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by
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EFFETS DE L'ECHANTILLONNAGE, DES DIMENSIONS ET DE L'ENTREPOSAGE SUR LES RESULTATS D'ESSAIS D'UNE ARGILE MARINE

SOMMAIRE

Des essais de consolidation sur une argile marine tendre ont montré qu'elle était normalement consolidée lorsque les essais étaient réalisés sur des échantillons préleves au tube carottier de 2 po. (51 mm.) de diamètre et surconsolidée de 0.16 TSF (kg/cm²) lorsque les essais étaient réalisés sur des échantillons prélevés au tube carottier de 5 po. (127 mm.) de diamètre. La comparaison d'essais sur des échantillons de 20, 40 et 60 cm², taillés dans un bloc d'argile marine raide surconsolidée, montre que la pression maximale de préconsolidation a été obtenue avec les échantillons de 40 cm². L'entreposage du bloc dans une chambre humide à 55°F durant un an et demi a réduit la pression de préconsolidation mesurée. Un enduit de teflon at de graisse à base de bisulfure de molybdène sur les anneaux de l'oedomètre s'est avéré utile à réduire le frottement latéral.

Des essais de résistance à l'appareil triaxial avec mesure de la pression interstitielle ont été réalisés sur une argile marine tendre échantillonnée avec les carottiers de 2 po. (51 mm.) et 5 po. (127 mm.) de diamètre. Bien que les résistances mesurées soient comparables, les essais sur les échantillons taillés dans les carottes de 2 po. (51 mm.) de diamètre ont donné des plus grandes déformations à la rupture et un plus petit paramètre A de pression interstitielle que ceux obtenus avec les échantillons provenant des carottes de 5 po. (127 mm.) de diamètre.

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Effect of Sampling, Size, and Storage on Test Results for Marine Clay

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ABSTRACT: Consolidation tests on a soft marine clay formation indicated that it was normally consolidated when the tests were performed on cores obtained with a 2-in.-diameter (54-mm) tube sampler and overconsolidated by 0.16 tons/ft^2 (kg/cm^2) when the tests were performed on cores obtained with a 5-in.-diameter (124-mm) tube sampler. From comparative tests on 20, 40, and 60-cm^2 test specimens trimmed from a block of stiff overconsolidated marine clay, the maximum preconsolidation pressures were measured on the 40-cm^2 size. Storing the block sample in a humid room at 55 F for one and a half years decreased the measured preconsolidation pressure. Coating the consolidometer rings with Teflon and molybdenum-disulphide-based grease was effective in reducing side friction.

Triaxial strength tests with pore pressure measurements were performed on the soft marine clay, sampled with both 2-in.-diameter (54-mm) and 5-in.-diameter (124-mm) tube samplers. Although the measured strengths were comparable, the tests on specimens trimmed from the 2-in.-diameter (54-mm) cores produced greater strains to failure and a smaller pore pressure parameter A than did tests on specimens from the 5-in.-diameter (124-mm) cores.

KEY WORDS: marine clays, sampling, consolidation test, triaxial tests, shear strength, pore water pressure, storage, evaluation, tests

Engineering tests on soils provide design parameters for predicting their performance under applied loads. The triaxial test commonly is used to determine strength and pore water pressure response in investigations of bearing capacity and stability of embankments or slopes. Consolidation tests enable prediction of settlement of structures due to consolidation of subsoils.

Representative "undisturbed" samples of soil have to be obtained for these tests. For shallow depths, hand trimmed block samples can be carved

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from an excavation. For greater depths the usual practice is to use a thin-walled piston tube sampler. This paper describes the effects of sampling technique, size of test specimen, and storage time on the consolidation and and strength properties of sensitive marine clay at Ottawa, Canada.

Consolidation Test

Settlement can be predicted with reasonable accuracy for many soils using the results of the standard consolidation test, as described by Taylor [*1*][2] and Lambe [*2*]. For sensitive marine clays, predictions usually over-estimate observed settlements by a factor of from two to four. Studies of the consolidation test on these clays by Hamilton and Crawford [*3*], Crawford [*4, 5*], and Jarrett [*6*] have shown that the standard procedure for applying a load increment ratio of $\Delta P/P = 1$ to the test specimens produces rates of compression far exceeding those that occur in the field. This "shock" treatment destroys the soil structure, reducing the measured preconsolidation pressure. These studies also indicated that rate of loading affects it. To improve the determination of this value, a small load increment ratio should be used. Crawford [*4*] suggested that the test should be performed at a steady rate of compression sufficiently slow to prevent development of significant pore pressures. This procedure, however, is more difficult and requires considerably more testing time. Other factors such as size of sampler, size of test specimen, wall friction in the consolidometer rings, and length of time a sample is stored also tend to reduce the preconsolidation pressure measured in the test.

The effect of sampler size on measured preconsolidation pressure is illustrated in Fig. 1 where the results of fifteen tests on soft marine clay from CFS Gloucester are plotted. Samples were obtained from depths of 5 ft (1.5 m) to 17 ft (5.2 m) with the Norwegian (NGI) piston sampler [*7*] and the Osterberg hydraulic sampler [*8*]. The NGI sampler yields 2-in. diameter (54-mm) tube samples 3 ft (0.91 m) long with a clearance ratio at the cutting edge of 1 percent. The samples were taken using a single rapid thrust with the hydraulic feed of a drill rig. Precautions were taken to ensure that the piston remained stationary and that the samples were not overdriven. The Osterberg sampler provides 5-in.-diameter (124-mm) tube samples 2½ ft (0.76 m) long and has a clearance ratio of 0.42 percent at the cutting edge. The sampler has a fixed piston and a safeguard to prevent overdriving. The sampling thrust is provided by water pressure. After the samples were obtained, they were transported in the tubes to the laboratory where they were extracted by jacking vertically in the same direction that the soil had entered the tube. The samples were cut into 4 in. (10 cm) lengths and stored at constant temperature of 55 F in a humid room until they were ready to be tested. From the 2-in.-diameter (54-mm)

[2] The italic numbers in brackets refer to the list of references appended to this paper.

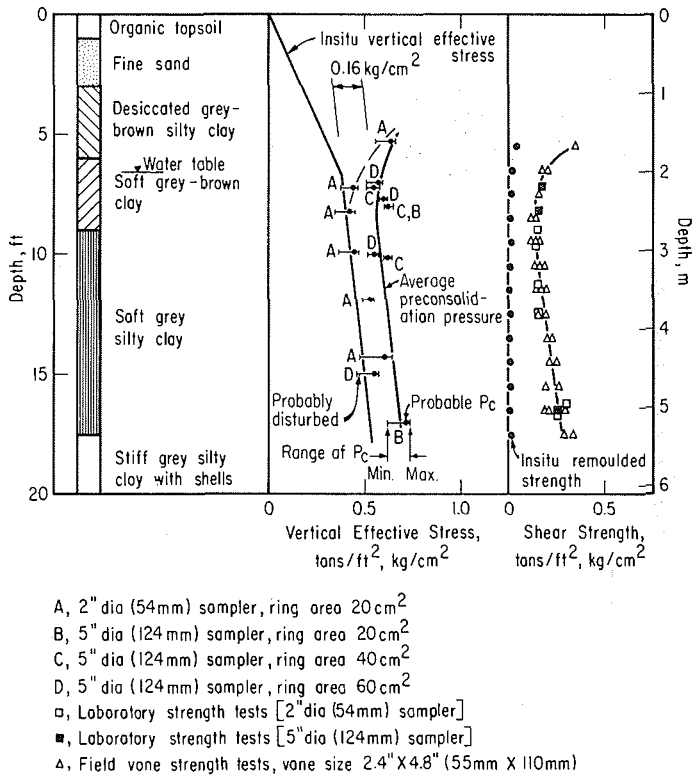
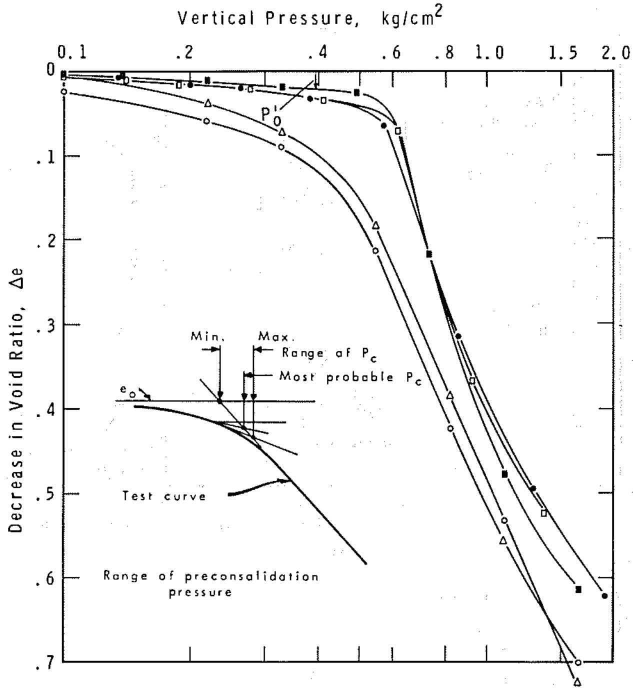


FIG. 1—*Results of consolidation and strength tests on soft marine clay at CFS Gloucester.*

cores, specimens 20 cm² in area by 2 cm high were tested using a load increment ratio $\Delta P/P = \frac{1}{2}$. Specimens 20, 40, and 60 cm² by 2 cm high were trimmed from the 5-in.-diameter (124-mm) cores and subjected to a load increment ratio of about $\frac{1}{4}$. For these tests, the stainless steel rings were coated with Teflon and lubricated with molybdenum-disulphide-based grease to reduce side friction. At the time of testing the 2-in.-diameter (54-mm) and 5-in.-diameter (124-mm) cores had been stored for 2 and 12 months, respectively. Below the desiccated zone the test results from the 2-in.-diameter (54-mm) cores straddled the *in situ* vertical effective stress line, indicating that this clay formation is normally consolidated. Consequently, any loading applied to it should cause substantial settlement. Tests on the 5-in.-diameter (124-mm) cores, however, show that this clay has been overconsolidated by at least 0.16 kg/cm².

Pressure void ratio curves of five tests from about the same depth are compared in Fig. 2. Specimens 164-1-9 and 164-2-1 were trimmed to 20 cm² in area by 2 cm high from the 2-in.-diameter (54-mm) cores, and



Code	Number	Depth	Sampling Method	Area of Specimen	Probable P_c
Δ	164-1-9	7.2ft (2.2 m)	2" dia tube (5 mm)	20 cm^2	0.44 $tons/ft^2$ (kg/cm^2)
○	164-2-1	8.2ft (2.5 m)	2" dia tube (5 mm)	20	0.47
●	164-25-3Z	8.0ft (2.4 m)	5" dia tube (12 mm)	20	0.59
□	164-25-3Y	8.0ft (2.4 m)	5" dia tube (12 mm)	40	0.62
■	164-25-3X	7.8ft (2.4 m)	5" dia tube (12 mm)	60	0.60

Note: 2- in (54mm) specimens tested two months after sampling
5-in (124 mm) specimens tested twelve months after sampling

FIG. 2—*Effect of sampling and size of test specimen on the preconsolidation pressure measured in soft marine clay.*

specimens 164-25-3X, 164-25-3Y, and 164-25-3Z were trimmed to 60, 40, 20 cm^2 in area by 2 cm high, respectively, from the 5-in.-diameter (124-mm) cores. The index properties of these specimens are given in Table 1.

Tests on the 2-in.-diameter (54-mm) cores produced lower and rounder

TABLE 1—*Summary of the engineering properties of soft and stiff marine clays.*

Number	Site	Depth	Sampling Method	Natural Density, lb/ft³	Water Content, %	Liquid Limit, %	Plastic Limit, %	Clay Size, %	*In Situ* Void Ratio	*In Situ* Vane Strength, kg/cm²	Sensitivity
164–1–9.....	CFS Gloucester	7.2 ft (2.2 m)	2-in.-dia tube (54-mm)	100 (1602 kg/m³)	80	50	22	58	2.2	0.15	17
164–2–1.....	CFS Gloucester	8.2 ft (2.5 m)	2-in.-dia tube (54-mm)	100 (1602)	72	50	22	58	2.0	0.12	17
164–2–5.....	CFS Gloucester	8.9 ft (2.7 m)	2-in.-dia tube (54-mm)	102 (1632)	64	46	22	58		0.13	17
164–25–3C...	CFS Gloucester	8.3 ft (2.5 m)	5-in.-dia tube (124-mm)	105 (1681)	57	50	22	58		0.12	17
164–25–3X...	CFS Gloucester	7.8 ft (2.4 m)	5-in. dia tube (124-mm)	102 (1632)	66	50	22	58	1.8	0.12	17
164–25–3Y...	CFS Gloucester	8.0 ft (2.4 m)	5 in.-dia tube (124-mm)	102 (1632)	62	50	22	58	1.7	0.12	17
164–25–3Z...	CFS Gloucester	8.0 ft (2.4 m)	5-in.-dia tube (124-mm)	102 (1632)	63	50	22	58	1.8	0.12	17
94–22.......	Ottawa Sewer Plant	52.1 ft (15.9 m)	hand trimmed block	107 (1713)	52	35	23	64	1.5	1.5	>100

curves. The absence of a pronounced knee at the preconsolidation pressure is an indication of sample disturbance, caused either during sampling or during preparation of the test specimens. The tests on the 5-in.-diameter (124-mm) cores display a sharp knee in the vicinity of the preconsolidation load and indicate less recompression. Furthermore, using the Casagrande construction [*9*], the highest probable preconsolidation pressure of 0.62 kg/cm^2 was measured on the 40-cm^2 specimen. This was only slightly greater than the 0.59 kg/cm^2 and 0.60 kg/cm^2 measured, respectively, on the 20-cm^2 and 60-cm^2 specimens trimmed from the 5-in.-diameter (124-mm) cores. On the average, preconsolidation pressures measured on the specimens trimmed from the 5-in.-diameter (124-mm) cores exceeded those on the 2-in.-diameter (54-mm) cores by about 40 percent. Assuming that the disturbance during trimming in the laboratory is about the same for all test specimens, it appears that the difference in the test results is due to the size of sampler used in this soft marine clay.

To extend the investigation of size effect on measured preconsolidation pressure, specimens 20, 40, 60 cm^2 in area by 1 and 2 cm in height were trimmed from a block of stiff sensitive marine clay (No. 94-22, Table 1) hand cut from a depth of 52 ft (15.9 m) in an excavation for the Ottawa Sewer Plant. A description of the soil profile and some of the engineering properties have been given by Bozozuk [*10*]. The block was large enough to allow all test specimens to be obtained side by side from exactly the same bedding plane. The consolidation rings were stainless steel, coated with Teflon and lubricated with molybdenum-disulphide-based grease to reduce side friction. Pressure increments of 0.6, 1.3, 2.0, 2.5, 3.0, 3.5, 4.2, 5.0, 6.0, 9.0 kg/cm^2 were used. The tests were conducted in a constant temperature room at 67 F within a period of 61 to 92 days after sampling.

The results of twelve tests (Table 2) show that on the average the 2-cm-thick specimens produced higher preconsolidation pressures with the maximum values measured on the 40-cm^2 size. For the 2-cm-thick specimens, the preconsolidation pressure measured on the 40-cm^2 size exceeded that measured on the 20-cm^2 size by about 9 percent. Increasing the size to 60 cm^2, however, caused a reduction in preconsolidation pressure. This phenomenon can be attributed to soil disturbance. If the depth of disturbance due to trimming the test specimens is constant for all sizes, the proportion of disturbed to undisturbed soil in the 1-cm-thick specimens would be about double that for the 2-cm-thick specimens, which accounts for the lower preconsolidation pressures on the thin specimens [*11*]. Similarly the proportion of disturbed to undisturbed soil decreases as the diameter increases, which accounts for the higher preconsolidation pressures produced with the 40-cm^2 test specimens. Increasing the test specimens to 60 cm^2, however, introduces considerable difficulty in trimming and handling and the extent of disturbance increases, which accounts for the drop in the measured preconsolidation pressure. Nevertheless, these tests

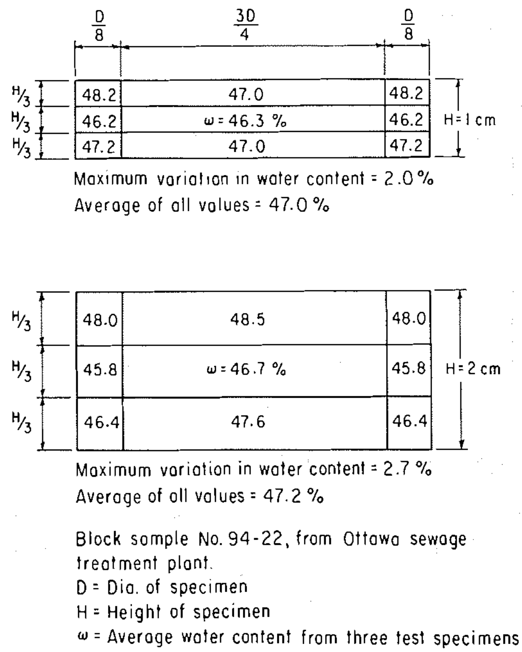


FIG. 3—*Distribution of water content in test specimens of stiff marine clay after consolidation.*

agree with those performed on the soft marine clay in that the consolidation test can be improved by using 40-cm^2 test specimens.

The distribution of water content at the end of consolidation was investigated in three 1-cm-thick and three 2-cm-thick specimens. The results were averaged and are shown in Fig. 3. The maximum variation in water content was 2.0 percent for the 1-cm specimen and 2.7 percent for the 2-cm-thick specimens. The highest water contents were found at either the corners or the faces, which could have been caused by suction due to swelling while the soil rebounded on being removed from the testing machine. The results show, nevertheless, that the techniques used to reduce side friction were effective. If there had been substantial side friction, the water content in the central layer of the test specimen would have been higher because this zone would not have been consolidated to the same degree as the soil in direct contact with the drainage stones [*3*].

The block sample obtained from the sewage treatment plant was stored in a humid room at a temperature of 55 F and a relative humidity of from 90 to 100 percent for about 1½ years. By conducting consolidation tests at various times on 40-cm^2 by 2-cm specimens during this period it was possible to observe the change in measured preconsolidation pressure with time. Figure 4 shows that the maximum preconsolidation pressure of 4.95

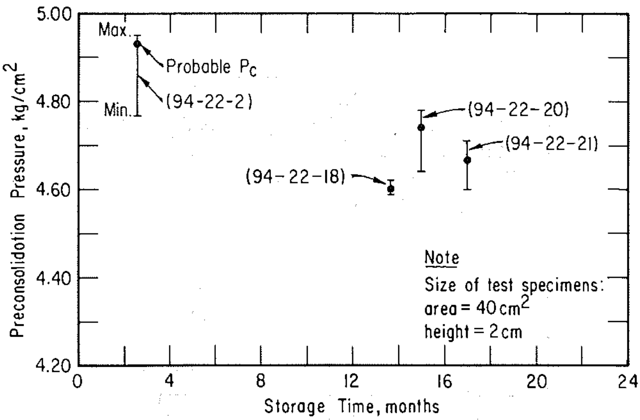


FIG. 4—*Effect of storage time on the measured preconsolidation pressure.*

kg/cm² measured two months after the sample was taken reduced to about 4.71 kg/cm² after 17 months of storage. Although this reduction is not great (4.8 percent), it does indicate that consolidation tests should be performed as soon as possible after the samples are obtained.

Strength Tests

The soft clay formation at CFS Gloucester is a sensitive weak clay, with vane shear strengths measured *in situ* varying from 246 psf (0.12 kg/cm²) to 512 psf (0.25 kg/cm²) (Fig. 1). Triaxial strength tests were performed on test specimens of 1.4-in.-diameter (35-mm) by 3-in.-high (76-mm) trimmed from 2-in.-diameter (54-mm) and 5-in.-diameter (124-mm) cores taken from borings located within a few feet of each other. The specimens were consolidated anisotropically to the *in situ* stresses, then loaded in the undrained condition to failure at a rate of strain of 0.2 percent per hour. Pore pressures were measured during loading by means of a pressure transducer installed in the base pedestal. The results of nine tests indicated that the strengths measured on specimens trimmed from the two core sizes compared well with each other and with the *in situ* vane strengths, as shown in Fig. 1. In general, however, the measured strain to failure was smaller and the pore pressure parameter A greater on specimens trimmed from the 5-in.-diameter (124-mm) cores. Figure 5 compares the stress strain curves and pore pressure parameter A for test specimens 164-2-5 (trimmed from the 2-in.-diameter (54-mm) core) and 164-25-3C (trimmed from the 5-in.-diameter (124-mm) core). These specimens are soft and weak, have a sensitivity of 17, a clay size fraction of 58 percent, and a natural water content exceeding the liquid limit (Table 1). They also come from unequal depths, 8.9 ft (2.7 m) and 8.3 ft (2.5 m), respectively, and this accounts for the slight difference in density and classification properties.

The curves in Fig. 5 are typical of the tests performed to date on this soft clay. The measured pore pressure parameter A was significantly greater on the specimen from the 5-in.-diameter (124-mm) core. In addition, the initial portion of the stress strain curve is straighter and the failure strain less than that on the 2-in.-diameter (54-mm) core. The difference appears to be the result of the sampling technique. It appears that the larger diameter sampler provides better samples of the soft clay layer, but more comparative tests should be carried out.

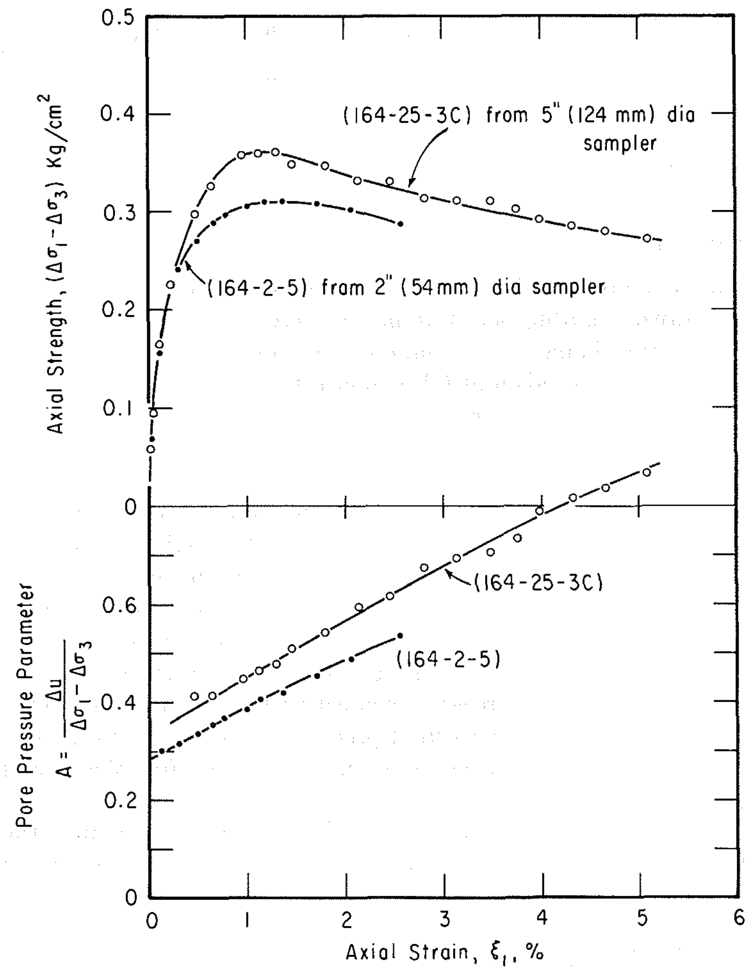


FIG. 5—*Effect of sampling equipment on the measured strength, strain, and pore water pressure parameter A in soft marine clay.*

TABLE 2—*Summary of twelve consolidation tests on stiff sensitive marine clay using various sizes of test specimens.*
(Tests conducted from 61 to 92 days after sampling)

Height, cm	Maximum Preconsolidation Pressure, kg/cm²			
	[a]20 cm²	40 cm²	60 cm²	Average of Six Tests
1..............	4.79	4.87	4.80	4.68
1..............	4.40	4.60	4.60	
2..............	4.60	4.91	4.76	4.75
2..............	4.50	4.99	4.74	
Average of four tests.....	4.57	4.84	4.72	

[a] Area of test specimen.

Conclusions

From the limited number of test results reported the following conclusions may be drawn regarding sensitive marine clays from the Ottawa area:

1. The larger diameter tube sampler provides better quality samples in the soft marine clay taken at CFS Gloucester.
2. The strain and pore pressure parameter of the soft clay was affected by the size of the sampler.
3. The preconsolidation pressure of soft marine clay measured in the consolidation test was affected by the size of tube sampler. Specimens trimmed from the 5-in.-diameter (124-mm) cores generated higher preconsolidation pressures than those from the 2-in.-diameter (54-mm) cores.
4. The 40-cm² by 2-cm-high test specimens provided the maximum preconsolidation pressures in both soft and stiff marine clays.
5. Coating the consolidometer rings with Teflon and greasing with molybdenum-disulphide-based grease was effective in reducing side friction.
6. Storage reduces the measured preconsolidation pressures. Consolidation tests should be performed as soon as possible after the samples are obtained.
7. The effect of size of samplers and of test specimens on laboratory test results needs further study. Future investigations should be extended to include other clay deposits.

Acknowledgments

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