DISCUSSION

CONTRIBUTIONS FROM SCANDINAVIA

Vane Testing in Norway

Messrs. A. Andresen[1] and L. Bjerrum.[1]—Professor J. Osterberg, Northwestern University, has asked the Norwegian Geotechnical Institute to give a short review of Norwegian experiences, for publication in relation to the "Symposium on In-Place Shear Testing of Foundation Soil by The Vane Method," held at the ASTM Annual Meeting, Atlantic City, N. J., June 17–22, 1956. This paper describes the experience gathered during five years of intensive use of vane testing in Norway. It should, however, be pointed out that the vane was invented and developed in Sweden, and the work done in Norway is, thus, to a high degree based on the Swedish research.

Field of Application

The vane is an instrument for determining the undrained shear strength of saturated clay. This means that the results of a vane test represent the shear strength which can be mobilized if the clay is brought to failure without any dissipation of pore pressures. The vane shear strengths are comparable to the shear strengths determined by unconfined compression tests. The vane however cannot be directly related to the Coulomb parameters C and ϕ in terms of effective stresses if the pore pressures set up during the test are not known.

Due to the time required in fine grained soils for the dissipation of pore pressures set up by construction, where it is in general necessary to consider the stability first, during the construction before any appreciable dissipation and, secondly, when the pore pressures have dissipated and a stationary equilibrium condition is reached, there are, two corresponding groups of stability problems:

1. End of construction stability.
2. Long term stability.

The application of the undrained shear strength as determined by the vane or by unconfined compression tests on undisturbed samples is limited to approaching end of construction stability problems in saturated clays. The reliability of this approach has been clearly illustrated by an analysis of failure of footings, fillings and cuttings which occur during or immediately after construction (Skempton and Golder 1948 (**1**)[2], Skempton 1951 (**2**), Bjerrum and Kjaernsli 1957 (**3**).[3] If the remolded as well as the undistrubed shear strength is determined during the vane testing, the sensitivity of the clay can be calculated.[4]

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[2] The boldface numbers in parentheses refer to the list of references appended to this discussion, see p. 58.

[3] On the other hand, it has been proved by an analysis of slides in natural slopes (Skempton 1955, Bjerrum and Kjaernsli 1957) that a stability analysis based on the undrained shear strength of the clay is a most unreliable procedure for solution of long term stability problems. Only a co-analysis in terms of effective stresses if applicable to this type of problem.

[4] In general, the *in situ* sensitivity determined by the vane is somewhat smaller than found in laboratory samples. This is probably due to the fact that a remolding of a sample in the laboratory is more effective than even 25 revolutions of the vane in the field.

The direct results of vane tests are, thus, the undrained shear strength and the sensitivity of the clay for different depths. These two figures have proved to give a very characteristic description of a clay. From the increase with depth in undrained shear strength it is possible to evaluate if a clay layer is normally consolidated or preconsolidated, and the variation in shear strength and sensitivity gives a picture of the homogeneity of the clay. A high sensitivity is a warning against the troubles which are met with by excavations, piling etc.

Due to the fact that valuable information is obtained by the vane and that vane testing in soft clay, where no casing is required, is relatively inexpensive, the vane has found widespread application in Norway. In the majority of subsoil explorations carried out by the Institute, a relatively great number of vane borings are performed in order to clarify variation in properties of the clay layers. This application of the vane as a sounding instrument permits a reduction of the borings requiring undisturbed sampling, and thus, a reduction on the over-all cost of the investigations. As an illustration of the extensive use of the vane, it can be mentioned that there are 20 vanes in use in Norway today and the number of vane borings carried out by the Norwegian Geotechnical Institute alone exceeds 150 per year. This is, of course, due to the fact that the Norwegian clays are relatively soft. A vane boring to a 15 m depth with determination of the

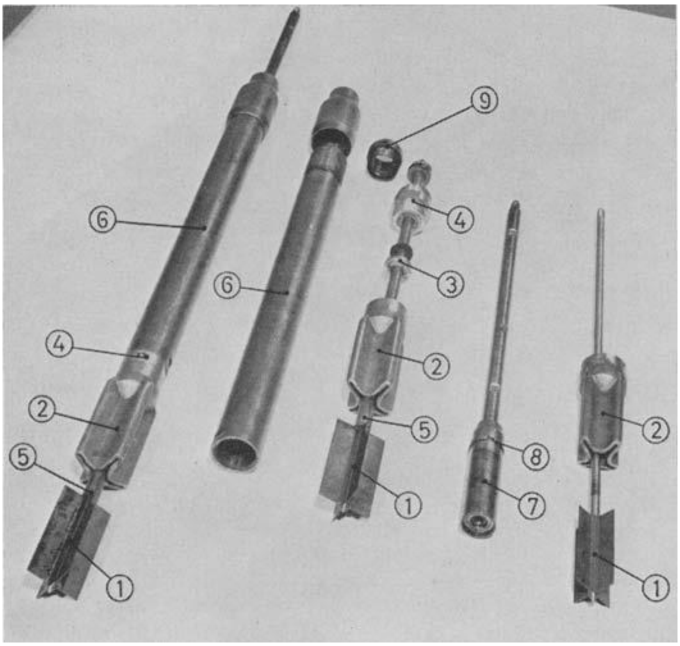

FIG. 1.—The Lower Part of the Vane Equipment.

(*1*) Vane
(*2*) Protection shoe
(*3*) Brass ring
(*4*) Connection piece
(*5*) Protection tube
(*6*) Housing
(*7*) Coupling piece
(*8*) Locking spring
(*9*) Locking sleeve

undisturbed and remolded shear strength at one meter intervals can be performed by two men in less than 8 hr.

Vane Equipment:

A characteristic feature of the vane equipment used in the soft clays in Sweden and Norway, is its use as a penetration device without casing. The lower part of the equipment is forced into the clay with the vane withdrawn into a protection shoe. When the desired depth is reached, the vane is pushed down into a lower position and the shear test is performed in undisturbed clay.

The vane equipment consists of two parts, the lower part with the vane and the instrument. They are connected with one meter lengths of extension rods (ϕ 42 mm OD and ϕ 35 mm ID made of high quality steel) used for forcing the lower part into the clay and with one meter lengths of ϕ 20 mm steel rods for pressing down and rotating the vane. The main part of the lower equipment (Fig. 1) is the vane. The vane is welded on a steel rod and it is exchangeable as it is screwed into a coupling piece (*7*). In order to avoid adherence between the vane rod and the clay during the rotation of the vane, the rod is protected by a protection tube (*5*). To reduce friction in the system the space between rod and protection tube is filled with grease under pressure and a thrust ball bearing is placed between coupling piece and protection tube.

During the penetration of the equipment the vane is withdrawn in the protection shoe (*2*) and locked into this

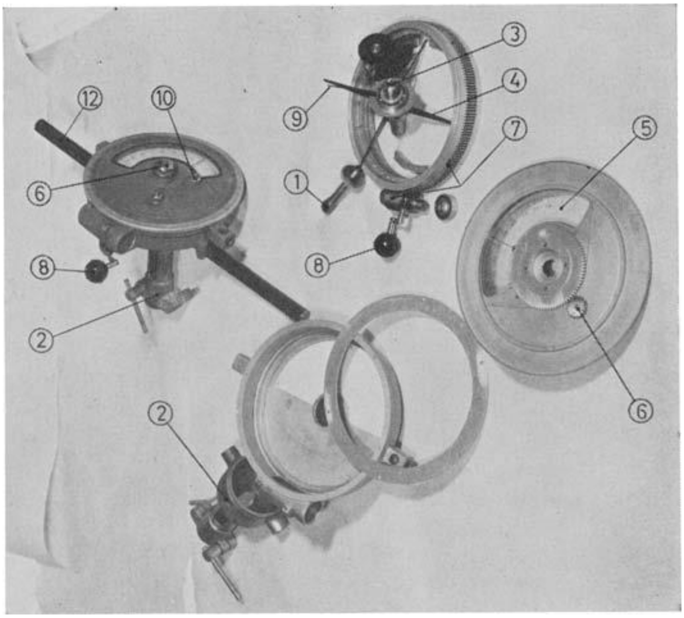

FIG. 2.—The Instrument of the Vane Equipment.

(*1*) Square connecter
(*2*) The lower portion
(*3*) Pivot tap
(*4*) Blade spring
(*5*) Scale
(*6*) Screw
(*7*) Worm wheels
(*8*) Crank handle
(*9*) Pointer
(*10*) Screw
(*11*) Adjusting screw
(*12*) Handle

position by the spring (*8*) being pressed into a slot in the locking sleeve (*9*). The vane is unlocked by a slight blow on the extension rods.

The protection shoe is designed to fit closely around the vane and different shoes are used for different sizes of the vane. This is done in order to remove the clay which might adhere to the blades of the vane when it is retracted into the shoe. A brass ring (3) and a rubber sealing ring prevent the clay from sticking to the protection tube and entering into the equipment during withdrawal of the vane.

The vane is pushed 50 cm below the shoe before a test is carried out. This insures that the vane test is made well below the zone which is disturbed during the penetration of the equipment. Tests have been made in very sensitive clays with two vanes using 35 and 50 cm lengths of the rods. The test with the 50 cm length of the vane rod showed an average 9 per cent higher shear strength than when the 35 cm rod was used.

To minimize the friction between the inner rods and the pipe during measurements, centering guides (brass rings) are installed every 4 m. The straightness of the pipes and the rods is also controlled for every bore hole. Experience has proved that friction between rods and pipes is negligible when measurements are taken on remolded quick clays, the instrument then reads zero.

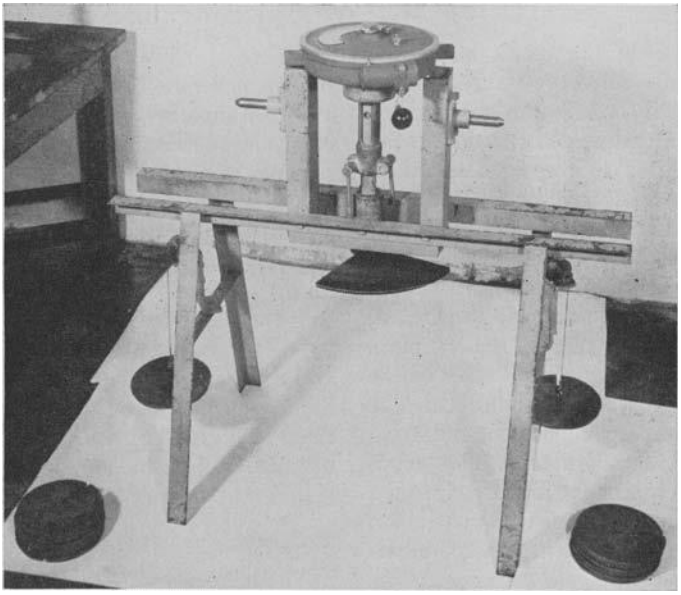

FIG. 3.—The Calibration Apparatus.

The instrument for measuring the torque moment which is applied to the vane is shown in Fig. 2. It is fastened to the extension tubes which again are kept in a fixed position.

The inner rods to which the vane is fastened, are connected to the central axis—the pivot tap— of the instrument by a square connector (*1*). The torque is transmitted to the rods through 4 blade springs, (*4*), one end of the spring being fastened to the central pivot tap (*3*), the other end to an outer ring wheel with worm threads (*7*). The outer ring wheel is rotated by a crank handle (*8*). This arrangement permits the rod to be subjected to a pure torque moment, and evades horizontal forces on the rods, thus reducing the friction.

The test is carried out by rotating the crank handle at the speed of one revolution per sec. Assuming no deformation of the rods this will result in a constant rate of rotation of the vane equal to $\frac{1}{10}$ deg per sec.

The force from the crank handle is, as mentioned, transferred through the blade springs (*4*). The torque moment is proportional to the deformation of the springs and thus to the angular difference between the pivot tap (*3*) and the large worm wheel. The difference in angle is measured by the pointer (*9*) and magnified by the string and the gear wheels. The position of the scale (*5*) can be adjusted by the screw (*10*) on the top plate so that the pointer reads zero before testing. Larger adjustments can be made by tightening or loosening the string by means of the screw (*11*). The maximum torsional moment reached during a test is indicated by a maximum pointer. The pointer is withdrawn after the measurement by the gear arrangements operated by a screw (*6*) on the top plate. Each pair of blade springs can be disconnected for smaller readings, so that greater accuracy is obtained for small moments. This is especially important for measuring the shear strength of remolded sensitive clays.

The vane equipment is constructed for torsional moments up to 600 kg per sq cm. The smallest size of the vane, (width 5, 5 and height 11 cm) corresponds to a shear strength of 9.8 tons per sq m. (= 0.91 tons per sq ft).

To remold the clay, the vane is rotated by means of the handles. In general, the vane is rotated approximately 25 times before the shear strength is measured.

The instrument is calibrated by dead loading in a special calibration apparatus which is shown in Fig. 3.

EXAMPLE OF A VANE TEST

Figure 4 shows an example of the results of a vane test in Oslo. The profile also contains the geotechnical data of the clay as determined on undisturbed samples.

As seen from the figure, the shear strengths found with the vane are slightly smaller than the values determined on undisturbed samples (using a thin-walled, fixed-piston sampler (Vold (7)). This observation is valid for soft and sensitive clays. On the average it is found from a great number of borings that the ratio of the shear strengths measured by unconfined compression tests and by vane tests is 1.12.

Acknowledgement:

The measuring instrument is designed on the basis of experience collected from the use of a Swedish model. It was designed in co-operation with the Swedish and Norwegian Geotechnical Institutes and private firms in Norway. Marstrand & Astrup made the final construction and have put the equipment into production.

The lower part of the equipment with the vane is almost identical to the Swedish model.

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(1) A. W. Skempton and H. Q. Golder, "Practical examples of the Q = 0 analysis of stability of clays," *Proceedings*, International Conference on Soil Mechanics and Foundation Engineering, No. 2, Vol. 2, pp. 63–70 (1948).

(2) A. W. Skempton, "The Bearing Capacity of Clays," *Papers*, Division 1, Building Re-

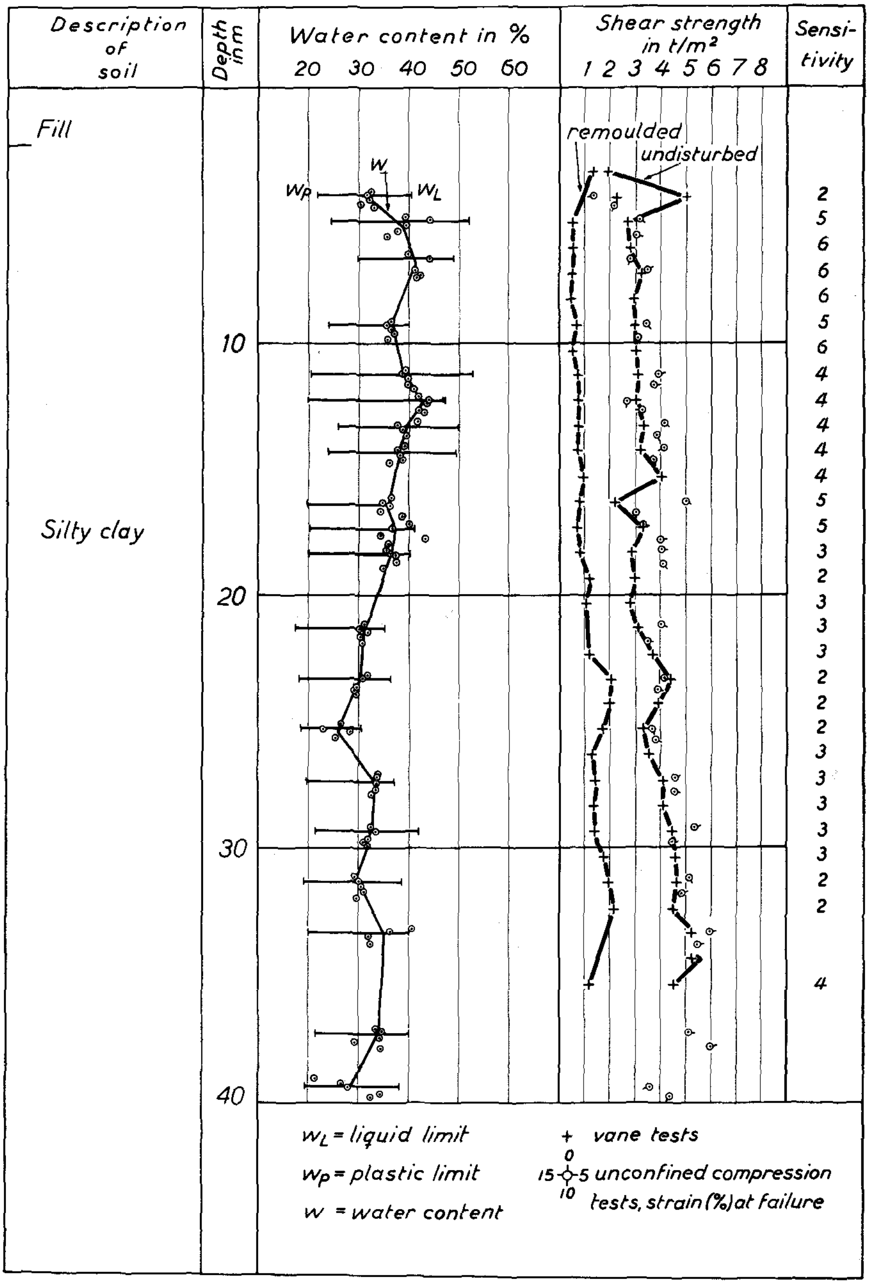

FIG. 4.—Soil Profile with Results of Vane Test.

search Congress, London, pp. 180–189 (1951).

(3) L. Bjerrum and B. Kjaernsli, "Analysis of the Stability of Some Norwegian Natural Clay Slopes," *Proceedings*, International Conference on Soil Mechanics and Foundation Engineering, No. 4, London (1957).

(4) L. Cadling and S. Odenstad, "The Vane Borer," *Proceedings, No. 2,* Royal Swedish Geotechnical Inst., Stockholm, p. 87 (1950).

(5) B. Jakobson, Influence of Sampler Type and Testing Method on Shear Strength of Clay Samples," *Proceedings, No. 8,* Royal Swedish Geotechnical Institute, Stockholm, p. 59 (1954).

(6) A. W. Skempton, "Opening Address," *Proceedings,* European Conference on Stability of Earth Slopes, Stockholm, Vol. 3, pp. 16–20 (1955).

(7) R. Chr. Vold, "Opptaging av uforstyrrede jordprøver-Ramforsøk på stålpeler," *Publication No. 17,* Norwegian Geotechnical Inst., Oslo, p. 22 (1956).

SWEDISH VANE BORER DESIGN

MR. TORSTEN KALLSTENIUS.[5]—When the Swedish Geotechnical Institute started vane borer investigations the equipment was of course of a tentative type. When designing the first recording instrument (shown in Fig. 7 of Proceeding 2 of the Institute) the intention was to make the reading independent of personal errors. It was decided to operate the instrument by means of handles, which has the advantage that the reaction forces from the turning are taken by the operator and not the casing, which makes it possible to measure deformations more exactly.

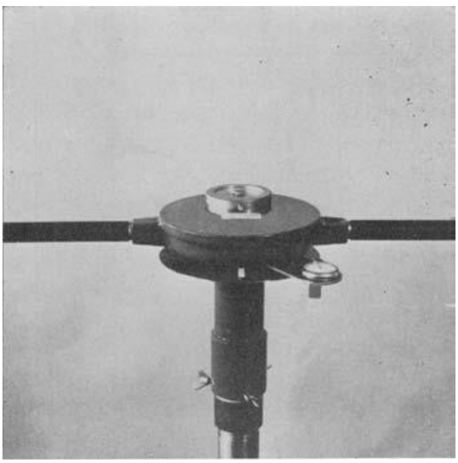

FIG. 5.—Recording Instrument.

[5] Head of Mechanical Department, Swedish Geotechnical Institute, Stockholm, Sweden.

As practical experience soon showed that in most cases only the peak strength value was required, the instrument was redesigned as shown in Fig. 5. The torque is here measured by means of a circular spring which is stressed very little and therefore keeps its calibration values constant for years. It is enclosed in a rugged bronze case of about 10 in. diameter. The torque is read by means of a pointer, which can rotate a full turn. Besides, a maximum pointer remains at the point of maximum torque after the turning force has begun to decrease. On the instrument shown there are still the two turning handles in order to measure deformations of the soil better. There may be cases where deformation measurement is desirable. Such a case for instance is possible if two adjacent soil layers with very different elastic properties are associated in providing for stability.

In Scandinavia there exists a modified type of the instrument described above. Light metal is used for the case and the spring is simplified. This makes the instrument a little lighter but less rugged while the simpler spring is probably not as constant as in the original type. The turning handles are also replaced by a hand-operated worm drive. A similar arrangement has been introduced on some of our own instruments but maintaining the possibility to turn it with

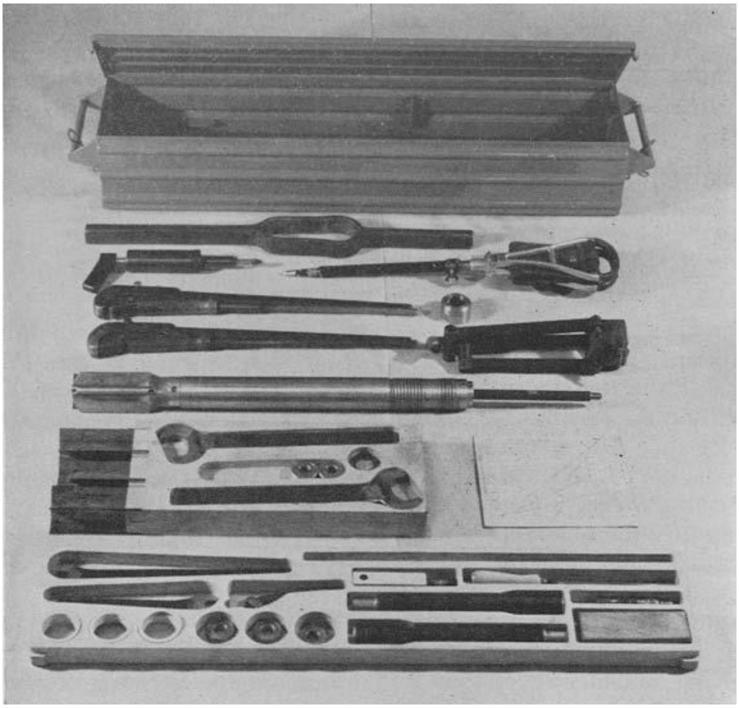

FIG. 6.—Standardized Set of Equipment.

handles, and we think that is the best combination.

In comparison with American equipment, the Swedish instrument is smaller and more compact. We can see no great advantage in using proving rings and dial gages for field mesurements as the rings are bulky and the gages easily corroded.

As to the rest of the equipment, Fig. 6 shows a standardized set. The lowest part of the borer has also been simplified but the turning rods are still protected all the way from the vane up to the instrument. The calibration diagram in Fig. 6 has been substituted for a calibration table which is easier to read than a diagram under conditions in the field. Every instrument is checked and recalibrated twice a year. Although the instruments remain very constant it must not be forgotten that vane tests should

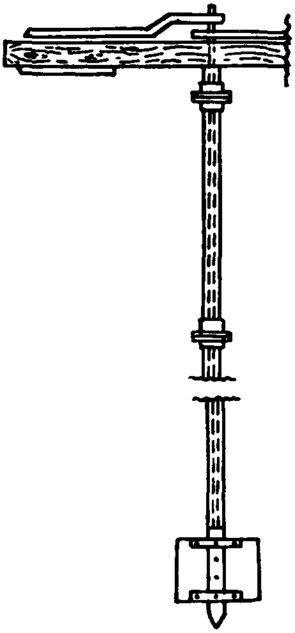

FIG. 7.—Early Vane Borer Apparatus.

be performed with the same care as laboratory tests.

It may interest some readers to see the vane borer that was used as early as 1918–1919 by John Olson in Sweden, for investigations for a foundation for the Lidingö bridge near Stockholm. It is shown in Fig. 7. The main reason why the vane borer was not extensively used in Sweden at that time was the lack of a good theory for evaluating results.

SOME NOTES ON FIVE YEARS EXPERIENCE FROM FIELD VANE TESTS IN SWEDEN

MESSRS. L. CADLING[6] AND G. LINDSKOG.[7]—Field vane tests are used extensively in Sweden. Since 1951 the vane test has been used by the Swedish Geotechnical Inst. as a routine test in consulting work. Six pieces of apparatus are in service and up to the present the test has been used in connection with about 300 consultations, involving various problems of stability.

The test has been used in bearing capacity problems (earth embankments and structures), in problems involving stability of natural slopes, and in problems involving stability of slopes in temporary cuts.

The testing procedure now in use is with few exceptions identical to that described in a 1950 report (**1**),[8] though the apparatus has been rebuilt.[9] When performing a test the stress-strain curve is usually not recorded but only the peak value of the applied torsional moment. Tests for measuring the remolded shear strength are normally performed in connection with all tests.

In our clays we have found the vane strength values to be reliable when applied to the problems mentioned above and when using the $\phi = 0$ method of stability analysis.[10] As to the problem of stability of natural slopes this conclusion may seem remarkable, since recent findings (**2**, **3**) show that stability analysis of such slopes should logically be based on results of drained tests. However, taking the characteristics of our soils into consideration, the remarkable conclusion may be explained. Our soils in which vane tests are performed are with very few exceptions soft normally consolidated or slightly overconsolidated clays (and organic clays) with high plasticity and of marine and lacustrine origin. Investigations by L. Bjerrum (**3**, **4**) indicate that the undrained and drained shear strength of such clays seem to be of the same order of magnitude, which thus may explain the apparently illogical results obtained by vane tests in connection with the stability of natural slopes.

It must, however, always be kept in mind that the vane test, as it is normally performed, is an undrained test (a quick test) and thus strictly is applicable only in cases where the undrained strength is representative of the strength of the soil under the actual condition of loading.

The field of application of vane tests according to the statement above is exemplified below for some typical extreme cases, that is, problems without any drainage and problems with complete drainage in both normally consolidated and typical overconsolidated clays.

When taking the state of consolidation of the clays into consideration, some apparently strange relations between vane shear strength values and corresponding laboratory strength values

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[8] The boldface numbers in parentheses refer to the list of references appended to this discussion, see p. 63.

[9] Torsten Kallstenius, "Swedish Vane Borer Design," see p. 60 of this symposium.

[10] The Swedish Circular arc method.

Type of Problem	Type of Clay	
	Normally Consolidated	Overconsolidated
Short-time bearing capacity (No drainage)	Correct	Correct
Long-time bearing capacity	Conservative	Unsafe?
Slopes of temporary cuts (No drainage)	Correct	Correct
Slopes of long time cuts	Unsafe (Swelling)	Unsafe
Natural slopes	Conservative to correct	Unsafe

may be explained. The tests in the Gulf of Mexico reported by W. Fenske show the consolidated undrained shear strength values to be smaller than the field vane test values. A reverse relation seems to be valid in our clays (1). The clay tested in the Gulf of Mexico is overconsolidated while the clay referred to in Sweden is normally consolidated. Considering the different recompression characteristics of an overconsolidated and a normally consolidated clay when the calculated overburden pressure is applied to the sample the different relations obtained seem to be explained.

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(1) L. Cadling and S. Odenstad, "The Vane Borer," *Proceedings, No. 2,* Royal Swedish Geotechnical Inst., Stockholm (1950).

(2) Various papers and discussions in *Proceedings*, European Conference on Stability of Earth Slopes, Vol. 1–3, Stockholm (1954 and 1955). (Note specially Opening Address and Discussion by A. W. Skempton in Vol. 3.)

(3) Lecture by L. Bjerrum, "Stability of Natural Slopes," held at a meeting at the Swedish Geotechnical Society in Stockholm on Dec. 15, 1955. (Unpublished.)

(4) L. Bjerrum, "Theoretical and Experimental Investigations on the Shear Strength of Soils," Norway Geotechnical Inst., *Publication No. 5,* Oslo (1954).

GENERAL DISCUSSION

MR. WILLIAM S. HOUSEL.[11]—One question I would like to raise has to do with the rate of loading, both in the laboratory and in the field. Mr. Gibbs mentioned in his paper that there was a variation in shearing resistance due to the rate of loading, the rate at which the vane was rotated. In comparison, however, with the laboratory tests, it was not stated what rate of loading was used in the triaxial compression tests or the unconfined compression tests, and what basis there was for comparing them with the rate of loading in the field.

Those who are familiar with the static shearing resistance or yield value test, which is used in the University of Michigan laboratory, know that the observations are extrapolated to a zero rate of deformation. There is a four-to-one ratio between the results from that test and the results from the unconfined compression test which is run in a 5-min loading period.

In other words, from the 5-min or rapid unconfined compression test, the shearing resistance value is four times the value which we obtain from the ring shear test in which the rates of deformation are extrapolated to zero rate of deformation.

These observations show that there is a wide variation in shearing resistance due to rate of loading that must be accounted for in some way. That four-to-one ratio as shown in the data which

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