Technical Note N-1438

DOSIST II - AN INVESTIGATION OF THE IN-PLACE STRENGTH BEHAVIOR OF MARINE SEDIMENTS

By

H. J. Lee

June 1976

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Port Hueneme, CA 93043

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TN-1438	2. GOVT ACCESSION NO. DN144023	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) DOSIST II – AN INVESTIGATION OF THE IN-PLACE STRENGTH BEHAVIOR OF MARINE SEDIMENTS		5. TYPE OF REPORT & PERIOD COVERED Not final; Jul 1974 - Jul 1975 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) H. J. Lee		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS CIVIL ENGINEERING LABORATORY Naval Construction Battalion Center Port Hueneme, California 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62759N; YF52.556.999.01.101
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command Alexandria, Virginia 22332		12. REPORT DATE June 1976 13. NUMBER OF PAGES 16
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)		15. SECURITY CLASS. (*of this report*) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Soil testing, corers, sediment cores, deep-ocean sediments, vane shear tests, soil strength profiles.

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

DOSIST II (Deep Ocean Sampling and In-Situ Testing) was a cruise in the Western North Atlantic Ocean conducted to evaluate the in-place engineering behavior of several typical deep ocean sediments. In-place vane shear tests were performed, and sediment cores (gravity, piston, and box) were taken. Laboratory tests were conducted on the cored samples to classify the sediments and to determine which testing procedure best reproduces the measured in-place strength. This was found to be consolidated-undrained triaxial

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testing. The sediments tested in-place were a foraminifera-dominated calcareous ooze and a proximal turbidite. Both of these sediments are nearly cohesionless and retain little of their in-place strength when sampled. A deep sea pelagic clay was cored and subjected to laboratory testing, but was not tested in-place. Estimated in-place strength profiles were derived for each of these sediments to subbottom depths in excess of 50 feet (15 m).

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TN-1438 16 p. illus. June 1976 Unclassified

1. Soil testing 2. Sediment cores I. YF52.556.999.01.101

DOSIST II (Deep Ocean Sampling and In-Situ Testing) was a cruise in the Western North Atlantic Ocean conducted to evaluate the in-place engineering behavior of several typical deep ocean sediments. In-place vane shear tests were performed, and sediment cores (gravity, piston, and box) were taken. Laboratory tests were conducted on the cored samples to classify the sediments and to determine which testing procedure best reproduces the measured in-place strength. This was found to be consolidated-undrained triaxial testing. The sediments tested in-place were a foraminifera-dominated calcareous ooze and a proximal turbidite. Both of these sediments are nearly cohesionless and retain little of their in-place strength when sampled. A deep sea pelagic clay was cored and subjected to laboratory testing, but was not tested in-place. Estimated in-place strength profiles were derived for each of these sediments to subbottom depths in excess of 50 feet (15 m).

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INTRODUCTION

The DOSIST (Deep Ocean Sampling and In Situ-Testing) cruises are part of a continuing effort at CEL to investigate the engineering properties of marine sediments. The cruises consist of in-place vane shear testing and sediment coring leading to laboratory engineering property testing. The overall objective of the work is to develop laboratory testing and coring procedures that can be used to obtain good estimates of in-place engineering behavior of sediments. Coring and laboratory testing is emphasized because it is more economical, more parameters (including long-term drained properties) can be measured, and a greater range of subbottom depths can be investigated. In-place testing is conducted during the DOSIST cruises to provide a basis for evaluating the properties measured in the laboratory. That is, the properties measured in the laboratory are compared with the in-place properties, and techniques are developed for estimating the latter given only the former. The difference between the results obtained from the two types of measurements is termed sampling disturbance. The procedures used for obtaining in-place properties using results of laboratory tests are termed sample disturbance correction techniques.

One sample disturbance correction technique was presented by Lee (1973a). It involved measuring the residual negative pore water pressure retained by cored samples and using the relative magnitude of this pressure as an indicator of the property changes that occurred during coring and handling. Good correlations between degree of disturbance and the residual pore water pressure were found for cohesive marine sediments. Other sample disturbance correction techniques have also been proposed (Ladd and Lambe, 1963).

OBJECTIVE

The objective of this interim report is to present and analyze the results of in-place and laboratory tests conducted on typical ocean sediments from the Western North Atlantic Ocean. A final report to be prepared in about one year will recommend procedures for coring, testing, and estimating the in-place behavior of most of the typical deep ocean sediment types.

A secondary objective of DOSIST II was to obtain the strength properties of three sites where the CEL 20K anchor is to be field-tested. The results presented in this report can be used to predict the holding capacities of the anchors prior to the field tests.

Another objective of DOSIST II was to obtain box core samples for dynamic property testing. These have been transported to the University of California, Berkeley, where they are currently being tested.

FIELD OPERATIONS

Vessel

The USNS LYNCH (T-AGOR-7) was used as a support vessel during DOSIST II. The ship is typical of the Navy's oceanographic vessels and is adequately equipped with winches and U-frames for deploying conventional oceanographic corers and other gear.

Equipment

In-place vane shear strength measurements were made with the ONR vane tower developed by Dr. Adrian Richards of Lehigh University (Richards et al., 1972). The device is capable of inserting standard vanes (2 x 4 inches to 4 x 8 inches) (50 x 100 mm to 100 x 200 mm) to about 8 feet (2 m) into the seafloor. The vane is rotated at about every foot (third of a meter) of penetration, and the peak torque is used to calculate the in-place undisturbed strength of the sediments. The sediment is remolded by rapidly returning the vane to its original position. A second strength measurement is made on the remolded sediment, and a sensitivity is calculated (undisturbed strength divided by remolded strength). The vane is rotated at 90 deg/min (1.6 rad/min), a relatively rapid rate. This rate was chosen for operational convenience to reduce the time the device needs to remain on the seafloor.

The ONR device was used rather than CEL's DOTIPOS (Demars and Taylor, 1971) because of its lighter weight and greater water depth capabilities (15,000 feet versus 6,000 feet) (4,600 m versus 1,800 m). One of the major problems with the ONR device is that it is tall and can be easily tipped over on the seafloor. The support vessel must remain close to the tower, or large lateral forces will be exerted by the tether line. Single-point deep sea anchoring was used to maintain the ship's position during testing.

Coring was conducted with a typical long piston corer and a spade-type box corer. Cores were also taken with free-fall boomerang corers and a NAVOCEANO hydroplastic corer.

The long piston corer used is a Benthos Model 2450, a 2.6-inch-ID (66-mm) triggered corer, weighing 2,700 pounds (1.2 Mg). The piston is self-deactivating. During corer penetration, the piston is held at the sediment surface, and greater core recovery is produced. As the corer is being withdrawn, the piston splits, with one section locking into place at the top of the sediment and the other section being pulled to a stop at the top of the corer. By allowing the piston to split in this manner, additional material (''flow-in'') is not sucked into the bottom of the corer during withdrawal.

The corer was not designed to obtain engineering quality samples as defined by Hvorslev (1949). However, it is typical of the intermediate-size piston corers currently in use by the oceanographic community (Clausner and Lee, 1975). The corer has obtained samples up to 40 feet (12 m) in length in very soft sediments. The longest sample CEL has obtained is 28 feet (8.5 m) (on an earlier cruise).

The spade-type box corer obtains samples that are only 2 feet (0.6 m) in length. However, the cross-sectional area of the sample is so large (12 x 8 inches) (300 x 200 mm) that almost completely undisturbed samples are guaranteed. These samples were taken to determine the maximum quality of sample that could be achieved and to use them in triaxial testing to simulate strength profiles to greater subbottom depths (as explained later). Also, high quality samples were needed for CEL's soil dynamics program.

Free-fall boomerang cores were taken to determine the general sediment type of a site prior to deploying the vane tower or long-piston corer. A NAVOCEANO hydroplastic corer was used at one of the sites after the CEL piston corer was lost.

Sites Visited

Table 1 lists the sites that were investigated along with their geographic coordinates. Site I is located north of the Puerto Rico trench in deep water (18,000 feet) (5,500 m). It was selected as a site with a low calcium carbonate content that would probably contain a pelagic clay deposit. This was found to be the case. Site III is located north of Grand Bahama Island on the Blake Plateau in about 4,000 feet (1,200 m) of water. This site was selected as a location with a high calcium carbonate content (calcareous ooze). Site IV is located a few miles (several kilometers) southeast of Puerto Rico in a 6,000-foot-deep (1,800 m) enclosed basin. The sediment at this site is a calcium carbonate-rich proximal turbidite (alternating silt and sand layers). Site II was to be located in a deep channel north of Nassau. This site was not visited because of highly irregular bottom topography.

The cruise was conducted between 23 November and 13 December 1974. During this time the LYNCH sailed from Charleston, South Carolina, to San Juan, Puerto Rico. Some ship time was lost as a result of adverse weather conditions, especially in the vicinity of the Bahamas Islands.

The in-place vane shear tests, which were conducted from a moored ship, had locations that were within 300 feet (90 m) of each other at each general test site. The cores, taken while the ship was in a drifting mode, are much more widely scattered. The distance between cores at a general site is as much as 3 miles (5 km). Since the test sites were selected partly for their flatness and areally uniform sediment conditions, it is assumed that variations among properties over the area of a general test site are neglegible.

Table 1. Summary of Test Sites Investigated

Site	Approximate Longitude	Approximate Latitude	Water Depth		Sediment Type	In-Place Vane Tests	Box Cores	Piston Cores	Other	General Comments
			Feet	Meters						
I	66°15'W	21°N	17,900	5,460	pelagic clay		1		1 hydro-plastic core	Numerous manganese nodules; typical "red clay"
III	77°12'W	28°N	3,700	1,100	foram ooze	3	1	1	1 boomer-ang	Sediment is highly sensitive with laboratory strength less than 1/10 field strength
IV	65°54'W	17°53'N	6,500	2,000	turbidites	2	1	2		Alternating sand-silt clay layers; relatively dense and competent

IN-PLACE TEST RESULTS

In-place vane shear tests were conducted at Sites III and IV. Site I was too deep for the ONR vane tower.

The results of these tests are given in Figures 1 and 2 in the form of original vane strength and sensitivity versus subbottom depth. At several points (usually in sand layers) insufficient torque was available to rotate the vane. At these points an arrow is drawn indicating the maximum shearing resistance developed. The actual strength would be higher.

In the sand layers at Site IV, some drainage must have occurred during vane rotation. The strength given, therefore, is not a true undrained shearing strength, but rather a strength index property. The strengths in the Site III oozes and the Site IV silts are probably true undrained shearing strengths.

Table 1 lists the number of cores that were obtained at each site. Table 2 gives the CEL identification for each core and its exact geographic coordinates.

The CEL piston corer was lost during lowering at Site I. It evidently pre-triggered 5,000 feet (1,500 m) below the ship and fell to the end of the coring cable, causing the cable to part. Apparently, resonance in the coring cable was set up by a series of consistent, large swells passing through the area. The resulting large motions of the corer could easily have caused pre-triggering. Future coring operations will be conducted with a pressure-activated triggering device, thereby reducing problems with pre-triggering.

To conduct the coring operations at Site IV, a similar Benthos corer was borrowed from NAVFAC (FPO-1) in Washington.

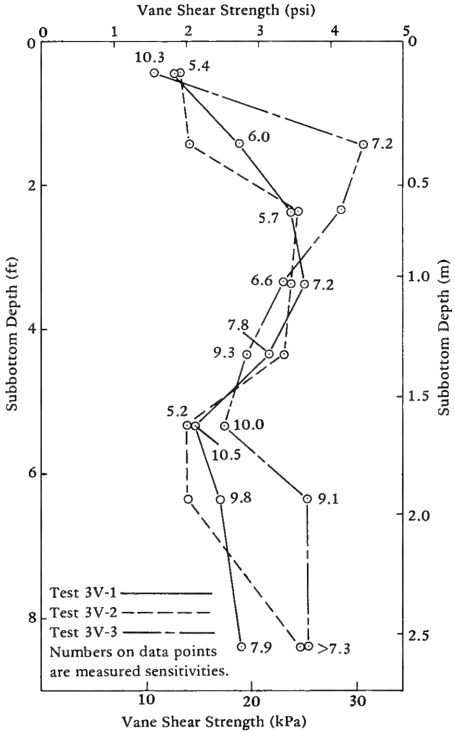

Figure 1. In-place vane shear strength profile for Site III.

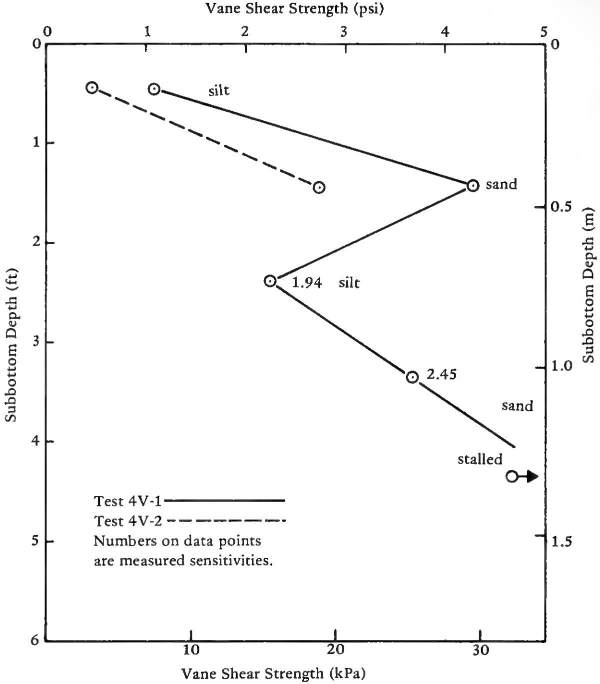

Figure 2. In-place vane shear strength profile for Site IV.

Table 2. Identification of Cores Taken and In-Place Vane Tests Performed

Site Number	Core or Vane Test Number	Corer Type	Core Length Ft-in.	Core Length Meters	Latitude	Longitude
I	DOS-1B	box	2-0	0.61	20°57′41″N	66°15′12″W
	DOS-1D	hydroplastic	4-1	1.24	20°56′17″N	66°15′24″W
III	DOS-3A	boomerang	3-6	1.07	27°59′30″N	77°10′32″W
	DOS-3B	box	2-0	0.61	28°02′00″N	77°12′00″W
	DOS-3C	piston	18-0	5.49	28°01′52″N	77°12′43″W
	Vane Test 3V-1				28°00′10″N	77°11′39″W
	Vane Test 3V-2				28°00′11″N	77°11′36″W
	Vane Test 3V-3				28°00′17″N	77°11′36″W
IV	DOS-4A	box	2-0	0.61	17°52′36″N	65°55′11″W
	DOS-4B	piston	8-7	2.62	17°52′00″N	65°55′08″W
	DOS-4D	piston	8-8	2.64	17°53′13″N	65°53′13″W
	Vane Test 4V-1				17°53′00″N	65°53′48″W
	Vane Test 4V-2				17°53′00″N	65°53′48″W

LABORATORY TESTS

The core samples were subjected to standard index property tests (water content, sieve analysis, hydrometer, Atterberg limits, grain density, and carbonate content), miniature vane shear tests, consolidated-undrained triaxial tests with pore pressure measurements, and residual pore water pressure tests. Standard CEL procedures were followed as described in earlier reports (Lee, 1973a and 1973b). Some difficulties were encountered, however, because the sediments from Sites III and IV were nearly or completely cohesionless. Atterberg limits tests could not be performed; the samples retained no negative residual pore water pressures, and most of the specimens could not be trimmed for triaxial testing in the usual manner. The samples that could not be trimmed were remolded and placed in a triaxial specimen former. An attempt was made to place the sediment at its original density.

The index properties and vane shear strengths of the cores taken at the three sites are given in Tables 3, 4, and 5. Triaxial test results are presented in the form of stress paths (Figures 3 through 6). A stress path is a plot of the principal stress difference versus the sum of the major and minor principal effective stresses ($\bar{\sigma}_1$ and $\bar{\sigma}_3$). The stress path diagram defines the drained strength parameters, $\bar{\phi}$ and $\bar{c}$, and provides considerable additional data about the sediment's behavior (as discussed by Lee, 1973b).

ANALYSIS AND DISCUSSION

As discussed above, no residual pore water pressures were retained by samples from the two sites where in-place vane tests were performed. This is because these samples contained relatively coarse-grained material (50% or more sand-sized). The pore sizes are large, so the pore water menisci at the sample surface have large radii. The residual pore water pressures attainable vary inversely with the radii of the pore water menisci.

Table 3. Index Properties of Site I Cores

Core No.	Subbottom Depth		Water Content (%)	Sand (%)	Silt (%)	Clay (%)	Color (Munsell)	Original Vane Strength		Remolded Vane Strength		Liquid Limit (%)	Plastic Limit (%)
	Inches	cm						psi	kPa	psi	kPa		
1D	1.0	2.5	96.3										
1B	1.5	3.8	97.7					0.38	2.6	0.11	0.8	73.1	34.7
1D	3.5	8.9	103.5	2	13	85	10YR4/3 brown/dk br	0.32	2.2	0.13	0.9	78.4	34.9
1B	4.0	10.2	111.8										
1B	4.5	11.4	98.9										
1D	6.5	16.5	99.5										
1B	12.0	30.5	94.0										
1B	14.0	35.6	97.5					0.47	3.2	0.18	1.2	78.1	37.3
1B	20.0	50.8	99.0										
1D	21.0	53.3	94.5										
1D	22.5	57.2	97.8	0	7	93	10YR4/3	0.63	4.3	0.27	1.9	85.1	40.1
1D	25.0	63.5	94.0										
	36.0	91.4	100.0										
1D	47.0	119.4	96.3	0	7	93	10YR4/3	0.64	4.4	0.25	1.7	110.5	47.9

Table 4. Index Properties of Site III Cores

Core No.	Subbottom Depth		Water Content (%)	Grain Density (g/cc)	Sand (%)	Silt (%)	Clay (%)	Color (Munsell)	Carbonate Content (%)	Original Vane Shear Strength		Remolded Vane Shear Strength	
	Inches	cm								psi	kPa	psi	kPa
3B	3.3	8.4			63	37							
3B	10.0	25.4	54.0		49	51							
3B	16.8	42.7			46	54							
3C	22.0	55.9	67.8	2.72					86				
3C	23.0	58.4	63.1						80				
3A	25.5	64.8	70.6	2.71	59	41				0.057	0.4	~0.0	~0.0
3C	30.5	77.5	63.8	2.68	62	38		10YR8/3 v pale br					
3C	33.5	85.1	63.8	2.68	59	41							
3C	36.5	92.7	55.6	2.69	53	47		10YR7/3 v pale br	83	0.26	1.8	0.01	0.1
3A	38.5	97.8	50.9	2.71	37	63							
3C	66.5	168.9	48.2	2.68	54	46							
3C	69.5	176.5	49.5		54	46							
3C	71.0	180.3	54.7										
3C	72.0	182.8	52.3						80				
3C	119.0	302.3	57.7						80				
3C	120.0	304.8	53.7						82				
3C	163.5	415.3	52.8										
3C	168.0	426.7	54.7						77				
3C	202.5	514.4	50.5	2.67	35	29	36	10YR8/3					
3C	205.5	522.0	49.4	2.67					86	0.35	2.4	0.009	0.1

Table 5. Index Properties of Site IV Cores

Core No.	Subbottom Depth		Water Content (%)	Grain Density (g/cc)	Sand (%)	Silt (%)	Clay (%)	Color (Munsell)	Carbonate Content (%)	Original Vane Shear Strength		Remolded Vane Shear Strength		Comments
	Inches	cm								psi	kPa	psi	kPa	
4A	2.0	5.1	79.0											Clayey silt
4A	5.6	14.2	70.0											Clayey silt
4D	13.5	34.3	34.7	2.71										Coarse sand
4D	16.5	41.9	32.1	2.71	91				54					Coarse sand
4B	43.0	109.2	57.0	2.71	10	52	38							Silt
4B	47.0	119.4	58.8	2.72					78					Silt
4B	50.0	127.0	52.0		11	59	30	5Y7/2 lt gray		1.43	9.96	0.37	2.6	Silt
4B	53.5	135.9	51.5					5Y7/2		0.70	4.83	0.12	0.8	Fine sand
4B	89.5	227.3	44.8					5Y7/3 pale yellow		0.25	1.72	~0.0	~0.0	Fine sand
4D	98.0	248.9		2.88	16	50	34		56					Very fine sandy silt
4B	cc							5Y7/3						Silty sand

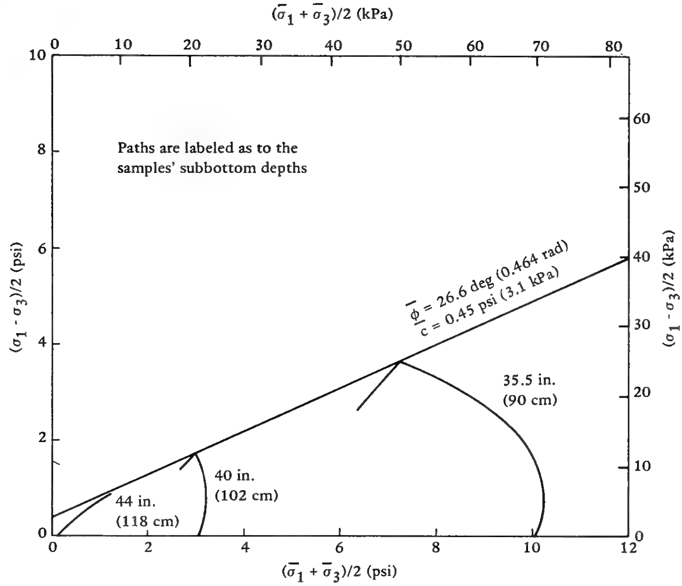

Figure 3. Triaxial test stress path diagram for Site I – core DOS1D.

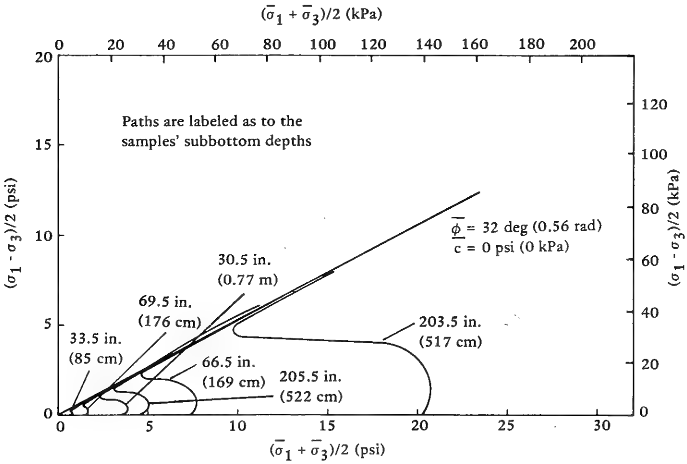

Figure 4. Triaxial test stress path diagram for Site III – core DOS3C.

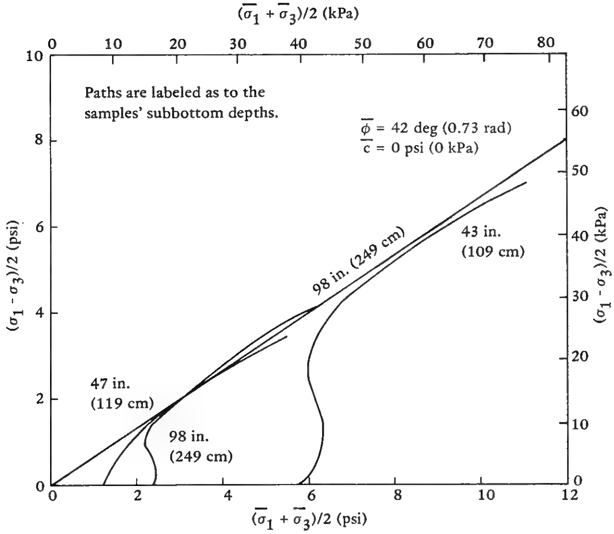

Figure 5. Triaxial test stress path diagram for silt from Site IV – cores DOS4B and 4D.

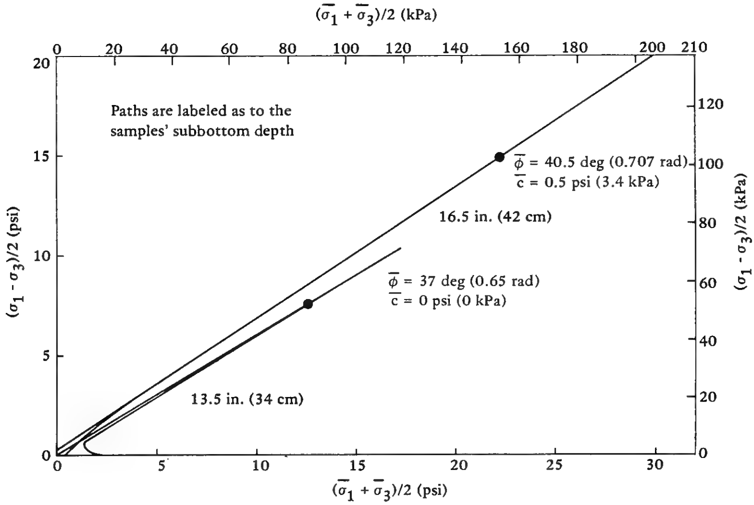

Figure 6. Triaxial test stress path diagram for sands from Site IV – cores DOS4B and 4D.

Since there were no residual pore pressures, the sample disturbance correction procedures of Lee (1973a) could not be applied. Instead the procedures of Lee (1973b), which are based on Ladd and Lambe (1963), were used. These procedures involve the application of relatively large consolidation stresses (i.e., well above the in-place overburden pressures) in the triaxial cell. Basic stress path parameters (Skempton's parameter, A, and $\bar{c}$ and $\bar{\phi}$) are obtained. The strength of the sample under the correct in-place overburden pressure is calculated (using an equation given by Lee, 1973b). Most of the effects of sample disturbance are corrected for in this manner. This procedure can also be used to obtain estimated strength profiles for the sediment below the level of sampling. To do this, it must be assumed that the type of sediment does not change greatly below the level of sampling.

Estimated undisturbed undrained shear strength profiles were developed in this manner for the sediments at each of the three sites. These are given in Figures 7, 8, and 9 along with the measured in-place strengths and the measured, uncorrected laboratory vane strengths. Discussions of the characteristics of the data from each of the sites are given below.

Site I (pelagic clay)

No in-place vane shear tests were conducted at Site I because of the great water depth. The strength profile estimated from triaxial tests is almost identical to that developed for a Pacific Ocean pelagic clay (Lee, 1973b). The miniature vane strengths are smaller, by almost 50%, than the estimated profile. This is probably a result of sample disturbance, which is corrected for in the triaxial test profile. However, since no in-place measurements were made, it is impossible to determine whether the estimated profile is actually correct. Direct in-place strength measurements will be made in a pelagic clay this fiscal year (DOSIST III) so that a determination of the best means of sample disturbance correction can be made.

Site III (globigerina ooze)

Calcareous oozes often contain the relatively large (fine sand size) tests of globular foraminifera, the much smaller tests of nannofossils, and often a good deal of clay. The engineering behavior of the sediment appears to be strongly related to the relative proportions of these materials. If the percentage of fines is high (as was the case with the sediment tested by Valent, 1974), the behavior is similar to that of a silty clay. If the percentage of foraminifera (globigerina) is high enough, the behavior is quite different. The forams form an open framework, and the fines only partially fill the interstices. Overburden stresses are carried by the forams, and the fines do not consolidate until the stresses become large enough to crush the forams. Virtually no cohesion develops. When the material is sampled and overburden stresses are removed, it takes on the consistency of partially melted ice cream.

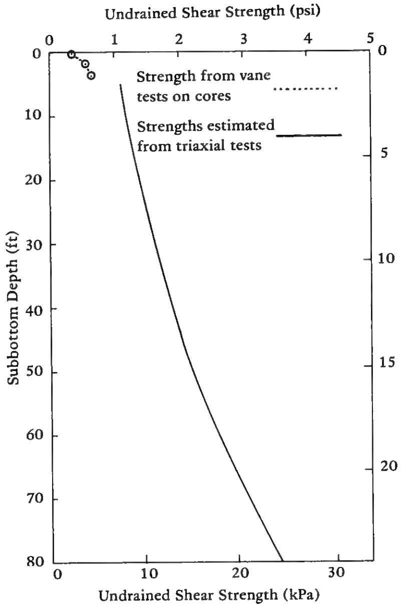

Figure 7. Strength profiles for Site I (pelagic clay).

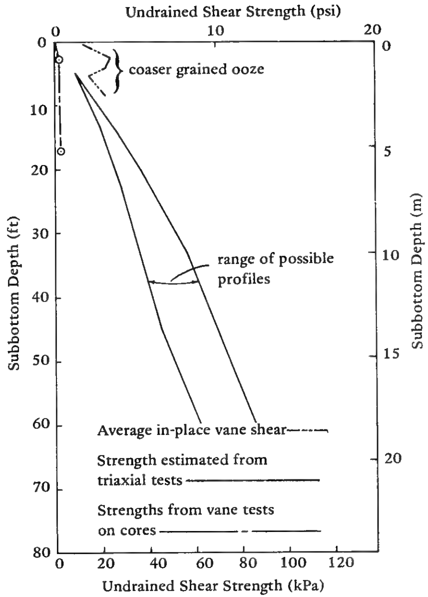

Figure 8. Strength profiles for Site III (globigerina ooze).

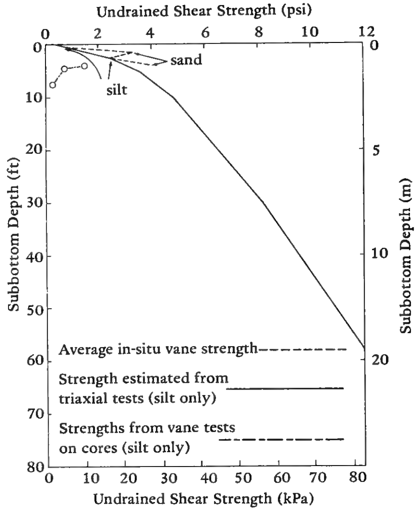

Figure 9. Strength profiles for Site IV (turbidite).

The sediment at Site III is a typical foraminifera-dominated calcareous ooze. The strength of the sampled material (vane tests on cores, Figure 8) is nearly zero. However, the measured in-place strengths are quite high [2 to 4 psi (10 to 30 kPa), Figure 1]. This is clearly a ''problem material'' for geotechnical investigations. The method of residual pore water pressures cannot be used to correct for disturbance since the residual pressures are negligible.

Strength profiles constructed using the results of triaxial tests (Figure 8) are about 70% of the measured in-place values. This is a relatively good correlation considering the overall difficulty involved in working with this material. The differences may be a result of the strain level at which strength is measured. In the triaxial tests the strength was taken at the 20% strain level. In the field vane test the actual strain is undefined but is certainly very high along the plane of failure, well in excess of 20%. Since the ooze appears to mobilize its strength at high strain levels, the difference in the type of test performed could account for the difference between field vane and triaxial test results. Also, partial drainage during field testing could cause the difference. In any case, strength profiles constructed using triaxial tests and the methods of Lee (1973b) appear to reproduce, at least relatively closely, strengths measured in the field. These procedures are recommended for dealing with very difficult materials like globigerina oozes.

The measured in-place sensitivities (5 to 10) of this ooze are very high. A facility that applies repeated loads to the material could easily cause it to liquefy. Dynamic testing of cores from this site, currently underway at the University of California, Berkeley, will provide additional information on this problem.

Site IV (turbidites)

The sediment at Site IV consists of alternating layers of silt and sand, characteristic of turbidity current deposition. Since the deposit is near land [about 10 miles (16 km) off the coast of Puerto Rico] and the sands are coarse, the sediments are termed proximal turbidites.

The in-place strength profile of Figure 2 illustrates how the properties vary as one progresses through the layers of silt and sand. The ''strength'' in the sand is not a true undrained shearing strength, since partial drainage is certain to occur. However, it is an index of how strong and dense the material is. The strengths of the silts are probably valid as undrained shearing strengths.

The comparative strength profile of Figure 9 once again demonstrates how poorly the laboratory vane test duplicates field behavior when dealing with coarser grained material (i.e., material that cannot retain a residual pore pressure). The strength profile developed through triaxial testing of the silt samples reproduces the measured field strengths very well. This procedure is recommended for compensating for disturbance when dealing with the silt layers of proximal turbidites.

Procedures for dealing with the sand layers require further development. A new work unit initiated in FY76 will approach this problem and utilize the data presented in this report.

The measured field sensitivities (around 2) are quite low. The sediments at Site IV appear to be well suited for supporting foundations or resisting anchor pullout.

SUMMARY AND CONCLUSIONS

1. In-situ strength testing and coring were conducted in a proximal turbidite and a foraminifera dominated calcareous ooze. Coring was conducted in a deep ocean pelagic clay.

2. The pelagic clay is quite weak and displays properties similar to Pacific Ocean pelagic clays tested previously.

3. The calcareous ooze has high in-place strength [2 to 4 psi (10 to 30 kPa)] which is almost completely lost during sampling. Consolidated-undrained triaxial tests produce strengths which are about 70% of the in-place values. The material is very sensitive (sensitivities of 5 to 10) and would probably serve as a poor foundation or anchorage support.

4. The proximal turbidites also have high in-place strengths that are greatly reduced by sampling. Triaxial testing of silt layers accurately reproduces the field strengths. The material has low sensitivity and should provide an excellent support for foundations or anchors.

5. The method of residual pore pressures cannot be used to correct the strengths of highly foraminiferal oozes and proximal turbidites. Triaxial testing and the methods of Lee (1973b) appear to offer a suitable means of disturbance correction for these materials.

6. Techniques for dealing with seafloor sands require additional research and development.

7. Estimated strength profiles are given for the three sites so that predictions of anchor holding capacity can be made. Tests of the CEL 20K anchor will be conducted at the these sites in the near future.

ACKNOWLEDGMENTS

Many individuals contributed to the successful execution of this field and laboratory testing program. The help of the crew and officers of the USNS LYNCH, the personnel of the Naval Material Center, Charleston (particularly LCDR Waldrop), Mr. Shun Ling of NAVFAC (FPO-1), Mr. Bache of Roosevelt Roads Annex, San Juan, Puerto Rico, and F. O. Lehnhardt and A. Jackson of CEL is gratefully acknowledged.

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