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GEOTECHNICAL PROPERTIES OF SAMPLES FROM BORINGS OBTAINED IN THE CHUKCHI SEA, ALASKA

by

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INTRODUCTION:

This report summarizes the geotechnical properties of samples from seven borings that were obtained by the U.S. Geological Survey in the Chukchi Sea during September 1983. Geotechnical tests were performed both at sea and in a shore-based laboratory to measure down-hole variations in physical and geotechnical properties. Stratigraphic interpretation of the nearly continuous sediment and rock samples is presently underway.

Hope basin underlies much of the southern Chukchi Sea. The northern part of Hope basin is bounded by Herald arch, an uplifted welt of Paleozoic and Mesozoic bedrock (Grantz and others, 1975, Holmes and Creager, 1981). Another sedimentary basin, the North Chukchi basin, lies north of Herald arch. Two closely spaced borings were located in the northern margin of Hope basin, two holes (spaced 7 meters apart) were in the southern North Chukchi basin, and the remaining three holes were on Herald arch (Table 1).

SHIPBOARD SAMPLING OPERATIONS:

Continuous sampling was conducted from the M/V KARA SEAL using the FUGRO Offshore Drilling Rig (FODR). FODR has a three-meter-stroke integral heave compensator that reduces sample disturbance caused by ship motion. In conjunction with rotary drilling used to advance the hole, four sampling devices were used to obtain sediment or rock samples. The devices included: Shelby tubes (thin-walled metal tubes) (Hvorslev, 1949), split barrel samplers (split spoons) (thick-walled metal samplers) (Peck and others, 1974), "O" samplers (split spoon with a liner to better preserve sample integrity), and a Christensen core barrel.

Sample disturbance was reduced by using the sampling device that was most compatible with anticipated sediment behavior at various subbottom depths. Shelby tubes were used in soft material, whereas the split spoon and "O" sampler were used in more competent sediment that would have bent the thin walls of the shelby tube. Although the Christensen core barrel was used in stiffer material, rotary drilling during advancement of the core barrel caused concentric fractures spaced every few centimeters to occur parallel to bedding within the recovered samples.

Except for rotary drilling with the Christensen core barrel, the samplers were driven into the sediment by a hammer. Percussion samples typically are more disturbed than samples obtained with push techniques (Hvorslev, 1949). Emrich (1971) observed a 40 percent decrease in shear strength compared to push samples. However, percussion sampling can indicate relative resistance to penetration by the number of hammer blows required to drive the sampler a fixed distance, typically 0.3 m (Table 2). At least one technique (Bhushan and others, 1976) is available that converts shipboard hammer drops into a blow count analogous to the widely used standard penetration test (SPT) (Peck and others, 1974). The SPT has been used to estimate the compactness or friction angle of granular material and the consistency or undrained shear strength of fine-grained soils (Hunt, 1984).

SHIPBOARD TESTING METHODS AND RESULTS:

Three devices were used at sea to measure the undrained shear strength of fine-grained sediment: a Torvane, pocket penetrometer, and miniature vane shear machine (Hunt, 1984). Samples for water content (later corrected for a salinity of 35 ppt) were obtained down-hole in coarse-grained material and in fine-grained sediment near strength test locations (Table 2, Figs. 1-4). The undrained shear strengths were determined in finer grained sediment only.

The Torvane has eight small vanes attached to a circular plate; the blades are pushed about 6 mm into a flat sediment surface. The torque required to shear the material at the base of the vanes is measured and related to the undrained shear strength. The Torvane was not used in brittle material where the insertion of the vanes would have fractured the sediment, thereby producing an unrealistically low shear strength.

The pocket penetrometer is operated by pushing a 6-mm-diameter spring-loaded rod 6-mm into a flat sediment surface. The force measured is related to the undrained shear strength. However, the test is only valid for soils with plasticity indices greater than twelve (Hunt, 1984) or shear strengths less than 220 kPa. At many locations the capacity of the device was exceeded (Table 2, Figs. 5-8).

Laboratory miniature-vane tests were performed on the ends of samples, using a 12.6 by 12.6 mm vane, with a rotation rate at the top of the machine's spring of approximately 90 degrees per minute (Lee, in press). The miniature-vane tests were performed to a subbottom depth at which the resistance of the sediment exceeded the allowable torque of the machine's springs. One unconfined compression (UC KS-2) test was performed at sea (Table 4, Fig. 5).

SAMPLE STORAGE:

Different methods were used to preserve samples for shore-based geotechnical testing depending on the type of sampler used. Wax was poured into the interior of Shelby tubes in order to form a plug against the sediment surface to prevent slumping and dewatering during handling and storage. End caps were then taped onto the ends and dipped in wax. Samples obtained with the Christensen core barrel were cut into approximately 200-mm lengths, wrapped in tin foil, and placed in cardboard tubes. Warm wax was then poured over the sample to completely enclose it. The "O" liner samples were capped and the ends were dipped in wax. All samples were stored on their side at a temperature of approximately four degrees centigrade.

SHORE-BASED TESTING METHODS AND RESULTS:

Constant rate of strain (CRS) consolidation tests were performed within a triaxial chamber according to the techniques of Wissa and others (1971) in order to evaluate the stress history of the sediment. The test results are plotted as void ratio, e, versus the logarithm of the vertical effective stress, σ'_v (Appendix A).

Typical e - log σ'_v curves form a straight line segment, the virgin line, at higher stresses. The slope of the virgin line is termed the compression index, C_c. The maximum past stress, σ'_{vm}, can be determined from consolidation test results that have a straight virgin line by Casagrande's (1936) technique. However, most of the consolidation tests performed on Chukchi Sea material did not produce a straight virgin line. That curvature made determination of the maximum past stress highly uncertain (Table 3).

The overconsolidation ratio, OCR, is defined as $\sigma'_{vm}/\sigma'_{vo}$ where σ'_{vo} is the in-place overburden stress. Sediment with a high OCR typically has experienced a greater amount of preloading than a similar material with a lower overconsolidation ratio at the same overburden stress. The OCRs for the Chukchi Sea material reflect the wide range of values of the maximum past stresses (Table 3). The coefficient of consolidation, c_v, a factor that reflects the rate at which consolidation occurs, is plotted in Appendix A as a function of the vertical effective stress for each test.

Triaxial tests incorporating the stress history and normalized soil engineering properties (SHANSEP) approach of Ladd and Foott (1974) were planned to estimate the undisturbed in-place shear strength. However, that method relies upon well defined maximum past stresses obtained from consolidation tests. Because consolidation tests typically produced poor results, the SHANSEP approach was not used. Instead, 36-mm-diameter triaxial samples were isotropically consolidated to their estimated in-place vertical effective stress, σ'_{vo}, and sheared undrained using guidelines presented by Bishop and Henkel (1964). The undrained shear strength, S_u or q_{max}, was determined as the maximum shear stress attained before 20 percent axial strain was reached (Table 4, Figs. 5-8). The effective friction angle, ϕ', was determined at the point of maximum obliquity, σ'_1/σ'_3, assuming no cohesion intercept (Table 4).

A number of unconfined compression (UC) tests were also performed (according to ASTM Standard D2166-66). They were run in a similar manner to the triaxial tests except that no lateral confinement was given to the samples during testing. Triaxial test and unconfined compression test results are plotted in Appendix B.

DISCUSSION:

Based on visual identification, sediment type varies markedly down-hole; sand and gravel are present in some beds whereas only fine-grained sediment exists elsewhere. Geotechnical properties possibly reflect changes in sediment type, as well as, different stress histories for similar sediment types.

Water contents, w, vary with subbottom depth (Figs. 1-4). In borings 2 and 3 a trend of decreasing water content with depth is apparent, but "spikes" of both higher and lower water content are present. The overall trend of decreasing water content with depth probably results from increasing overburden stresses that cause greater consolidation of the sediment. Borings 4, 7, and 8 show wide variability down-hole. A slight increase in water content with depth is apparent in holes 4 and 7, possibly reflecting down-hole changes in lithology.

Casagrande's (1936) technique for determining σ'_{vm} requires high-quality test results, whereas consolidation testing of the Chukchi Sea samples almost invariably produced poor results (Appendix A). The sharp break in slope between the reloading and virgin consolidation line apparent in most tests performed on high-quality samples was typically absent. Poorly defined, or nonexistent, straight virgin consolidation lines and difficult to determine points of maximum curvature produced erratic σ'_{vm} determinations (Table 3). The poor results are due to a combination of sample disturbance caused by percussion sampling or rotary drilling and in a few instances result from performing tests on samples with grain sizes that were too coarse to produce well defined consolidation behavior. Some tests may have had such a high maximum past stress that the virgin line was not reached because of equipment limitations.

With few exceptions (CE 137, CE 150, CE 172, and CE 173) the sediment tested appeared overconsolidated (OCR > 1.5, Hunt 1984) to heavily overconsolidated, possibly the result of desiccation caused by low stands of sea-level. The exceptions indicate normal consolidation, i.e., they never experienced a greater vertical effective stress than now exists in situ. The OCR values less than 1.0 are caused by disturbance and hysteretic effects of sampling and testing (Zeevaert, 1983).

Plots of strength values for the various test types versus depth show wide scatter in borings 2 and 3 (Fig. 5). Strengths typically increase with depth, but exceptions occur. Laboratory vane-shear data suggest that an abrupt increase in strength occurs in borings 2 and 3 at a depth of approximately nine meters. However, triaxial tests (TE 257, TE 259) show a gradual increase in strength with depth in that interval. A strong correlation does not exist between different strength-testing methods, although trends are evident. Torvane strengths typically are lower than pocket penetrometer derived values, possibly as a result of remolding soft sediment or fracturing stiff and brittle material.

Triaxial (TE) and unconfined compression (UC) test shear strengths were typically bounded by the pocket penetrometer and torvane values. Relatively good agreement between unconfined strength (UC KS-2, UC 10) and triaxial strength (TE 265, TE 264) was obtained at two locations where the tests were performed on adjacent samples. Considering the size of the tested samples, and operator and equipment inconsistencies associated with shipboard testing, the triaxial and unconfined test results represent the best estimation of in-situ strength. The unconfined compressive strength is probably less than the in-situ strength because of sampling disturbance. The triaxial strength, however, is probably larger than the in-situ strength because consolidation in the laboratory to the in-situ vertical effective stress densifies the material before shear (Ladd and Lambe, 1963, Ladd and Foott, 1974).

Some trends that are evident in holes 2 and 3 also are present in the other borings. However, boring 4 encountered very stiff material within two meters of the seafloor, reflecting the presence of Herald arch. Wide scatter in test results is evident in boring 7.

CONCLUSIONS:

Many different sediment types are present on the northern margin of Hope basin and on the southern margin of the North Chukchi basin. The varying material types may be responsible for observed non-uniform geotechnical behavior down-core. Typically water contents decrease and strength increases with depth in borings 2 and 3 located in the North Chukchi basin. Water content and strength determinations are more erratic in the other borings.

Consolidation test results were very poor because of sample disturbance caused by percussion sampling and the presence of clay-lacking grain-sizes. Percussion sampling produces extensive disturbance; therefore, in order to obtain more meaningful geotechnical data push sampling methods should be used whenever possible in future operations.

Pocket penetrometer strength values were typically higher then triaxial and unconfined compression values, and torvane test strengths were the lowest. Triaxial and unconfined compression tests probably produced values closest to the in-situ strengths.

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Table 1. Station Locations.

Boring	Latitude	Longitude	Water Depth (m)	Location
2*	70°40.014'N	167°19.594'W	53.9	Southern margin of North Chukchi Basin
3*	70°40.014'N	167°19.594'W	53.9	Southern margin of North Chukchi Basin
4	70°27.676'N	167°05.205'W	51.2	Northern flank of Herald Arch
5	69°59.146'N	168°04.943'W	48.5	On Herald Arch
6	69°50.506'N	168°22.205'W	47.0	On Herald Arch
7**	69°37.901'N	168°51.785'W	49.4	Extreme Northern margin of Hope Basin
8**	69°37.911'N	168°51.776'W	53.0	Extreme Northern margin of Hope Basin

* Borings 2 and 3 are spaced approximately 7 meters apart.
** Borings 7 and 8 are spaced approximately 7 meters apart.

Table 2. Boring Information, Shipboard Strength Test Results, and Water Contents.

Boring	Section No.	Depth To Section Top (m)	Sampler Type	Hammer Blows/0.3m	Test Depth (m)	Water Content(a) (%)	S_u lab vane (kPa)	S_r lab vane (kPa)	S_t	S_u Torvane (kPa)	S_u pocket pen. (kPa)
2	1	0.4	S		0.6	24.4				7	37
3	1	0.0	S		0.6	53.8	7.6	2.3	3.3	5	
2	2	0.6	S		1.2	52.6	3.1				
	3	1.2	S		2.1	32.4	0.4				
	4	2.1	S		2.7	27.6					20
	5	2.7	S		3.4	27.6	24				
	6	3.4	S		4.0	31.4	23				
	7	4.0	S		4.6	25.7	14				
	8	4.6	S		5.2	27.1	6.4				
	9	5.2	S		5.8	23.3					
3	2	5.2	S	12	5.8	32.5	2.8	2.0	1.4		
	3	5.8	S	10	6.4	26.0					
	4	6.4	S	17	7.0	25.6					
	5	7.0	S	17	7.6	37.7					
	6	7.6	S	20	8.2	24.1					
	7	8.2	S	25	8.8	30.7	14	3.2	4.4		
	8	8.8	S	27	9.4	25.3					
	9	9.4	S	25	10.0	28.9					
	10	10.1	S	30	10.6	13.8					
	11	10.7	S	30	11.3	19.1	200	49	4.0	120	190
	12	11.3	S	30	11.9	14.1					
	13	11.9	S	37	12.5	24.8				91	180
	14	12.5	S	37	13.1	24.9					>220
	15	13.1	S	40	13.7	25.7					>220
	16	13.7	S	35	14.3	22.6					>220
	17	14.3	C		15.0	38.8					74
	18	15.2	C		16.2					86	170
	19	16.2	C		17.6	25.4				74	>220
	20	17.7	C		19.2	25.3				54	120
	21	19.2	C		19.4	22.5					>220
	22	20.1	C		20.4	26.9					170
	23	21.6	C		22.0	19.8					>220
	24	22.6	C		23.2	22.6					>220
	25	23.5	C		24.6	23.2					>220

Table 2. continued

Boring	Section No.	Depth To Section Top (m)	Sampler Type	Hammer Blows/0.3m	Test Depth (m)	Water Content(a) (%)	S_u lab vane (kPa)	S_r lab vane (kPa)	S_t	S_u Torvane (kPa)	S_u pocket pen. (kPa)
	26	24.7	C		24.8	20.3					>220
	27	25.5	C		25.7	16.8					
	28	26.5	C		27.7	37.7					>220
	29	27.7	C								
	30	29.3	C		30.4	24.4					210
	31	30.8	C		31.6	24.3					
	32	32.3	C		32.7	48.3					
	33	33.5	C		34.9	22.7					>220
	34	35.4	C		36.4	19.8					>220
	35	36.9	C		37.3	20.7					>220
	36	38.4	C		39.3	20.7					>220
	37	39.9	C		40.1	19.2					>220
	38	41.5	C		42.8	21.4				100	>220
	39	43.0	C		44.3	43.7				110	>220
	40	44.5	C		45.6	18.0				>49(b)	>220
	41	46.0	C		47.2	17.5					>220
	42	47.5	C		47.3	18.8					>220
	43	49.1	C		49.7	19.5					220
	44	50.0	S		51.3	13.9					220
4	1	0.0	S	1	0.1	20.8	116	36			170
	2	0.6	S	2	1.2	23.9	58	22			80
	3	1.2	S	5	1.8	19.1	185	54			210
	4	1.8	S	10	2.7	18.7					220
	5	2.7	SS	15	2.9	20.0					
	6	4.0	C		4.5	20.4					>220
	7	5.2	C		5.6	22.5					>220
5	1	0.0	S	10	0.6	11.4					
	2	0.6	S	20	1.2	12.8					
	3	1.2	SS	50	1.5						
	4	1.5	SS	100	1.7						
	5	1.7	SS	120	1.8						
	6	1.8	SS	100(?)	2.4						
	7	2.4	SS	100(?)	2.7						
6	1	0.0	S	10	0.2	53.4					
	2	0.2	SS	20	0.2						
	3	0.6	SS	80	0.6						
	4	0.8	SS	100	0.8						
	5	0.9	SS	75	0.9						

Table 2. continued

Boring	Section No.	Depth To Section Top (m)	Sampler Type	Hammer Blows/0.3m	Test Depth (m)	Water Content(a) (%)	S_u lab vane (kPa)	S_r lab vane (kPa)	S_t	S_u Torvane (kPa)	S_u pocket pen. (kPa)
7	1	0.0	S	1	0.6	14.0	>200			49	>220
	2	0.6	S	17	1.2	16.8				70	130
	3	1.2	S	17	1.8	17.3				76	120
	4	1.8	SS	10	2.4	23.1					
	5	1.8	S		2.4	24.0					
	6	2.4	O	20	3.0	21.8					150
	7	3.0	S	15	3.7	18.9					
	8	3.7	O	20	4.3	13.2				130	>220
	9	4.3	O	20	4.9	18.9				56	130
	10	4.9	O	20	5.5	17.1					>220
	11	5.5	O	20	6.0	17.5					>220
	12	6.1	O	25	6.7	28.3					37
	13	6.7	S	15	7.3	21.7					51
	14	7.3	O	20	7.9	17.0					>220
	15	7.6	O	20	8.5	19.4					86
	16	7.9	S		8.5						
	17	8.5	O	25	9.1	13.7					98
	18	9.1	O	25	9.8	11.5					>220
	19	9.8	O	25	10.4	16.1					>220
	20	10.4	SS	20	11.0	17.8					
	21	11.0	O	15	11.6	19.2					>220
	22	11.6	O	15	12.0	26.9					
	23	12.2	O	15	12.8	15.3					>220
	24	12.8	O	15	13.4	24.1					>220
	25	13.4	O	15	14.0	26.6					>220
	26	14.0	O	15	14.6	24.3					150
	27	14.6	O	15	15.2						
	28	15.2	O	15	15.3	18.0					220
8	1	0.0	O	20	0.5	30.7				29	120
	2	0.6	O	25	1.2	13.9				61	>220
	3	1.2	O	20	1.8	21.1				39	127
	4	1.8	O	20	2.4	23.6				37	86
	5	2.4	O	25	3.0	15.8				12	98
	6	3.0	O	30	3.6	17.5				2	10

(a) Water content was corrected for a pore water salinity of 35 ppt.
(b) Insertion of Torvane fractured stiff sediment.