift.

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ABSTRACT

This report concerns the soil mechanics instrumentation which has been developed for use by the RUM vehicle in studies of the trafficability of the sea floor. The in-situ test equipment consists of a vane shear meter, cone penetrometer, track depression profiler and anchor winch system. Each instrument and its operation is described and interpretation of its measurements is discussed. Methods of sample collection and subsequent laboratory analysis are also presented.

SOIL MECHANICS AND THE RUM

As described in the paper "Instrumenting RUM for in-situ Sub Sea Soil Surveys," presented at the 1971 ASTM Symposium on Soil Sampling, Testing and Construction Control, the RUM vehicle has been equipped to conduct soil mechanics and trafficability tests on the sea floor. The purpose of this report is to acquaint the reader with each of the instruments, their use and the significance of their measurements.

An adequate understanding of basic soil mechanics can be achieved with an introductory text,1/ but it is possible to understand simple aspects of soil behavior with only a few ideas. Soil is composed of mineral particles (and possibly organic matter), and water. The strength of the soil is due to the size and shape of the particles, the interactions between the particles, and the amount of water. As a load is applied to this system, it is first carried mainly by the water. This causes the water to flow out, so that ultimately, the load is carried completely by the mineral skeleton. This time varies widely for different soil types. As the size of the particles becomes smaller, the soil becomes more sensitive to disturbance. This is especially true of sea floor sediments which have accumulated undisturbed over long times, typically thousands of years. Sea floor sediments are in general, soft clays and silts with low shear strengths, and long drainage times, and are sensitive to disturbance.

THE VANE SHEAR METER
Introduction

The vane shear meter and various penetrometers are the only widely used methods of measuring in-situ soil strength. Even though most soil testing is done in the laboratory on samples gathered by various methods, in-situ testing is especially valuable in situations in which the soil is sensitive to disturbance or the properties of the soil vary vertically or laterally. Vane shear tests are also performed in the laboratory while penetration testing is usually restricted to the field.

Vane shear tests can be performed quickly with a relatively simple apparatus (compared with other strength determination methods). The test is conducted by inserting a four-blade paddle into the soil and measuring the resisting torque as the paddle is rotated. The ratio of height to diameter of the vane is generally about two, with the diameter of the vane one-half to four inches. Vanes for field use are usually larger than those used in the laboratory. The rotational velocity should be slow – about 0.1 degree per second, to ensure that viscous drag on the blades does not degrade the accuracy of the strength measurement.

The vane shear meter is also used to measure the remolded strength of the soil. The vane is rotated in place a number of times and the strength measurement is repeated.

The vane shear test has a number of important advantages as a method of measuring in-situ shear strength:

1. It is more accurate than penetration methods for measuring the strength of cohesive soils.

2. The apparatus is simple and easily adaptable to field use.

3. There is a minimum of disturbance of the soil during insertion in the soil. This is especially important in the case of highly sensitive clays.

4. The vane test is also commonly performed in the laboratory providing a means of comparing in-situ and sample-derived strengths using one method. An important qualification is that the laboratory vane is generally smaller. This fact introduces a small uncertainty.

Vane tests also have some deficiencies:

1. The tests are unfortunately not standardized. Rotation speed and vane size vary from one device to another and these effects have not been fully investigated.

2. The failure surface is fixed by the shape of the vane – it is cylindrical. The measured strength with such a predetermined failure surface will be higher than the actual in-situ strength if the soil is allowed to shear at its weakest points. In addition, the assumed cylindrical failure surface does not always occur in practice. For example, tests conducted on a clayey silt showed that the failure surface was almost square in cross-section.

3. The conditions of drainage are not well-known. The fact that the pore water pressure depends on the rate of strain and that this dependence is different for different sediment types, is expected to affect the vane shear determined strength.

4. The vane shear test becomes less accurate as the soil becomes less cohesive. The test is not applicable to granular soils.

The Present Vane Shear Instrument

A vane shear instrument has been designed for use with the RUM vehicle. The instrument is handled by the RUM manipulator and utilizes the RUM's telemetry capabilities for data transmission. The vane blade is attached to a motor-driven shaft which can be inserted into the sediment to a depth of 24 inches. The complete instrument is shown in Figure 1.

The shaft is rotated by a Stepper motor at constant angular velocity. Soil strength measurements are conducted at 0.025 RPM and a speed of 2.8 RPM is used for remolding the sediment. Interchangable springs attached to the motor housing provide the restoring torque on the shaft. As shown in Figure 2, four different vane blades are available and allow, in conjunction with the interchangable springs, combinations which measure a maximum shear strength of from 0.22 psi to 7.0 psi. The sensitivity of the instrument is better than 10% of the maximum in each case. A modification currently planned provides for the use of non-linear springs, which would increase the instrument's range while maintaining its high sensitivity. The usable torque range is expected to be 1 to 80 inch pounds.

The depth of the blade, as well as the restoring torque and angular position of the blade, are transmitted, via telemetry to the control console where they are plotted on a multichannel recorder.

The Vane Shear Test

The vane shear instrument is placed near the RUM vehicle on undisturbed sediment. The vane is lowered into the sediment for the first of about four test depths, the last being at a depth of 24 inches. The vane is then rotated at the slow speed with the restoring torque and angular position being recorded. A typical recording is shown in Figure 3. The torque gradually increases with increasing angular deflection until shearing failure occurs, and then it decreases. The peak of this curve is of most interest since it represents the peak shear strength of the sediment, but for some purposes, the entire curve is useful.

The next part of the test consists of measuring the remolded strength. Remolding is accomplished by rotating the vane a few times at the high speed. After remolding, a torque vs. angle determination is once again made at the slow speed. The torque will increase with angle to a constant value. The ratio of the undisturbed peak strength to the remolded strength is termed the sensitivity.

It is necessary to relate the restoring torque to the shear strength of the sediment. Subject to the limitations discussed above, one assumes

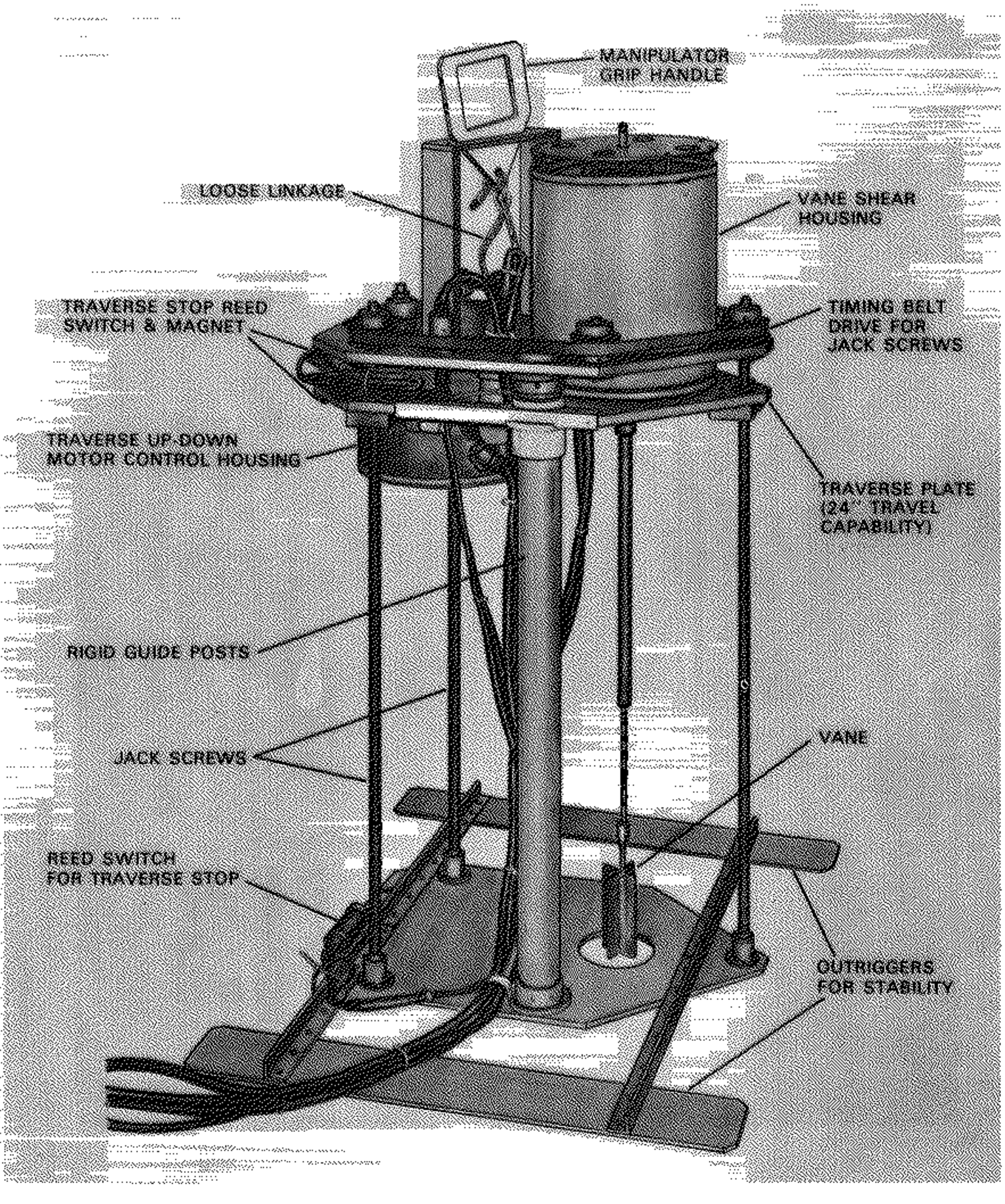


Figure 1. Vane Shear Meter Assembly.

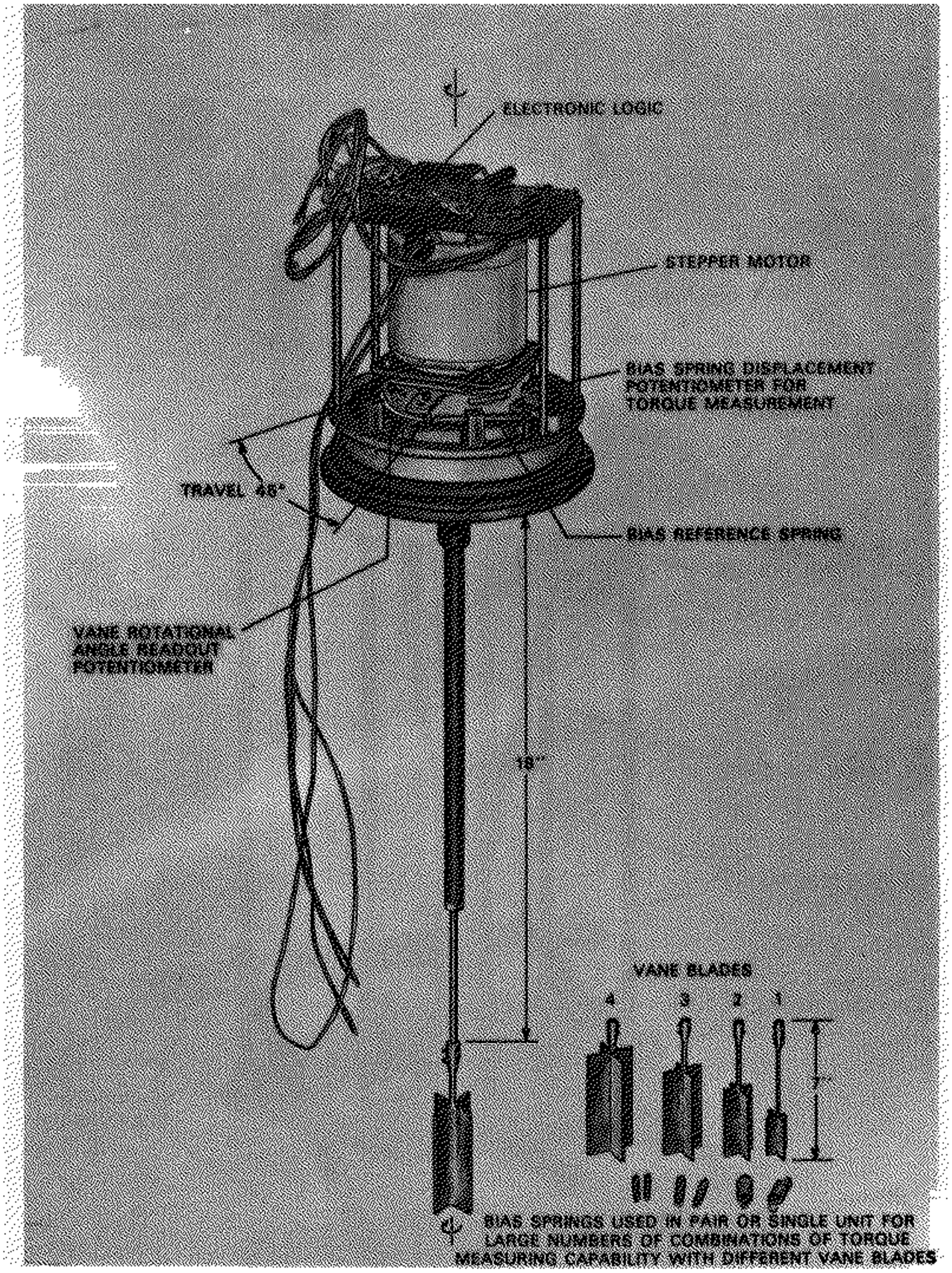


Figure 2. Vane Shear Meter-Internal View.

that the failure surface is a cylinder with the same dimensions as the vane blade, so that,

$$T = \int_{\text{surface}} \vec{R} \times \vec{F} ds \qquad (1)$$

where $\vec{F}$ is the force at a radius $\vec{R}$ on the blade. For the top and bottom of the cylinder,

$$2 \int_{\text{surface}} \vec{R} \times \vec{F} ds = 2\tau \int_{0}^{R} 2\pi R' \cdot R' dR' \qquad (2)$$

$$= \frac{\pi D^3 \tau}{6}$$

since D = 2R.
For the side of the cylinder,

$$\int_{\text{surface}} \vec{R} \times \vec{F} ds = \tau \int_{0}^{H} 2\pi R \cdot R dH \qquad (3)$$

$$= \tau \frac{\pi D^2 H}{2} .$$

Therefore, for the complete cylinder,

$$T = \tau \left(\frac{\pi D^3}{6} + \frac{\pi D^2 H}{2} \right). \qquad (4)$$

If the appropriate values ($D = 1.5$ inches and $H = 4.0$ inches) for one blade of the present instrument are inserted,

$$\tau = T/15.8 \qquad (5)$$

where τ is in psi and T is in inch-lbs. This relationship is shown graphically in Figure 4. As previously mentioned, springs of various strengths are available to vary the sensitivity and limit the maximum measurable torque.

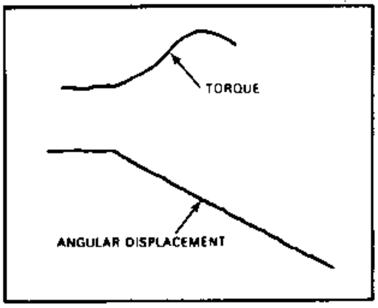


Figure 3. Vane Shear Test Recording.

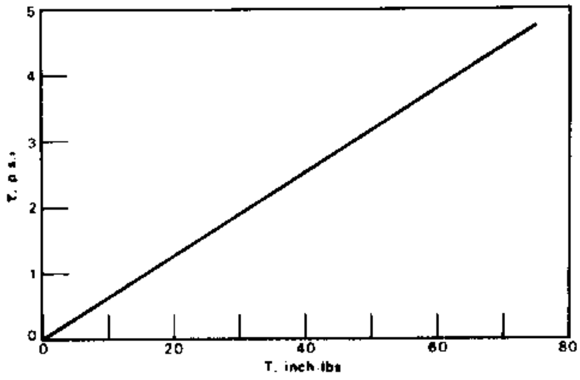


Figure 4. Vane Shear Conversion Graph.

The instrument is calibrated through the telemetry system of the RUM, by attaching a moment arm of known length and applying a series of torques to the vane shaft with a calibrated spring. The responses to the calibration torques are recorded so that direct comparison with test data can be made.

It is to be expected that vane shear strengths (as distinguished from shear strengths determined by other methods) will be less than a few psi. A typical value for the silty clays and clayey silts of the continental shelf or slope is one-half psi.

THE CONE PENETROMETER

Introduction

Various penetrometers constitute the most common method of measuring in-situ soil strength. The "static" penetration test consists of driving or pushing a shaft with a cone-shaped tip into the soil and measuring the penetration resistance as a function of depth. In the "dynamic" penetration test, the device is dropped from far above the surface and the deceleration as a function of depth is recorded. The most widely used test is termed the "standard penetration test" in which a standardized penetrometer is driven into the ground by repeatedly dropping a 140 lb weight from a height of 30 inches. The number of blows needed to drive it to various depths is recorded. It is clear that this is not an analytic measure of soil strength.

In certain countries, soil conditions are such that penetration techniques are a relatively reliable method to determine certain engineering properties. For sands and other granular soils, it has proved possible to develop a good correlation between the penetration resistance and the relative density, which determines, for example, the bearing capacity. Penetration tests should be used only as a guide however, because tests performed under controlled conditions have shown that the penetration resistance depends on factors other than the relative density, such as the confining stress and the pore pressure.[1]

Experience has also proven that determination of the strength of clays by penetration methods is very unreliable.

Begemann has given an analysis of the relationship between the strength of the soil and the penetration resistance in an attempt to increase the usefulness of cone penetrometer measurements.[2] He has included experimental results which show that his derived reduction factor of 13.4, when applied to the results of cone penetrometer tests in soft soils, gives good agreement with vane shear determined strengths. For some types of soils a smaller reduction factor should apparently be applied, but its magnitude depends on a number of factors of variable importance.

The Waterways Experiment Station has made extensive use of a manual cone penetrometer (with cone area 0.5 square inches and apex angle 30°) in trafficability studies.[3] All studies have been conducted on land, and applications of the cone method to the sea floor have not been extensive.[3, 4]

One concludes from the above references that it is probably not going to be possible to accurately correlate vane shear and cone penetrometer data, since they measure essentially different soil properties. It would however, appear feasible to develop a set of factors, one for each soil type, which would yield strength values from cone penetrometer data which agree with the vane shear strengths to within about 20%. It is therefore important that both types of measurements be conducted simultaneously in as many different types of sediment as possible.

The Present Cone Penetrometer

The present cone penetrometer is equipped, like the vane shear meter, with a handle to allow placement on the sea floor by the manipulator of the RUM. It conducts a "static" penetration test by inserting a shaft with a cone-shaped tip into the sediment at a constant velocity of one-half inch per second. The maximum depth of penetration is about 24 inches.

In the original design, the cone was fixed to the shaft so that the penetration resistance was due to not only the pressure on the cone, but the friction of the sediment on the shaft. To increase the likelihood that the cone penetrometer results can be related to the vane shear results, the present design allows measurement of the cone pressure alone. An internal view of the cone penetrometer assembly is shown in Figure 5.

Measurements have been conducted with cones having a 90° apex angle. Cones of different sizes from 0.1875 to 1.5 square inches are used. Force measurements in the range of 0.5 to 40 lbs can be made. The use of cones of different area at one sediment location can be informative (the penetration resistance is not merely proportional to the area of the cone), but it is more important to use the same cone at many different locations.

The Cone Penetrometer Tests

Data readout is provided for the cone pressure and the depth of the cone in the sediment. The instrument is calibrated by applying known forces (e.g. with a calibrated spring) to the cone and recording the results. The result of an actual test is a continuous recording of cone pressure vs. depth as shown in Figure 6.

In general, the cone pressure for a homogeneous silt or clay will increase to a constant value, independent of depth. In sand the cone pressure will continue to increase with depth with a more or less constant slope. The value of this slope, the cone pressure gradient, has been shown to be related to the strength of the sand for trafficability purposes.[3]

With the 1.0 square inch cone, the number of lbs force on the cone becomes directly the cone pressure in psi. As discussed above, a reduction factor is applied to the cone pressure to obtain a value of the soil strength. This is because the effective failure surface is much larger than the cone itself.

Even though for most purposes, the vane shear measurements will be most useful, the results of the cone penetrometer tests provide two important complements: 1) the presence of layering or lateral non-uniformity of the sediment will be quickly revealed and 2) if sand is encountered, the vane shear test is not applicable and the cone penetrometer will give a reliable indication of the strength.

The cone penetrometer measurements are made much more rapidly than the vane shear tests. Thus, the use of the cone penetrometer as a survey instrument, with the vane shear brought into use for absolute measurements, whenever an anomaly is noted, seems to be a satisfactory method of greatly increasing the area which can be surveyed in a given period of operation on the bottom.

CORING AND LABORATORY TESTING

Coring

In order to provide the opportunity of laboratory analysis on sediments from the same locations as the in-situ measurements, the RUM vehicle has been equipped to take core samples. Each coring tube is 24 inches long, corresponding to the maximum depths of the vane shear meter and cone penetrometer. The plastic tubes have an inside diameter of

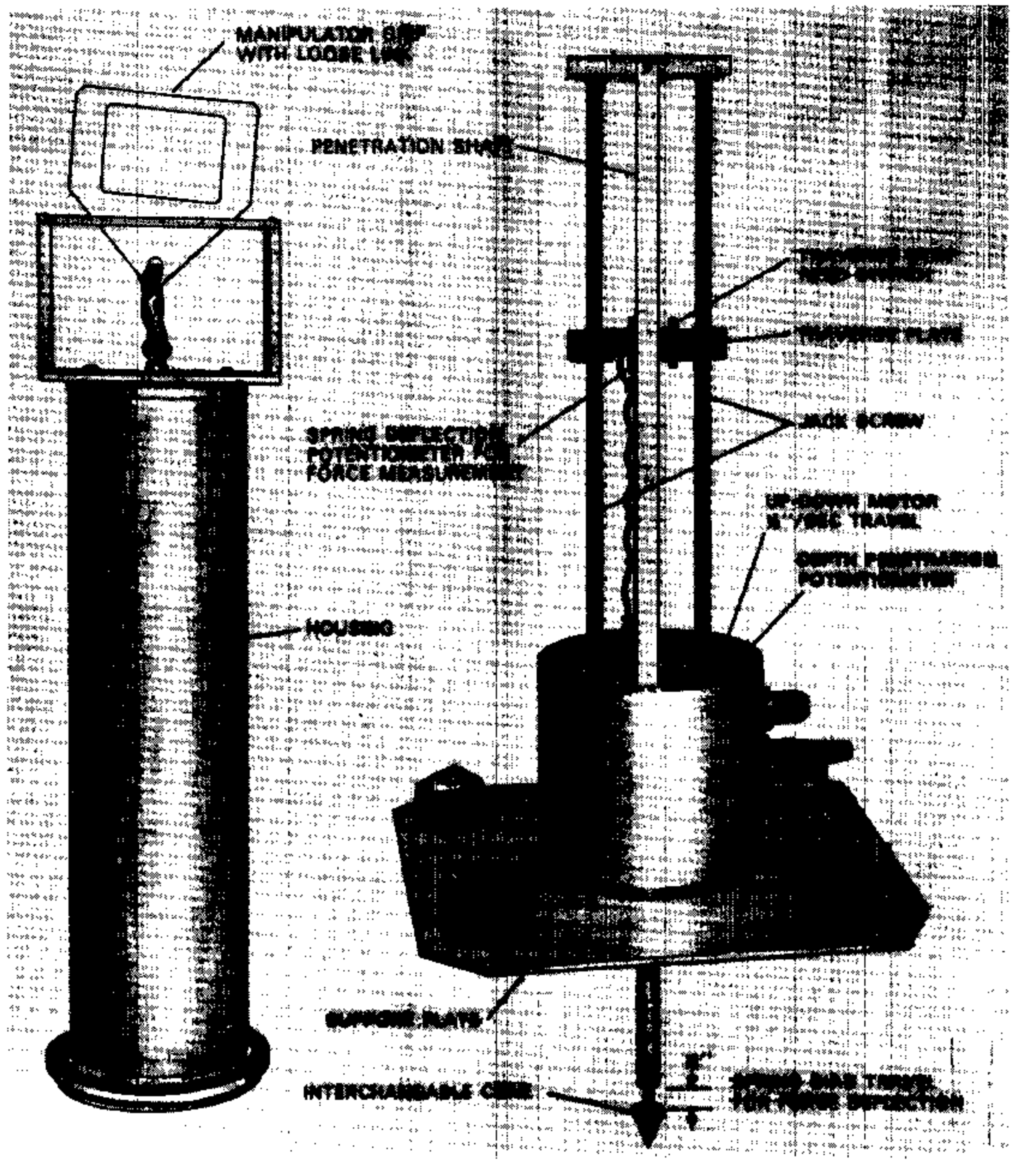


Figure 5. Cone Penetrometer Assembly.

2.875 inches and are equipped with a sharpened metal (brass or aluminum) nose piece (cutter angle 3.3°) and a tail piece which fits the manipulator jaws. The samplers were designed with an inside clearance ratio of 0.52 and an outside clearance ratio of about 6. The significance of these parameters with regard to disturbance effects during sampling is discussed by Rosfelder and Marshall.[5]

The coring tubes are stored in a rack on the RUM vehicle after a core is taken. Before RUM is reloaded aboard the ORB, divers remove the cores from the rack and bring them to the surface where the nose and tail pieces are replaced by caps and any excess water is drained off. Each tube is marked at the level of the sediment so that any subsequent contraction or expansion will be revealed. The tubes are stored vertically and refrigerated to retard bacterial growth which can cause sediment disturbance by gas evolution.

Disturbance Effects

The value of laboratory tests on core samples depends to a great extent on the degree of disturbance introduced by the coring operation itself and subsequent handling. Measurements of the shear strength are especially sensitive to disturbance since any slight "remolding" lowers the strength of most sediment types. Most other laboratory tests are only moderately sensitive to disturbance and some (e.g. grain size analysis and specific gravity of solids) are not affected by disturbance.

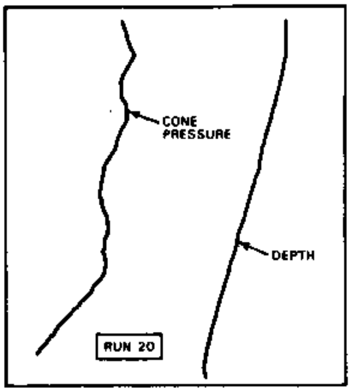


Figure 6. Cone Penetrometer Test Recording.

The drastic change in pressure as the core is taken to the surface will cause some disturbance because of the expansion of the pore water (1.4% per 10,000 feet of water depth). The magnitude of this effect is unknown, but it could be substantial because of the possibility of microscopic disruption of the contact interaction between the sediment grains. There is also the possibility that gases dissolved in the sediment might expand with the change in pressure and produce bubbles. It is felt that at water depths of up to a few thousand feet, this should not be a problem, but care should be taken to note bubble formation in cores taken from greater depths.

Temperature changes can also disturb cores, but this should not be a problem if the cores are immediately and continuously refrigerated.

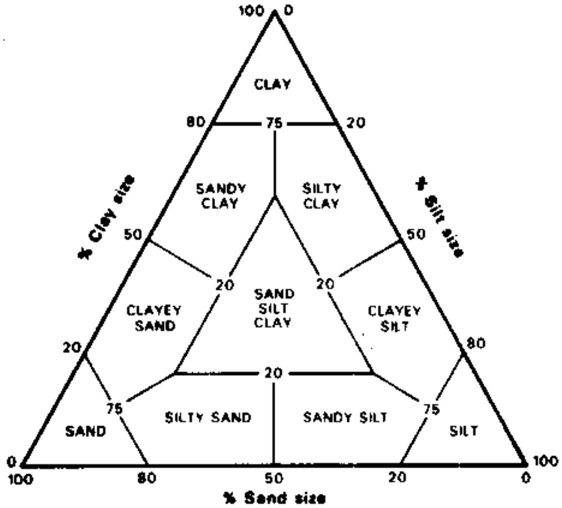
The Laboratory Tests

A number of tests are conducted on the core samples, taken by RUM, at the Soil Mechanics Laboratory at San Diego State College. The most important of these are the vane shear test and the grain size analysis. The vane shear test is conducted in the same way as the in-situ test except that the vane is smaller, and the test is conducted on a thin section of the core. It is usually assumed that the laboratory vane test measures the shear strength at the in-situ confining stress without drainage, but this is open to question. In any case, the effects of disturbance are a greater and constant concern.

Individual soil particles are classified according to size as:

Sand	0.06	to	2.0	mm
Silt	0.002	to	0.06	mm
Clay	less than		0.002	mm.

The properties of the soil will depend mainly on the size (and shape) of the particles, along with the amount of water and the history of their association. Two schemes are commonly used to classify soil type according to the percentages of particles of different sizes. Figure 7 shows the triangular classification system and Figure 8 the more descriptive Unified system.



GRAIN SIZE SCALES

	WENTWORTH SCALE, MICRONS	U.S.N.O.O. SCALE, MICRONS
SAND	2,000 TO 62.5	2,000 TO 62.5
SILT	62.5 TO 2	62.5 TO 3.9
CLAY	SMALLER THAN 3.9	SMALLER THAN 2

Figure 7. The Triangular Soil Classification System.

The following are also commonly measured in laboratory tests and most will be performed on the cores obtained by RUM:

water content = weight of pore water/weight of the solids, x100 (Note that the water content can be greater than 100%.)

density = total weight/total volume

dry density = weight of solids/total volume

specific gravity of solids = density of solids compared to water degree of saturation = percentage of pore space filled with water

void ratio = volume of voids/volume of solids

Atterberg limits As more water is added to a collection of soil particles, the properties change and four states, depending on water content can be defined: solid, semi-solid, plastic, liquid. The limits between these states are determined by standardized procedures.

liquid limit = water content at which the soil exhibits liquid behavior

plastic limit = water content at which the soil exhibits plastic behavior

plasticity index = liquid limit minus plastic limit

activity = plastic index/% of particles smaller than 2 microns

In addition to the vane shear test, the unconfined compression test and the triaxial compression test are commonly used to measure shear strength in the laboratory.

Unified Soil Classification

Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)								Group Symbols[a]	Typical Names	Information Required for Describing Soils
Coarse-grained soils More than half of material is larger than No. 200 sieve size[b]	(The No. 200 sieve size is about the smallest particle visible to naked eye)	Gravels More than half of coarse fraction is larger than No. 7 sieve size	(For visual classification, the 1/4-in. size may be used as equivalent to the No. 7 sieve size)	Clean gravels (little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes			GW	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name; indicate approximate percentages of sand and gravel; maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbols in parentheses For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains coarse to fine, about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM)
					Predominantly one size or a range of sizes with some intermediate sizes missing			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	
				Gravels with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures see ML below)			GM	Silty gravels, poorly graded gravel-sand-silt mixtures	
					Plastic fines (for identification procedures, see CL below)			GC	Clayey gravels, poorly graded gravel-sand-clay mixtures	
		Sands More than half of coarse fraction is smaller than No. 7 sieve size		Clean sands (little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes			SW	Well graded sands, gravelly sands, little or no fines	
					Predominantly one size or a range of sizes with some intermediate sizes missing			SP	Poorly graded sands, gravelly sands, little or no fines	
				Sands with fines (appreciable amount of fines)	Nonplastic fines (for identification procedures, see ML below)			SM	Silty sands, poorly graded sand-silt mixtures	
					Plastic fines (for identification procedures, see CL below)			SC	Clayey sands, poorly graded sand-clay mixtures	
Fine-grained soils More than half of material is smaller than No. 200 sieve size		Identification Procedures on Fraction Smaller than No. 40 Sieve Size								
					Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near plastic limit)			
		Silts and clays liquid limit less than 50			None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	Give typical name; indicate degree and character of plasticity, amount and maximum size of coarse grains; colour in wet condition, odour if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses For undisturbed soils add information on structure, stratification, consistency in undisturbed and remoulded states, moisture and drainage conditions Example: Clayey silt, brown, slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML)
					Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
					Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity	
		Silts and clays liquid limit greater than 50			Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	
					High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays	
					Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity	
		Highly Organic Soils			Readily identified by colour, odour, spongy feel and frequently by fibrous texture			Pt	Peat and other highly organic soils	

Figure 8. The Unified Soil Classification System.

TRACK DEPRESSION TESTS

The High Resolution Sonar

An echo-profiler has been constructed and installed on the rear right fender of the RUM in order to measure the depression left in the sediment by the advancing track. The instrument is mounted directly behind the center of the track, with the transducer scanning in a line perpendicular to the direction of the vehicle's motion as shown in Figure 9.

The high resolution capability is allowed because of the instrument's high operating frequency. Display is provided by an oscilloscope at the surface, with a photograph being taken to yield a permanent record. The X-axis of the oscilloscope is driven by a variable resistor attached to the transducer drive, the Y-axis sweep is triggered by the transmit pulse, and the Z-axis is controlled by the amplitude of the received echo.

The profiler operates at a frequency of 3.5 MHz and is pulsed at a repetition time of about 2 msec. The range is about four feet with a range resolution better than 1/4 -inch. The transducer is scanned through an arc of 110° and has a beam width of approximately one inch.

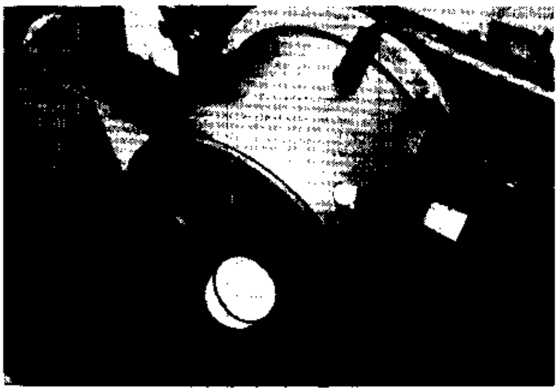


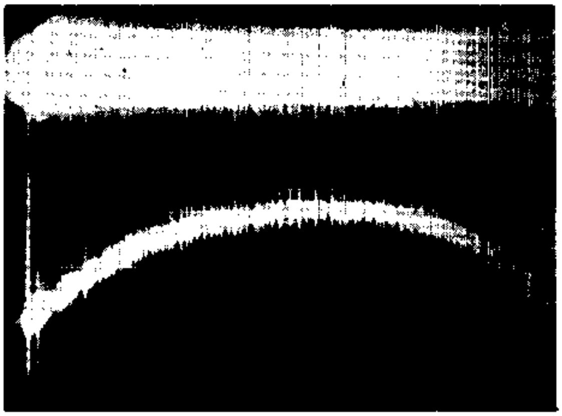
Figure 9. Track Depression Profiler.

Observing Track Depression

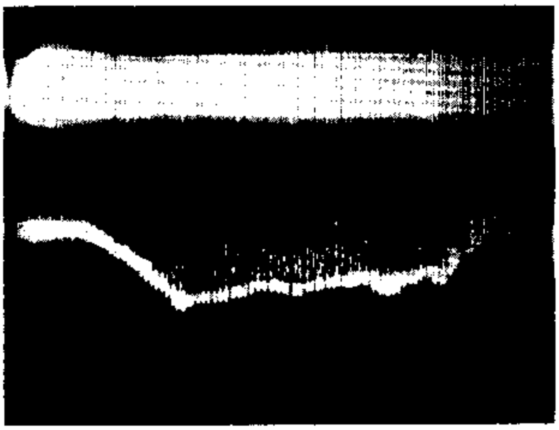
An oscilloscope recording of both undisturbed bottom and a particularly deep track depression is shown in Figure 10. The tracings must be corrected for the circular arc scanned by the transducer and this can be most easily accomplished by re-plotting the curve on polar coordinate paper, as shown in Figure 11. The reference base line represents the theoretical trace which would be obtained with RUM setting upon a plane surface with zero track penetration.

It is hoped that a number of track depression tests can be conducted at many different locations, at a series of different track pressures.

Even though it is of interest to have soil strength data at the same locations as the track depression tests, it is not reasonable to attempt to correlate one with the other. The extent of vehicle sinking while traversing soft sediment is a complicated dynamics problem related to many more parameters than those derivable from simple strength measurements. The track depression tests must in general be presented without interpretation.



Undisturbed Sea Floor
Behind Vehicle Upon Setdown



Undisturbed Sea Floor
Left by Forward Traverse

Figure 10. Oscilliscope Trace Produced by the Track Depression Profiler.

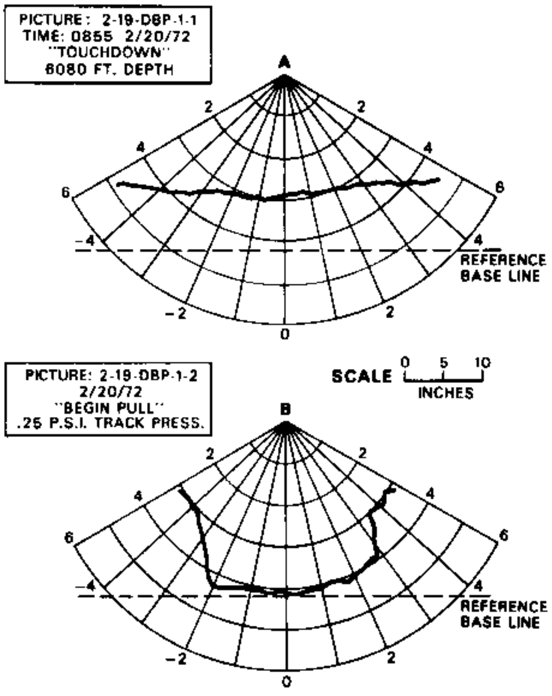


Figure 11. Replotted Track Depression Profile.

DRAWBAR PULL TESTS

The Winch System

The dependence of the drawbar pull on seafloor conditions is of interest in the design of bottom-crawling, work-performing vehicles as well as trafficability studies which attempt to correlate drawbar pull with the soil strength measurements. For these reasons, the winch-tensiometer system shown in Figure 12 has been installed on the RUM.

Figure 12. Winch Tensiometer System.

The winch is equipped with a 35-lb anchor and the tensionmeter allows a maximum pull of about 2000 lbs. The winch is driven by an induction motor through a gear reduction unit with the tension in the cable being measured by a compressive spring-potentiometer combination. The winch has been calibrated through RUM's telemetry with a dynamometer. The resolution is better than 100 lbs. The readings exhibit considerable hysteresis so that it must be remembered that actual tests are conducted with increasing tension cycles. If a situation of decreasing tension arises, a different calibration is used.

Little actual data has been accumulated relating trafficability to sediment type and strength for different types of tracks. The Naval Civil Engineering Laboratory has conducted some tests with a single track under controlled condition.[6] They have, in addition, given an analysis of the important parameters in determining trafficability.

The Drawbar Pull Test

To measure the drawbar pull developed by the RUM vehicle, the procedure is to pay out the winch cable at low tension while the RUM traverses undisturbed sediment. The winch drum is then locked and as the vehicle drives ahead, the tension of the cable increases until the tracks begin to slip. This sequence is repeated at different track pressures at each location. The cable length allows three measurements on undisturbed sediment for each time the anchor is set.

It is possible to approximately relate the maximum drawbar pull to sediment strength and sensitivity. In general, the drawbar pull will not depend on the track pressure for clays or plastic silts. For sands, the drawbar pull should increase linearly with track pressure. To estimate the maximum drawbar pull, it is merely necessary to multiply the area of the tracks by the shear strength of the soil. Since the running track will produce some remolding of the sediment, a partially remolded strength is the most relevant measure. Since this is, like the track depression test, a dynamic process, it is not possible to accurately analyse the pull in terms of the soil strength. It is also clear that the maximum pull will depend on the structure of the tracks and the extent to which the cleats are loaded with sediment. It is hoped that the installation of a water jet track-washing system will allow measurement of the importance of the sediment loading.

ACKNOWLEDGMENTS

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(ORB continued from front cover)

In addition to laboratory work spaces and machinery space, ORB is equipped with complete living facilities for 12 peop~~le in~~cluding 4 crew members.

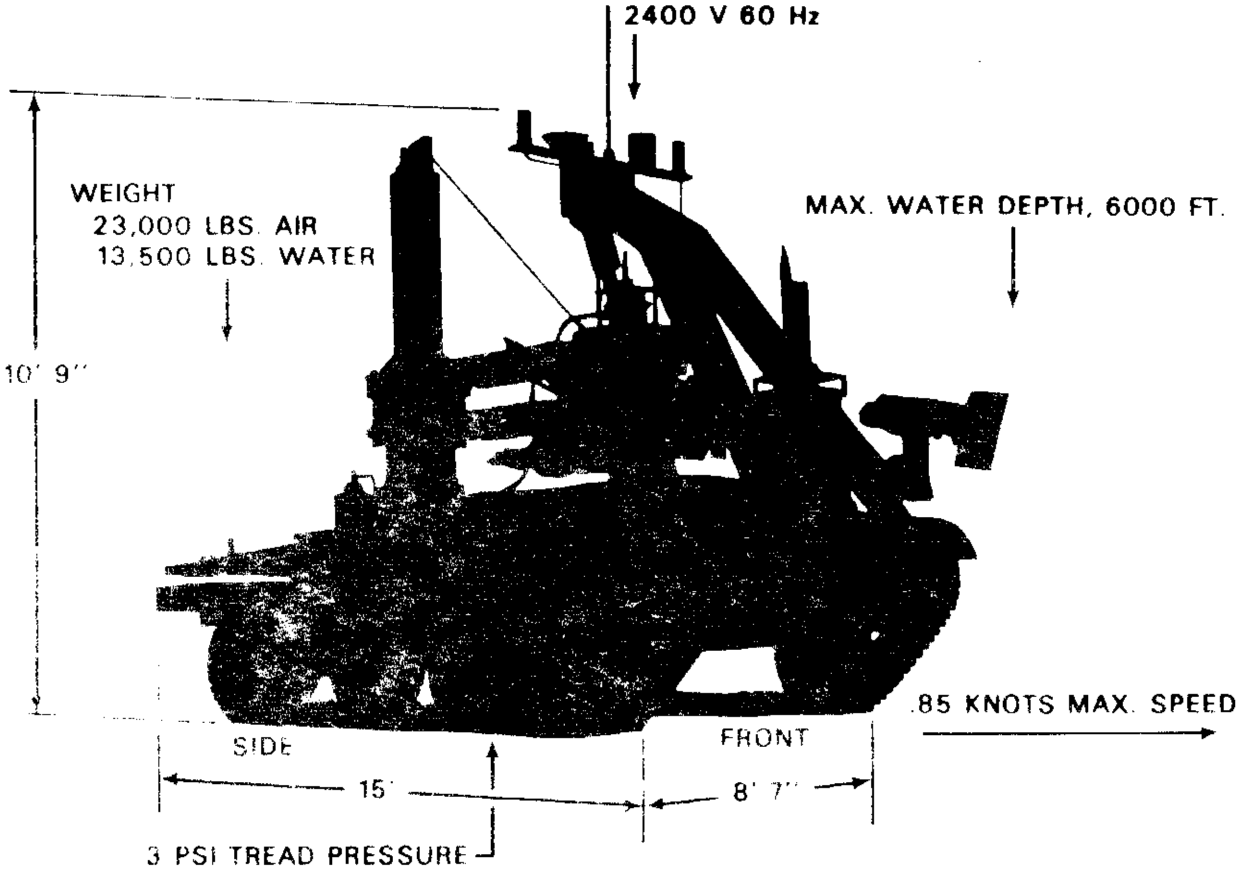
The "ORB" concept originated with Dr. Victor C. Anderson, Associate Director of the Marine Physical Laboratory. Preliminary design was carried out by Dr. Anderson, Associate Engineer F. N. Biewer and Marine Coordinator E. D. Bronson. The firm of L. R. Glosten and Associates of Seattle provided the Naval Architect services for final design. Construction was accomplished by California Steel Fabricating and Welding Engineering Corporation of San Diego under the sponsorship of the Office of Naval Research. The design of the buoy ORB emphasized simplicity and economy of construction and operation, functional utility, and minimum maintenance. Design, construction and outfitting were carried out at a total cost of $275, 000. 00.

(RUM continued from front cover)

The portside TV camera is boom-mounted with the pivot point near midway on the port side. The camera stows forward for driving but may be swung in a wide arc away from the side of the vehicle and around to the rear for close-in viewing of the manipulation areas. The starboard camera is mounted on a dolly which may be positioned anywhere from forward for driving to the rear for manipulation viewing.

Two telemetry systems are used for control and instrumentation, one, a time multiplex system providing 64 channels each way, up and down the cable, the other an amplitude modulated carrier system with four carriers transmitted down the cable and eight carriers returned.

During operations the vehicle is launched through the well on ORB, lowered to the sea floor and the cable tensioning system set for a reasonable tension from 5000 to 10, 000 pounds depending on bottom conditions and depth of water. Once RUM is on the bottom it serves as a more than adequate anchor for ORB. As RUM drives across the sea floor it tows ORB across the surface above it at speeds up to 1 knot. The cable constant tensioning system on ORB automatically pays in or pays out cable as needed.


2400 V 60 Hz
WEIGHT
23,000 LBS. AIR
13,500 LBS. WATER
MAX. WATER DEPTH, 6000 FT.
10' 9"
.85 KNOTS MAX. SPEED
SIDE
FRONT
15'
8' 7"
3 PSI TREAD PRESSURE