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Eden, W. J.

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An Evaluation of the Field Vane Test in Sensitive Clay

by

W. J. Eden

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INTERET DU DISPOSITIF A MOULINET POUR LES ESSAIS EFFECTUES IN SITU DANS DE L'ARGILE SENSIBLE

SOMMAIRE

Depuis 10 ans la Division des recherches en bâtiment du NRC emploie le dispositif à moulinet pour mesurer la résistance au cisaillement des argilesLeda très sensibles que l'on trouve dans l'Est du Canada. Ces argiles, non drainées, ont un taux de surconsolidation variant de 0.3 à 5.0 t/pd^2. Le dispositif est également employé dans les argiles varvées, presque normalement consolidées, que l'on trouve dans le nord de l'Ontario et du Québec. L'auteur décrit sommairement l'expérience ainsi acquise et évalue l'intérêt du dispositif à moulinet par rapport aux autres méthodes d'essai in situ. Pour les argiles molles légèrement surconsolidées et non drainées (résistance au cisaillement inférieure à 0.5 t/pd^2) le dispositif à moulinet a donné des résistances constantes correspondant bien à celles obtenues par d'autres méthodes d'essai in situ. Pour les argiles plus résistantes (surconsolidées de 3 à 5 t/pd^2) la valeur des essais par dispositif à moulinet est contestable.

W. J. Eden[1]

An Evaluation of the Field Vane Test in Sensitive Clay

REFERENCE: W. J. Eden, "**An Evaluation of the Field Vane Test in Sensitive Clay,**" *Vane Shear and Cone Penetration Resistance Testing of In-Situ Soils, ASTM STP 399*, Am. Soc. Testing Mats., 1966, p. 8.

ABSTRACT: For the past 10 years, the Division of Building Research has employed the field vane apparatus to measure the undrained shear strength of the sensitive Leda clays of Eastern Canada, which have an overconsolidation of from 0.3 to 5.0 tons/ft.^{2} The apparatus has also been used in the nearly normally consolidated varved clays of northern Ontario and Quebec. This paper summarizes this experience and attempts to assess the usefulness of the field vane in relation to other field evidence.

For the soft, lightly overconsolidated clays (undrained shear strength less than 0.5 tons/ft^2), the field vane yields consistent undrained strengths which have correlated well with other field evidence. For stronger clays (overconsolidated from 3 to 5 tons/ft^2), the value of field vane tests is questionable.

KEY WORDS: shear tests, soil (material), vane shear test, field tests, clay (material)

The field vane test has gained some prominence as a tool to determine the undrained shear strength of clays, but its reliability has been the object of some controversy. In 1957, ASTM [*1*][2] published a symposium on the vane shear test setting forth many of the arguments for and against its use. The purpose of this paper is to record views on the use and limitations of the test which lead to the opinion that in certain clay formations the field vane is a reliable method of assessing the undrained shear strength of a clay. It is hoped that other opinions will be offered for the establishment of satisfactory working rules and standard procedures.

Many of the desirable features of the test were pointed out in papers presented at the previous symposium [*1*]. Briefly, the two chief advantages are (1) that the test is conducted *in situ* and avoids the problems of stress release and sample disturbance, and (2) that the test is relatively inexpensive compared with conventional tube sampling and laboratory testing.

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

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

The obvious restrictions on the test are (1) it can only be used in rather uniform cohesive soils which are fully saturated, (2) it does not yield samples by which an accurate identification of the materials in a boring profile can be made, and (3) it imposes a failure surface on the soil which may not be relevant to the problem being studied.

Apparatus

The original apparatus used at the Division of Building Research was constructed for use with existing drilling equipment [*2*]. It was subsequently replaced with the "Geonor" apparatus described by Andresen and Bjerrum [*3*]. This equipment eliminates friction between the torque rods and the soil and does not require wash boring and casing. Recently the "Geonor" apparatus has been adapted for use with a truck-mounted hydraulic drill rig, which speeds up the pushing and pulling of the vane housing by placing the ball cone clamp below or above the drill head.

General Use

Experience with vane testing at the Division of Building Research has been almost entirely in sensitive to quick clays. Prior to the use of vane equipment, no consistent strength-depth relationships were observed in Leda clay. Results were generally quite erratic due primarily to sampling difficulties in the sensitive clays. Once the vane apparatus was obtained and a comprehensive vane testing and sampling program undertaken, it was possible to identify several important features of Leda clay.

Field vane tests revealed that the Leda clay had a fissured drying crust extending below the normal oxidation and to depths of about 30 ft in some locations [*4*]. Because of the fissuring, all methods of shear testing are questionable in this zone. Below the fissured-weathered crust, an increase in shear strength with depth was found. Recently the results of the testing program on Leda clays have been summarized by Crawford and Eden [*5*], and it has been possible to show a consistent relationship between surface elevation, preconsolidation pressure, and undrained strength. Shear strength of the intact, unweathered Leda clay in the Ottawa area ranges from 0.2 to 2.0 kg/cm^2, with corresponding preconsolidation pressures from 0.3 to 5.0 $kg/cm.^2$ In general, the Leda clays can be classed as sensitive to quick.

Field vane tests have also been conducted at three sites in nearly normally consolidated varved clays in northern Ontario and Quebec and compared with test results from tube sampling. The varved clays were quite sensitive and difficult to sample.

Table 1 describes 12 sites where the field vane test has been used with supporting information obtained from tube sampling. The first 9 sites are Leda clay sites in the Ottawa area; the last three listed are varved clay

TABLE 1—*Summary of soil properties at 12 sites.*

Site	Description	Surface Elevation, ft	Depth, ft	Undrained Shear Strength, S_u, kg/cm^2	Standard Error, kg/cm^2	Sensitivity, S_t	Averages				
							Natural Water Content, %	Plastic Index, %	Liquidity Index	$-2\,\mu$, %	Wet Density, lb/ft^3
Breckenridge	Uniform lightly overconsolidated clay	330	20 to 100	0.36 to 0.91	± 0.07	20 to 150	79	36	1.4	80	96
Sewage Plant	Highly plastic clay to 50 ft Below 50 ft, extremely sensitive overconsolidated by 4.5 kg/cm^2	171	20 to 70	1.0	± 0.15	25 to 500+	55	19	2.0	66	105
Green Creek Fill	Highly plastic, insensitive silty clay, overconsolidated by 4.0 kg/cm^2	182	20 to 100	0.75 to 1.98	± 0.20	5 to 25	66	40	0.9	70	104
Green Creek Slide	Extremely sensitive clay, overconsolidated by 1.7 kg/cm^2	277	20 to 90	0.64 to 1.02	± 0.12	20 to 500+	69	34	1.7	77	101
N.R.C.	Highly stratified silty clay, extremely sensitive, lightly overconsolidated	310	30 to 60	0.55 to 0.77	± 0.11	15 to 500+	68	20	2.5	66	98
Main St.	Highly plastic clay at surface becoming silty and sensitive with depth	222	15 to 65	0.57 to 1.03	± 0.15	15 to 500+	51	22	1.7	50	112
Gloucester	Sensitive highly plastic clay, overconsolidation 0.3 kg/cm^2	260	10 to 60	0.21 to 0.56	± 0.06	30 to 500+	72	23	2.0	71	99

Kars	Extremely sensitive clay, lightly overconsolidated	280	20 to 50	0.29 to 0.52	± 0.07	25 to 500+	60	20	2.0	60	101
Cumberland	Highly stratified sensitive clay, lightly overconsolidated	180	20 to 75	0.37 to 1.16	± 0.11	30 to 500+	61	25	1.5	74	104
New Liskeard	Finely stratified grey varved clay	724	7 to 46	0.11 to 0.37	± 0.03	6 to 20	71	32	1.6	78	100
Beattie Mine	Grey varved clay becoming siltier with depth	933	17 to 53	0.22 to 0.73	± 0.08	8 to 12	60	33	1.1	78	105
Steep Rock A-2 Shaft	Varved clay with thick clay layers	1288	20 to 61	0.80 to 1.05	± 0.16	...	47	21	1.2	49	110

sites. At each site, sufficient field vane tests were taken below the fissured crust to allow a line of regression to be determined representing the increase in strength with depth. The standard error gives an indication of the dispersion of individual test results about this line.

A study of the laboratory compression tests shows that from each good sample about one test per tube yields a shear strength equivalent to the field vane test. The average of the strength determinations from the tube samples was only about one-half of the field vane strength. The average strengths of the varved clays were in better agreement than for the Leda clays, presumably because the disturbance in the less sensitive soil was less serious.

In the following paragraphs, a more detailed examination of four sites is presented to illustrate the comparison between field vane strengths and undrained strengths obtained from samples.

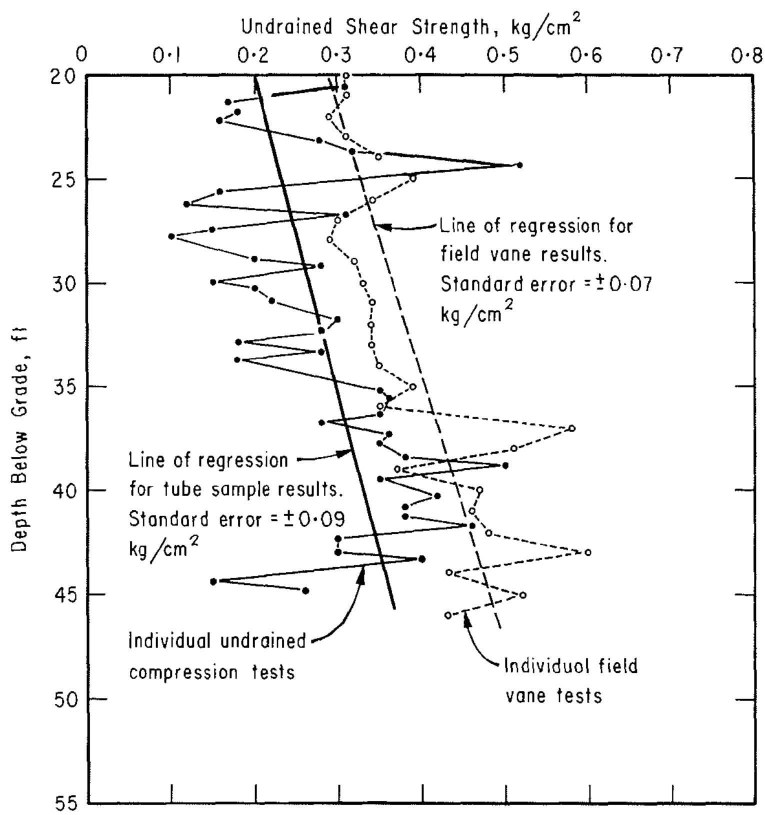

FIG. 1—*Comparison of vane and tube sample results at Kars bridge site.*

Kars Bridge Site

At the Kars Bridge site, a 26-ft fill was constructed for the approaches to a bridge over the Rideau River. The subsurface conditions at the site consisted of about 3 ft of organic silt (which was removed), 5 ft of alluvial material, 12 ft of stiff fissured Leda clay (a former drying crust), and 30 ft of extremely sensitive Leda clay. Several test holes were put down in the area. Two closely spaced borings are used for illustration. From one, continuous samples were taken with the 54-mm Norwegian Geotechnical Inst. piston sampler [*6*], and undrained shear strengths were determined by unconsolidated undrained tests (with confining pressure equal to the overburden pressure) and by unconfined compression tests. In such satu-

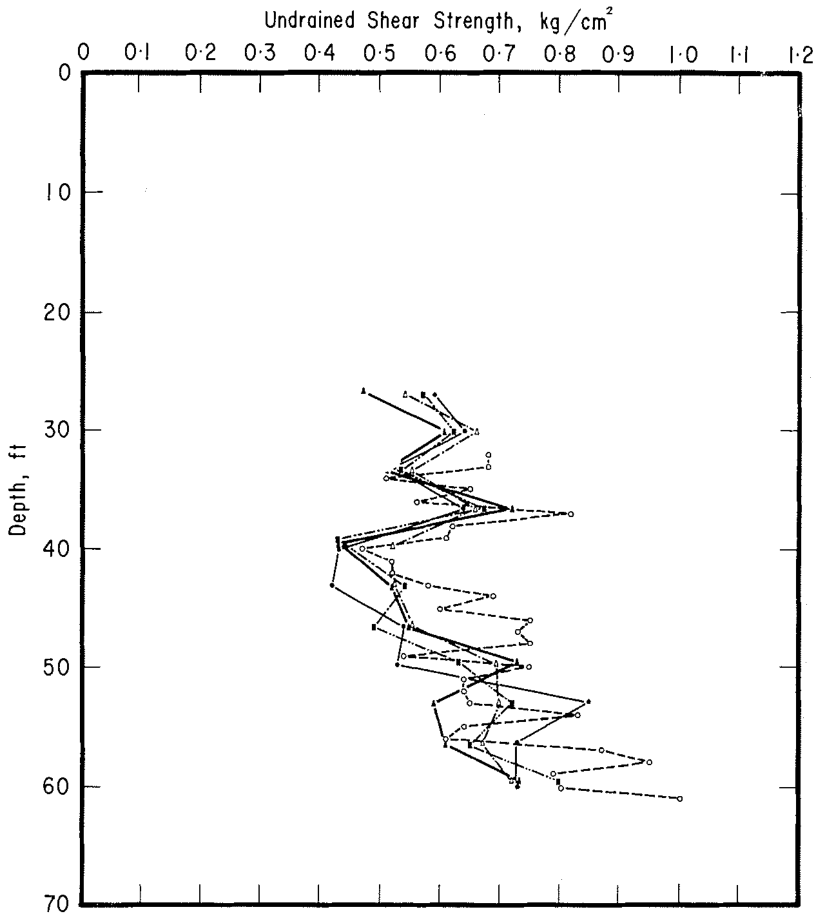

FIG. 2—*Results of 5 vane test holes at NRC site.*

rated clays, no advantage was indicated by the use of the triaxial undrained over the unconfined compression test. In the other hole, field vane tests were made at 1-ft intervals. The results of the two types of tests are shown in Fig. 1. Average results in the form of lines of regression with the standard errors indicate that the vane yields higher undrained strengths with somewhat less scatter than the laboratory tests.

The stability of this embankment during construction was in doubt. A stability analysis based on the field vane strengths had a factor of safety of only about 1.2, and, based on laboratory tests, a failure could be expected. The fact that the embankment has stood for 6 years indicates that in this instance, the field vane strengths were reasonably reliable.

The Kars borings are typical of the agreement achieved between results of field vane tests and laboratory tests in Leda clay. The vane yields higher strengths with more consistent results.

NRC Site

At the Montreal Road Laboratories of the National Research Council, there is a deep deposit of extremely sensitive Leda clay. The clay at this site is highly stratified. A series of field vane tests have been made to check the consistency of the results from one bore hole to the next. Fig. 2 presents the results of the five borings conducted on a 50-ft square. The top 30 ft of the clay is highly fissured, and tests in this zone were conducted only in the first boring. It can be seen from Fig. 2 that the reproducibility is reasonably good considering the stratified nature of the clay.

Sewage Treatment Plant

The Ottawa sewage plant was a unique site in that the Leda clay was overconsolidated by about 4.5 tons/ft.^{2} In spite of the overconsolidation and relatively high undrained strengths, the clay below 50 ft is quick (sensitivities 500 to 1000). During the excavation of pump wells for the treatment plant, it was possible to obtain large block samples of undisturbed clay to a depth of 72 ft. These provided an opportunity to check the undrained strength obtained from both the field vane and tube sampling methods against block samples. The results of this comparison are presented in Fig. 3. Here the field vane gave higher strengths than those yielded from tube samples, but both were considerably below the results obtained from the block samples. Each block sample strength represents the average of six undrained determinations, three by unconfined compression and three by undrained triaxial with confining pressure equivalent to effective overburden pressure. From other evidence in the Ottawa area [5], there is no reason to suspect that the strengths given by the block samples are too high, and it must be concluded that both the vane and tube sampling methods are much too conservative on this site.

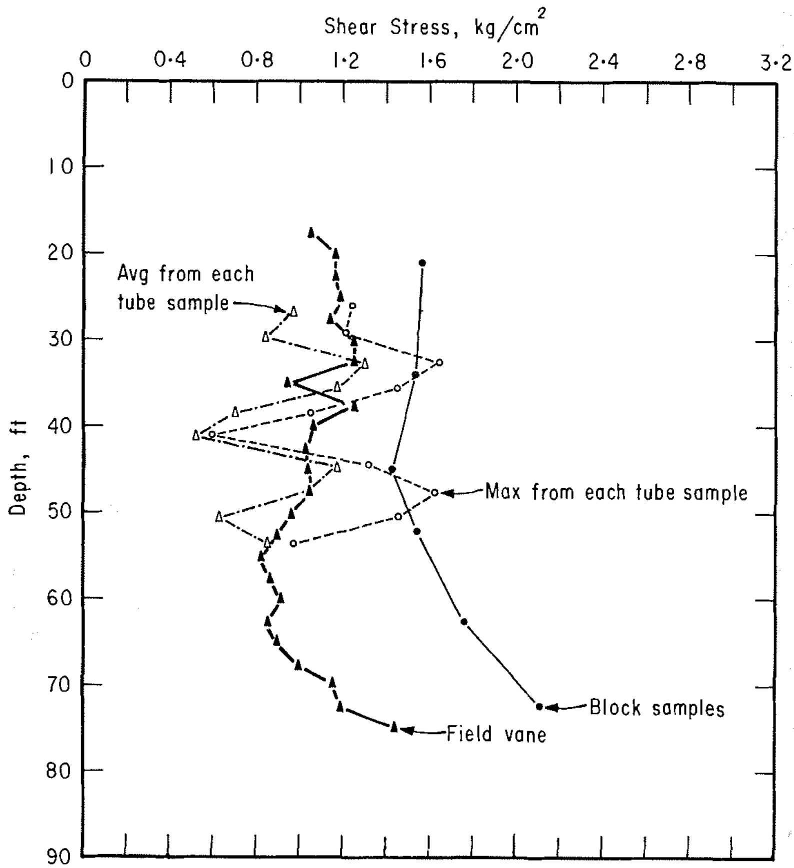

FIG. 3—*Comparison of vane, tube, and block sample results at Ottawa sewage treatment plant site.*

At two other sites in the Ottawa area, it has been possible to obtain block samples of unweathered Leda clay from tunnel excavations. In both cases, the field vane strengths compared closely with the undrained strengths obtained from the block samples. In both cases, the overconsolidation of the clay was only about 1 ton/ft.²

At the sewage plant site, the results obtained with the vane are of questionable value because they are considerably below those obtained from block samples. In spite of this, Fig. 3 demonstrates that the vane gave a somewhat more consistent indication of undrained strength than the thin-wall piston samples.

Sites in Varved Clay

At the three sites involving nearly normally consolidated varved clay, the pattern of more consistent and higher undrained strengths by the field vane over tube sampling methods is repeated. Because of the highly stratified nature of varved clays and the presence of somewhat silty layers, its use is open to more criticism than with homogeneous clays. Townsend [7] has detailed theoretical arguments against the use of the vane in such clays. In spite of this, in a number of cases, the field vane has yielded undrained strengths consistent with the strengths derived from the analyses of failures [*8*]. For example, in measurements made at New Liskeard at the site of a silo failure [*9*], the average field vane strength measured in the failure zone was 325 psf; average laboratory strength in the same zone was 235 psf, and the average of the maximum strengths per sample tube was 295 psf. Safety factors for the analysis based on these strengths were, respectively, 1.0, 0.75, and 0.9.

At the Beattie Mine [*10*] and Steep Rock, it is difficult to assess the reliability of the field vane strengths in comparison to failures, but in both cases more consistent and higher undrained strengths were achieved. In all cases, the varved clays tested were made up of a layered system with both the light and dark layers exhibiting appreciable plasticity and could be termed cohesive soils.

Conclusions

1. For the highly sensitive Leda clays and varved clays described by this paper, the field vane has yielded more consistent and somewhat higher undrained shear strengths than those obtained from carefully taken thin-wall tube piston samples.
2. For the softer clays with an undrained strength less than 0.5 kg/cm^2, the vane strengths have proved to be reasonably reliable in comparison with stability analysis for loading cases.
3. At one site where the Leda clay was appreciably overconsolidated, the field vane strengths were considerably lower than those obtained from block samples. Osterman [*11*] has suggested that the field vane should only be used in "contractant" soils, and it may be that the clay at the sewage treatment plant can no longer be considered contractant.

As the soils below 50 ft were supersensitive, it may be that the insertion of the field vane leads to serious soil disturbance and reduced strengths. This, however, cannot explain the lower results above 50 ft. The clays both above and below 50 ft could be termed brittle (failure strains less than 1 per cent), and the brittleness is a feature which should be considered. The clays at this site were much more brittle than the other sites in Leda clay referred to in Table 1.

It is the author's view that the field vane apparatus is a useful engineering tool for sites featuring soft saturated clays. It offers considerable economy over conventional tube sampling and testing, and in sensitive soils it overcomes to some extent the problems of disturbance in such soils. The field vane should always be supported by geotechnical information obtained by sampling. When the shear strengths are greater than 1 kg/cm^2 or when there is a tendency for the soils to dilate on shearing, then the use of the vane is questionable.

Acknowledgments

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