Sampler trials on overconsolidated sensitive clay
Eden, W. J.

Publisher's version / Version de l'éditeur:

ASTM Special Technical Publication, 483, pp. 132-142, 1971-01-01

ational Research Council of Canada
Conseil National De Recherches Du Canada

Sampler Trials in Overconsolidated Sensitive Clay

by
W. J. Eden

Reprinted from
American Society for Testing and Materials
Special Technical Publication 483, 1971
p. 132 -142

Research Paper No. 465
of the
Division of Building Research

OTTAWA
January 1971

Price 25 cents

NRCC 11753

ESSAIS D'ECHANTILLONNEURS DANS UNE ARGILE SENSIBLE ET SURCONSOLIDEE

SOMMAIRE

Au cours des travaux d'excavation de puits de pompes pour une usine de traitement des eaux usées, il a été possible d'obtenir plusieurs échantillons non-remaniés d'une argile extrêmement sensible, mais surconsolidée, à des profondeurs allant de la surface jusqu'à 70 pieds. En utilisant ces échantillons comme points de référence, on a procédé à un échantillonnage avec quatre genres d'échantillonneurs à piston et les résultats d'essais ont été comparés à ceux obtenus avec les échantillons de référence. La résistance in-situ de l'argile a aussi été évaluée à l'aide du scissomètre de chantier. Les échantillonneurs utilisés ont été les "Swedish Foil," le 54 mm. norvégien, le 50 mm. suédois et le corottier hydraulique Osterberg de 5 po. de diamètre.

Les résultats ont démontré que ni les échantillonneurs ni le scissomètre ne donnent des résultats qui peuvent se comparer de façon uniforme à ceux obtenus en utilisant les échantillons de référence. La principale conclusion de cette étude indique que les méthodes actuelles d'échantillonnage de ces sols par forage à partir de la surface ne peuvent fournir des échantillons non-remaniés satisfaisants.

Authorized Reprint from
Special Technical Publication 483
Copyright
American Society for Testing and Materials
1916 Race Street, Philadelphia, Pa. 19103
1971

W. J. Eden[1]

Sampler Trials in Overconsolidated Sensitive Clay

REFERENCE: Eden, W. J., "**Sampler Trials in Overconsolidated Sensitive Clay,**" *Sampling of Soil and Rock, ASTM STP 483*, American Society for Testing and Materials, 1971, pp. 132–142.

ABSTRACT: During the excavation of pump wells for a sewage treatment plant, it was possible to obtain large, undisturbed, block samples of extremely sensitive yet overconsolidated clay from depths ranging from the surface to 70 ft. With these block samples as a reference, sampling was conducted with four types of piston samples, and the test results were compared with those obtained from the block samples. The *in situ* strength of the clay also was measured with the field vane test. Samplers used in the trials were the Swedish Foil, the Norwegian 54 mm, the Swedish 50 mm, and the 5-in.-diameter Osterberg hydraulic sampler.

The results showed that none of the samplers nor the field vane test were successful in obtaining results that could be compared consistently with results obtained from the block samples. The main conclusion of this study is that present methods of sampling of such soils by boring from the surface do not produce satisfactory undisturbed samples in this material.

KEY WORDS: sampling, sample disturbance, marine clays, consolidation, shear strength, vane test, evaluation, tests

A complete evaluation of disturbance due to sampling requires the trial of a variety of sampling tools and techniques at sites where the soil properties are well known. This paper describes a study at one site where properties measured on large block samples could be compared with those measured using four types of thin-walled tube samples and the field vane test.

The opportunity for this study arose in 1961, when the City of Ottawa began the construction of a sewage treatment plant which required the excavation of 75 ft of sensitive, overconsolidated Leda clay for the pump wells. Large block samples of the clay were obtained from 6 levels as the

[1] Research officer, Division of Building Research, National Research Council of Canada, Ottawa, Ont., Canada.

excavation proceeded. Preconsolidation pressure and undrained-strength determinations on the block samples provided the data for comparison with test results obtained by other sampling methods.

The Site

The site for the sampling is located along the Ottawa River at the eastern outskirts of the City of Ottawa, in an extensive clay plain with a surface elevation of 175 ft (53 m). The entire soil profile down to the underlying glacial till consists of Leda clay. The geotechnical profile for the site is indicated in Fig. 1; the strength and preconsolidation pressures were obtained from block samples. From the surface down to 8 ft (2.5 m) the clay is friable and oxidized. From 8 ft (2.5 m) to about 45 ft (14 m) the clay is quite stiff with a sensitivity of about 20. Figure 1 shows in detail the change in water content and the plasticity characteristics. Below 45 ft (14 m) the clay becomes slightly coarser; natural water content decreases and sensitivity increases dramatically, being of the order of 1000 at 55 ft (17 m). As Fig. 1 indicates, the clay is overconsolidated by about 4 tons/ft^2 (4 kg/cm^2).

The site has been the subject of several investigations reported earlier: Crawford [*1, 2*],[2] Crawford and Eden [*3*], Jarrett [*4*], and Eden and Bozozuk [*5*]. A detailed description of the construction of the pump wells may be found in a paper by Pappas and Sexsmith [*6*]. The preconsolidation pressures and undrained strength which were determined from the block samples are considered reliable [*3*], because they agree well with regional correlations established for the Ottawa area.

Samplers and Sampling

The large, block "reference" samples were carefully taken as the excavation for the pump wells proceeded, at depths of 22 ft (6.7 m), 34 ft (7.9 m), 45 ft (13.7 m), 53 ft (16.1 m), 62.5 ft (19.1 m), and 72 ft (22 m). The blocks, which were about 10 in. to each side, were cut from clay that had not suffered disturbance by construction equipment, and were sealed and boxed in the field for transportation to the laboratory.

The tube samples were obtained with the Swedish foil sampler [*7*], the Norwegian piston sampler [*8*], the Swedish piston sampler [*9, 10*], and the Osterberg hydraulic sampler [*11*]. The Swedish foil sampler takes very long samples. After passing a cutting shoe, 2.48 in. (63 mm) in diameter, the sample entered retaining tubes which were 2.68 in. (68 mm) in diameter and 8 ft (2.5 m) long. Samples were obtained from a depth of 8 ft (2.5 m) to 75 ft (22 m) in two drives. The first drive was from 8 ft (2.5 m) to 42.5 ft (12.9 m) at which point the foils broke due to internal resistance. The second push was from 42.7 ft (13.0 m) to 75 ft (22 m)

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

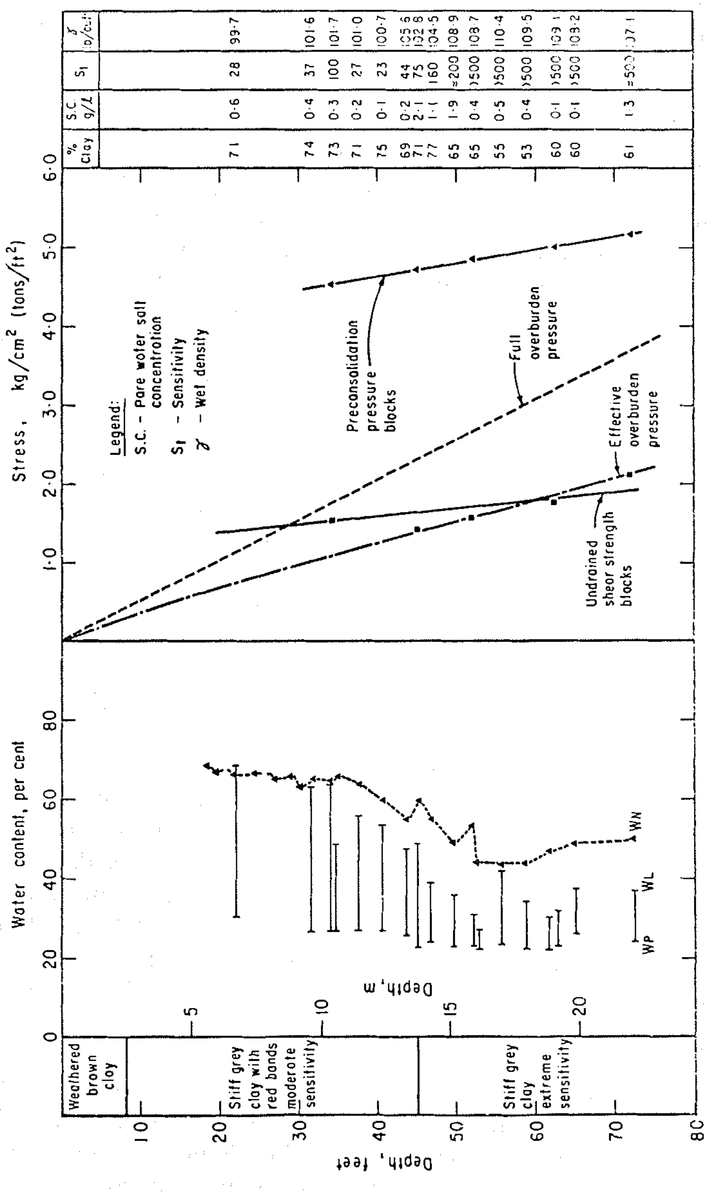

FIG. 1—*Geotechnical profile of sampling site.*

where refusal was met in glacial till. The samples were brought to the laboratory in the 8 ft (2.5 m) long retaining tubes. In the laboratory the samples were removed from the tubes, cut into 8 in. (20 cm) lengths, and sealed in wax until the time of testing. The foil sampling was conducted by a drilling contractor with an experienced crew.

The standard Norwegian Geotechnical Institute (NGI) piston sampler has a stationary or fixed piston, which yields a sample 54 mm in diameter. Each tube has a net sample length of 3 ft (0.91 m). A clearance ratio of 1 percent was maintained on the cutting edge. 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 sampler was not overdriven. Ten samples were obtained at depths ranging from 25 ft (7.5 m) to 55 ft (16.8 m). Each sample was transported in the sampling tube to the laboratory, where it was extracted from the tube by jacking it in the same direction that it had entered the tube. The 4 in. (10 cm) lengths of sample were then waxed and stored in a humid room until tested. The St-1 sampler is the standard piston sampler adopted by the Swedish Committee on Piston Sampling. This sampler has a fixed piston. The sampler barrel is relatively heavy, with specially shaped, detachable cutting shoes. The soil sample is retained in fiber glass resin tubes, 50 mm in diameter and 17 cm long. Four such retaining tubes are used in each sampling drive, which is made with a single thrust of a hydraulic feed on a drill rig. This sampler and its operation is described in detail by Kallstenius [*10*]. Nine samples were obtained with the St-1 sampler at depths ranging from 28 ft (8.5 m) to 54 ft (16.5 m). The samples were withdrawn from the sampler barrel in the field, stored in plastic tubes, and sealed with special fitting rubber caps.

The 5-in.-diameter Osterberg sampler has a fixed piston; the sampling thrust is supplied by water pressure and has a safeguard to prevent overdriving. For these tests, the sampling tubes had an inside diameter of 4.895 in. (124 mm), a wall thickness of 0.069 in. (1.75 mm), and a clearance ratio of 0.42 percent on the cutting edge. Six 24-in. (61-cm)-long samples were taken, one from a depth of 30 to 32 ft (9.1 to 9.8 m) and five between 41.5 ft (12.7 m) and 51.5 ft (15.7 m). The samples were transported to the laboratory in the tubes and extracted in the same manner as the NGI samples.

Figure 2 indicates the relative depths of the samples obtained by the last three types of sampler. The Swedish foil sampler yielded a 65-ft-long sample which is continuous except for a 3-in. (76-mm) gap between the two drives at 42.5 ft (13.0 m). The other three types of samplers were used in uncased holes kept filled to the surface with remoulded clay. All the known precautions were taken with these samplers, although the drilling crew was most familiar with the NGI sampler.

In addition to the four types of sampler, a NGI field vane [*12*] was

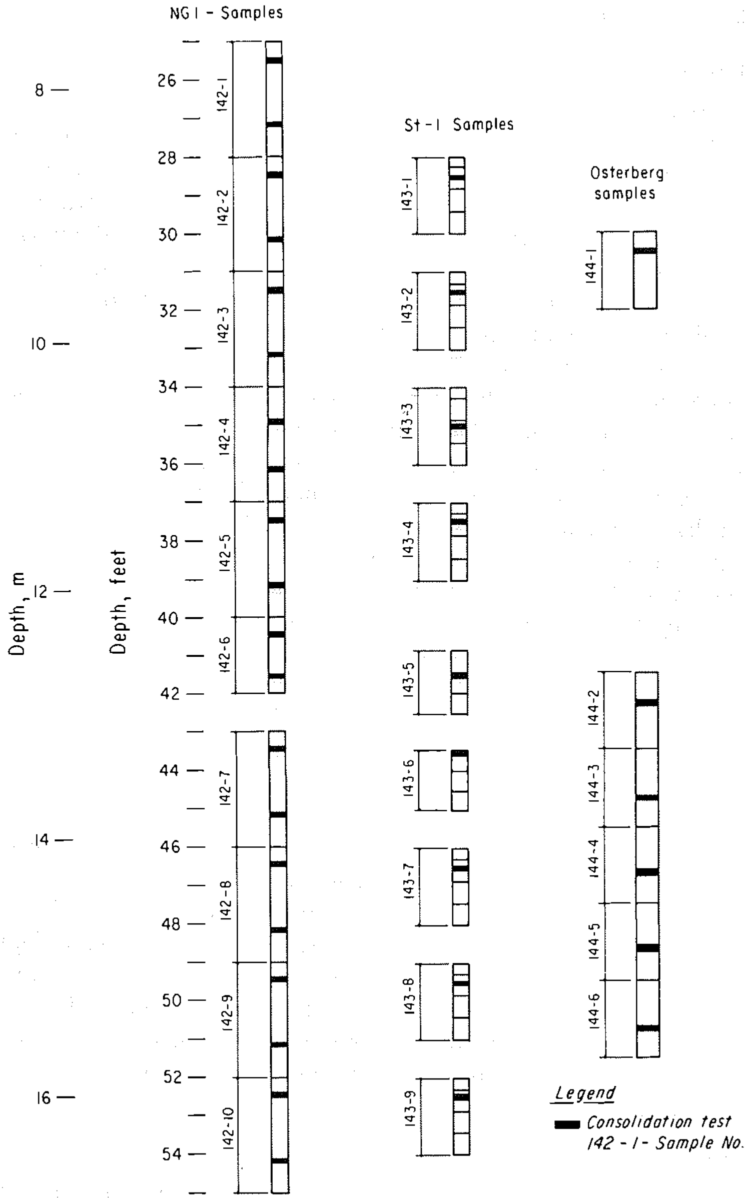

FIG. 2—*Log of samples obtained with three types of sampler.*

used to measure the undrained strength from a depth of 17.5 ft (5.3 m) to 72.5 ft (22.1 m).

Test Results

The relative quality of the samples was assessed on the basis of the measured preconsolidation pressure and the undrained shear strength. The preconsolidation pressure was determined with a floating ring consolidometer using samples 20 cm^2 in area by 2 cm high, trimmed from the middle of the samples. The test procedures described by Hamilton and Crawford [*13*] were followed. Because the same procedure was strictly followed for each test, the rate effects reported by Crawford [*2*] and Jarrett [*4*] should not have influenced one test more than another.

The undrained strength was measured on samples trimmed from both the tube and block samples to a size 1.4 in. (35 mm) in diameter and 3 in. (76 mm) in height. Both unconsolidated, undrained, triaxial tests using lateral pressures equivalent to calculated overburden pressures and unconfined compression tests were made. Tests were conducted with a gear-driven apparatus at a rate of strain of 1 percent/min. The shear strength was taken as one half the measured compressive strength. There was no evident difference between the results of the two types of test, and so they have not been distinguished in the tabulations.

The results of some 50 consolidation tests and 280 undrained strength determinations were available, from the different types of samples, for comparison purposes. Tests which had failure strains of more than 5 percent were discarded since these were considered to indicate disturbed material. All the test results are presented in Fig. 3. Tables 1 and 2 list the results of consolidation tests and undrained strength tests, respectively. To consider the test results in more detail, the clay profile has been divided arbitrarily into six zones. Arbitrary boundaries were used because no precise horizons could be identified physically in the samples. The boundaries of zones chosen are marked by the following depths: 28 ft (8.5 m), 39.5 ft (12.0 m), 49 ft (14.9 m), 57.5 ft (17.5 m), and 67 ft (20.4 m); the results for each zone are reported in Tables 1 and 2. The block samples were taken from the midpoint of each zone, and the results of tests on the block samples are considered to be the reference tests for that zone.

Discussion

An inspection of Fig. 3 or of the tabulated results indicates that the average test values obtained with the samplers fall far short of values obtained with the block samples. Only 4 of 35 preconsolidation test results equal or exceed the results from the block samples. Similarly, only 6 of 240 undrained strength determinations equal or exceed the results from the block samples. The value obtained in a great many sampler tests

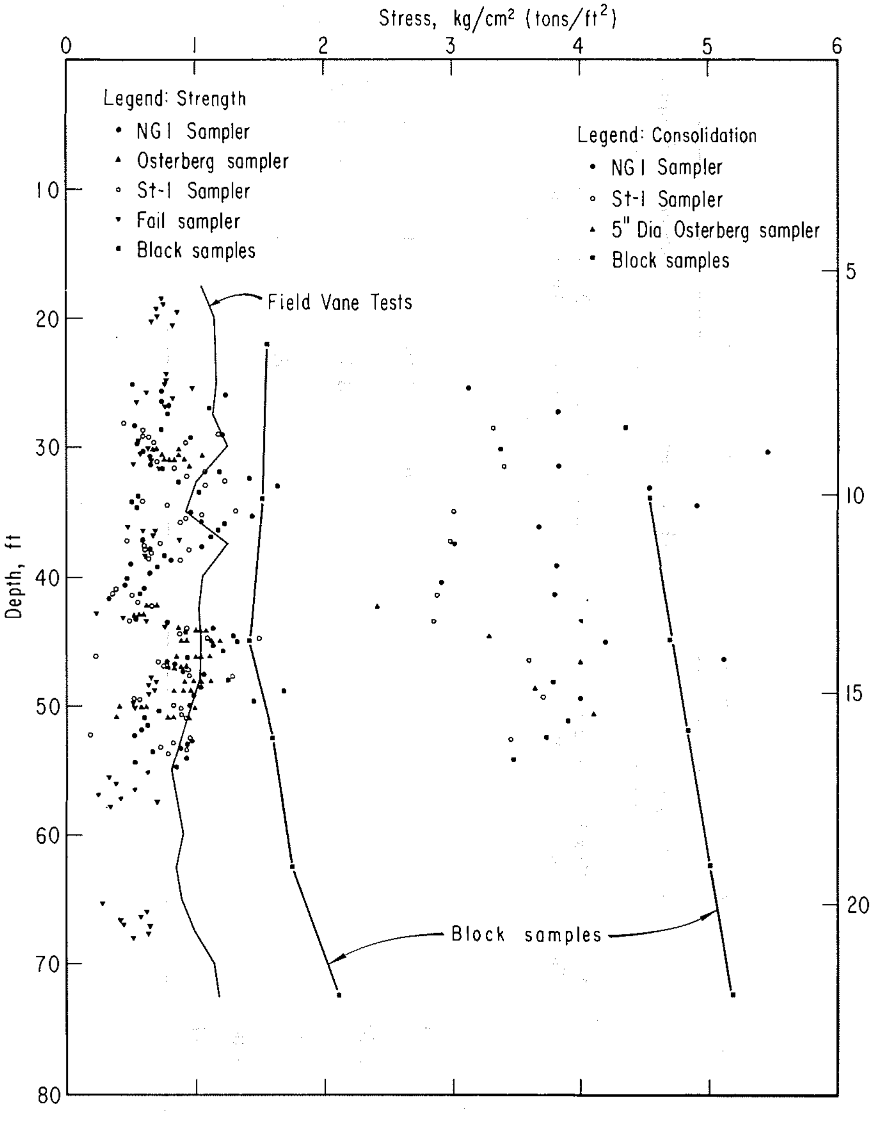

FIG. 3—*Comparison of test results obtained on various sampler types.*

amounted to only half the value obtained in the block sample tests, particularly in the sensitive clay below a depth of 50 ft (15 m). The field vane does not seem to provide a more reliable test method than the samplers although its results are somewhat more consistent [*14*].

As indicated previously, the results of the block samples are considered to be reliable because they agree well with a correlation between surface

TABLE 1—*Comparison of preconsolidation pressures determined on various samples.*

Depth, ft	Block Samples, %/tons/ft²	NGI Sampler			St-1 Sampler			Osterberg Sampler		
		No. of Tests	Max %, tons/ft²	Avg %, tons/ft²	No. of Tests	Max %, tons/ft²	Avg %, tons/ft²	No. of Tests	Max %, tons/ft²	Avg %, tons/ft²
22										
18 to 28		2	3.82	3.48						
34	4.54									
28 to 39.5		8	4.55	3.94	4	3.40	3.18	1	5.45	...
45	4.70									
39.5 to 49		6	5.10	3.96	3	3.60	3.11	4	3.99	3.34
52.5	4.84									
49 to 57.5		4	4.00	3.78	2	3.71	2.58	1	4.10	...
62.5	5.00									
72	5.17									

TABLE 2—*Comparison of undrained strengths determined on various samples.*

Depth, ft	Block			NGI			St-1			Osterberg			Foil		
	No. of Tests	Max Surface, tons/ft^2	Avg Surface, tons/ft^2	No. of Tests	Max Surface, tons/ft^2	Avg Surface, tons/ft^2	No. of Tests	Max Surface, tons/ft^2	Avg Surface, tons/ft^2	No. of Tests	Max Surface, tons/ft^2	Avg Surface, tons/ft^2	No. of Tests	Max Surface, tons/ft^2	Avg Surface, tons/ft^2
22	6	1.68	1.56												
18 to 28	...	...	...	9	1.24	0.66	...	...	...	...	...	...	16	0.98	0.74
34	4	1.60	1.53												
28 to 39.5	...	...	...	29	1.64	0.82	24	1.31	0.82	13	1.06	0.81	16	0.88	0.63
45	5	1.62	1.42												
39.5 to 49	...	...	...	24	1.68	0.88	16	1.49	0.76	32	1.18	0.88	8	0.78	0.59
52	14	2.23	1.60												
49 to 57.5	...	...	...	15	1.46	0.81	11	0.96	0.76	8	0.99	0.69	10	0.63	0.47
62.5	6	2.00	1.76												
57.5 to 67	...	...	...	...	...	...	...	...	...	...	...	...	6	0.70	0.49
72	5	2.19	2.11												
67 to 70	...	...	...	...	...	...	...	...	...	...	...	...	4	0.65	0.55

elevation and strength characteristics established for the Ottawa region [3]. Thus, it is apparent that the process of sampling and vane testing does disturb the soil. It has been suggested by a number of investigators that Leda clay possesses brittle or cemented bonds (Crawford [1], Townsend et al [15]), which are responsible for a significant portion of the undrained strength. LaRochelle and Lefebvre,[3] in a companion paper for this symposium, have indicated that small lateral strains have a great influence on strongly bonded clays. The results of the present investigation tend to support this view, since all the samplers used had some clearance ratio, which would allow some lateral strain. The field vane, through the act of insertion in the undisturbed soil, also causes lateral strain. The sampler with the largest clearance ratio in this investigation was the Swedish foil sampler, and it yielded the most divergent results.

Conclusions

This investigation involved the use of four types of fixed-piston samplers and the field vane in overconsolidated yet very sensitive clay. The performance of the samplers was compared with block samples by measuring the preconsolidation pressure and undrained shear strength.

The results indicate that the process of sampling from a bore hole causes serious disturbance to sensitive clay, leading to large discrepancies in the results of tests conducted on so-called "undisturbed" samples. In many cases, the undrained strength measured on the tube samples are only one half the strength measured on block samples. Other factors that might be involved in highly sensitive clays are disturbance in transporting the sample tube to the laboratory and disturbance in extruding the sample from the tube.

The investigation tends to support the opinion that the lateral strain allowed by the sampler leads to serious disturbance by destroying the brittle bonds in the highly structured clay.

The main conclusion of the investigation is that sampling of sensitive clays can lead to extensive disturbance and must be considered seriously in any geotechnical investigation. At the present time, it would seem that large, undisturbed, block samples are the only ones which can be relied upon consistently.

Acknowledgments

The work described in this paper was the result of the efforts of many staff members of the Geotechnical Section of the Division of Building Research. The writer gratefully acknowledges this assistance, and in

[3] See p. 143.

particular, the efforts of P. M. Jarrett (now at the University of Glasgow).

This paper is a contribution of the Division of Building Research and is published with the approval of the Director of the Division.

References

[1] Crawford, C. B., "Cohesion in an Undisturbed Sensitive Clay," *Geotechnique*, Vol. 13, No. 2, 1963, pp. 132–146.

[2] Crawford, C. B., "Resistance of Soil Structure to Consolidation," *Canadian Geotechnical Journal*, Vol. 2, No. 2, 1965, pp. 90–97.

[3] Crawford, C. B. and Eden, W. J., "A Comparison of Laboratory Results with In Situ Properties of Leda Clay," *Proceedings, 6th International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, University of Toronto Press, 1965, pp. 31–35.

[4] Jarrett, P. M., "Time-Dependent Consolidation of a Sensitive Clay," *Materials, Research and Standards*, Vol. 7, No. 7, 1967, pp. 300–304.

[5] Eden, W. J. and Bozozuk, M., "Earth Pressures on Ottawa Outfall Sewer Tunnel," *Canadian Geotechnical Journal*, Vol. 6, No. 1, Feb. 1969, pp. 17–32.

[6] Pappas, N. D. and Sexsmith, D. P., "Performance Monitoring of a Deep Cofferdam in Sensitive Clay," *Canadian Geotechnical Journal*, Vol. 5, No. 2, May 1968, pp. 80–96.

[7] Kjellmen, W., Kallstenius, T., and Wager, O., "Soil Sampler with Metal Foils," *Proceedings No. 1*, Royal Swedish Geotechnical Institute, Stockholm, 1950.

[8] Bjerrum, L., "Geotechnical Properties of Norwegian Marine Clays," *Geotechnique*, Vol. 4, No. 2, 1954, pp. 49–69.

[9] "Standard Piston Sampling," A Report by the Swedish Committee on Piston Sampling, *Proceedings No. 19*, Swedish Geotechnical Institute, Stockholm, 1961.

[10] Kallstenius, T., "Studies on Clay Samples Taken with Standard Piston Sampler," *Proceedings No. 21*, Swedish Geotechnical Institute, Stockholm, 1963.

[11] Osterberg, J. O., "New Piston Tube Soil Sampler," *Engineering News-Record*, Vol. 148, April 1952, pp. 77–78.

[12] Anderson, A. and Bjerrum, L., "Vane Testing in Norway," *Vane Shear Testing of Soils, ASTM STP 193*, American Society for Testing and Materials, 1956, pp. 54–60.

[13] Hamilton, J. J. and Crawford, C. B., "Improved Determination of Preconsolidation Pressure of a Sensitive Clay," *Papers on Soils 1959 Meetings, ASTM STP 254*, American Society for Testing and Materials, 1959, pp. 254–270.

[14] Eden, W. J., "An Evaluation of the Field Vane Test in Sensitive Clay," *Vane Shear and Cone Penetration Resistance Testing of In-Situ Soils," ASTM STP 399*, American Society for Testing and Materials, 1965, pp. 8–17.

[15] Townsend, D. L., Sangrey, D. A., and Walker, L. K., "The Brittle Behaviour of Naturally Cemented Soils," *Proceedings, 7th International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, Mexico, 1969, pp. 411–417.