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SYMPOSIUM ON IN-PLACE SHEAR TESTING OF SOIL BY THE VANE METHOD

INTRODUCTION

By J. O. Osterberg[1]

The purpose of this symposium is to acquaint the profession with a rather new tool for obtaining the in-place shear strength of medium to soft clay soils and organic silts. The Scandinavian countries have pioneered the development of the vane test and now use it widely in virtually all exploratory work where shear strengths are needed. There has been no attempt to standardize the test, although as this symposium will show much has already been accepted as standard. An additional purpose of the symposium is to bring in focus the developments made to date, so that the possibility of standardization can be considered. If it is possible to standardize certain elements of the vane test without stifling or restricting further progress through research and experimentation, then it would be desirable to do so. The following paragraphs constitute a summary of the development and principles of the vane test as an introduction to the papers and discussions which follow.

Briefly, the vane consists of four thin rectangular blades or wings brazed or welded to a small circular shaft making a cross in section (Fig. 1). Generally the height of the vane is about twice its width. The vane is pushed into the soil and then twisted until the soil is ruptured. A cylindrical piece of soil very nearly the height of the vane and of the same diameter is thereby ruptured. From the maximum moment needed to rupture the soil and the surface area of the cylinder, the shear strength at rupture is easily computed.

It appears that the vane-borer was developed simultaneously in Sweden by John Olsson in 1928, and in Germany, as evidenced by a German patent dated 1929. Little work was done on the vane until 1947, when the Swedish Geotechnical Inst. designed several improved vanes and used them on numerous projects. This culminated in a comprehensive report by Cadling and Odenstad, in 1950 (**1**).[2] About the same time Skempton (**2**), in England, designed and used a vane borer and the British Army designed and used one for shallow testing. Since that time, a number of publications covering vane testing have appeared, but all have based their actual testing on the original development of the Swedish Geotechnical Inst.

Method of Advancing Vane:

The vane can be used in a hole which is advanced by augering, washing, or rotary

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[2] The boldface numbers in parentheses refer to the list of references appended, see p. 7.

drilling. The hole may be cased or uncased. The vane is inserted in the hole and extension rods are added to the vane shaft until it reaches the bottom of the hole. The vane is then pushed into the soil without twisting, a sufficient distance to place the vane in soil undisturbed by boring operations. Various papers report distances of between $1\frac{1}{2}$ to 3 ft below the bottom of the hole, $1\frac{1}{2}$ ft being most commonly used. The vane rods are then twisted at the surface and the torque measured.

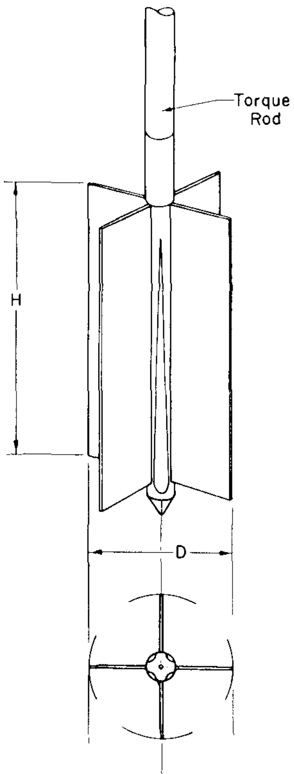

FIG. 1.—The Vane, Consisting of Four Thin Rectangular Blades or Wings Brazed or Welded to a Small Circular Torque Rod.

The vane can also be used in soft clays without drilling a hole by forcing the vane and rods into the soft soil. In this case the vane fits in a vane guard which is connected to an outer casing or pipe inside of which is the torque rod connected to the vane. The device is pushed into the soft clay to $1\frac{1}{2}$ ft above the depth at which the soil is to be tested. Then the vane is pushed out of the guard into the soil $1\frac{1}{2}$ ft. The soil is then tested by applying a torque at the ground surface. After the maximum torque is reached and the torque reading remains constant or drops as rotation continues, the maximum torque is recorded and the clay is remolded by turning the vane rapidly through twelve or more revolutions, the test is then repeated, thus obtaining the remolded strength. The vane is then retracted into the guard by pulling up the torque rod. The entire assembly is then pushed down to $1\frac{1}{2}$ ft above the depth for the next test. The process is then repeated. For many soft soils it is possible to proceed in this way for depths up to 50 ft. In some soils the resistance to penetration becomes so great that after 15 or 20 ft the vane must be removed and casing inserted. The vane can then proceed continuously ahead of the casing until the resistance gets too great. The vane must then be removed, the casing advanced and cleaned out, and the vane reinserted.

The vane test can be used in a cased hole alternately with sampling, but must then be removed after each test. It is better to make at least one exploratory hole close to one vane test in a given area. It is still better to make sufficient exploratory borings to construct a geologic profile so that an intelligent vane boring program can be set up. It would be a dangerous practice to make only vane tests in a given area without also obtaining samples to indicate what type of soil is being tested.

Size of Vane:

Swedish tests on the size of vane indicate no difference in results for various ratios of height to diameter of vane. This is so provided the vane is not so long compared to its diameter that the shaft has to be made large enough to take the increased maximum torsional stress and thus cause disturbance in the soil. Tests made on clays with height, H, over diameter, D, ratios of 1, 2, and 3 showed no difference in results. An H/D ratio of 2 was adopted and has been followed by virtually everyone using a vane. Sizes of up to 4 in. in diameter have been used, and although there are no specific tests to show that for an H/D ratio of 2 the results are independent of diameter, it is believed that such is the case. However, the author suggests that to avoid disturbance of the soil to be tested, the area of the vane section be not greater than 10 per cent of the area of the circular section it shears thus avoiding serious soil disturbance due to the displacement of the soil.

Calculation of Shear Strength:

In calculating the shear strength, it is generally assumed that the cylindrical surface failed has a diameter and height equal to that of the vane. This was shown to be true by Swedish experiments (1) made on sand and clay by carefully cutting away the soil half way down the vane and observing the failure surface. It is assumed that the shear stress is uniformly distributed on the cylindrical surface and on the ends of the cylinder. Since the ends have a different strain at the edge than near the center at failure, the shear stress may not be uniform. However, for an assumed linear distribution of maximum at the edge and zero at the center, the calculated shearing strength for a vane of $H/D = 2$ is only 3.6 per cent less than for a uniform distribution of stress. Furthermore, the tests already referred to for $H/D = 1$, 2, and 3 showed no difference in shear strength when computed on the basis of a uniform distribution of stress on the ends. Therefore, for this assumption and for an $H/D = 2$, the shearing strength is:

$$S = \frac{6}{7} \times \frac{T_{max}}{\pi D^3}$$

where T_{max} is the maximum torque, and D is the diameter of vane.

Measurement of Torque:

The torque applied to the vane must be applied from the surface through a shaft. Since the shaft is protected from soil friction by an outer casing and must be guided by bearings, the friction caused by the bearings must be negligible or allowed for in a calibration. When the rod is shoved ahead 1½ ft without a protecting casing, a calibration must be made with the device in soil with a dummy rod without the vane on the end to obtain the correction for soil friction resisting twisting of the portion of the rod in direct contact with the soil. This correction also includes bearing and rubbing friction. With the latest Swedish and Norwegian designs, this is not necessary since when the vane is pushed into the soil a thin tube sheaths the rod and does not turn when the inner torque rod with the vane on the end is turned. (This feature has been patented by Cadling.) Furthermore, the rubbing parts are well lubricated by means of grease fittings so that the friction is negligible, and therefore no calibration is necessary.

The torque has been measured by various means. The most simple device is a torque wrench, but this results in bending as well as twisting of the torque rod. It is also difficult to apply the torque uniformly at a prescribed rate using a torque wrench. The author considers a torque wrench a crude and unreliable method for measuring torque. The author was informed verbally that SR-4 strain gages have been used on the torque rod just above the vane to measure the torque applied to the vane. This has the advantage of eliminating measuring any frictional torque on the rod above the point of application of the SR-4 gages but has the disadvantage of lowering wires in the hole with the vane and of taking precaution to protect the gages from electrical shorts due to moisture and physical damage. What appears to the author to be the most practical and simple method is the one developed in Norway in which the torque rod extending to the surface is attached to two steel blades which are in turn connected to the outer rim of a circular housing. (See discussion by Andresen and Bjerrum).[3] By means of a small crank with a worm gear, the torque can be applied at approximately the correct speed (that is, 0.1 deg per sec) by turning it at 1 revolution per second. A small clicker gives an indication for each revolution. The torque meter can also be turned by two rods or arms that can be attached 180 deg apart on the housing. A direct reading calibrated dial on the housing gives the torque directly.

Rate of Application of Strain:

Swedish tests (1) were made using different rates of application of torsional strain. Rates from 0.1 to 1.0 deg per sec were used and it was found that at 1.0 deg per sec the strength was about 20 per cent higher than at 0.1 deg per sec. By extrapolating the strength rate of loading curve through zero rate, it was found that the 0.1 deg per sec rate caused only a few per cent error. Furthermore, this was the slowest rate at which the load can be applied practically by hand turning and corresponds to a test taking from 2 to 15 min depending on soil type and strength. Skempton (2) came to much the same conclusions by making a large number of vane tests at the same depth in the field and unconfined compression tests in the laboratory from the same location and depth. Both types of tests were made at test times ranging from 1 min to 50 min. He found that the laboratory and field strengths had the same relationships with time of test and concluded a 3- to 10-min vane test gave values consistent with conventional unconfined compression tests. Therefore, 0.1 deg per sec has been followed by virtually all vane test users, with a few reporting 0.2 deg per sec.

Stress-Strain Curve in Shear:

It is possible to calculate the shear modulus from the torque-angle of twist relationship. If a cylinder of infinite extent and an elastic soil mass is assumed it can be shown from consideration of equilibrium and elasticity that the shearing modulus is equal to one half the slope of the initial straight line portion of the shear stress-angle of twist curve. Since the cylinder tested is not infinite, the relationship is not exactly true, but the Swedish publication (1) has shown that for a sphere twisted in an elastic mass, the relationship is $\frac{1}{3}$ instead of $\frac{1}{2}$. The actual relationship for a cylinder of limited length should therefore be in between, but close to the $\frac{1}{2}$ relationship.

There is difficulty in measuring the shear modulus practically in the field due to the angle of twist of the torque shaft itself. The instrument must therefore be calibrated so that for a given length of torque rod, the angle of twist of the rod with no movement of the vane is known. This can be subtracted from the total angle measured in the field to find the net angle of twist of the vane. When the vane is used at depths of 20 to 50 ft, the angle of twist of the rod is so many times the angle the vane has rotated that the accuracy is extremely poor and the measurements become meaningless. Practically no experimental work has

[3] See p. 55.

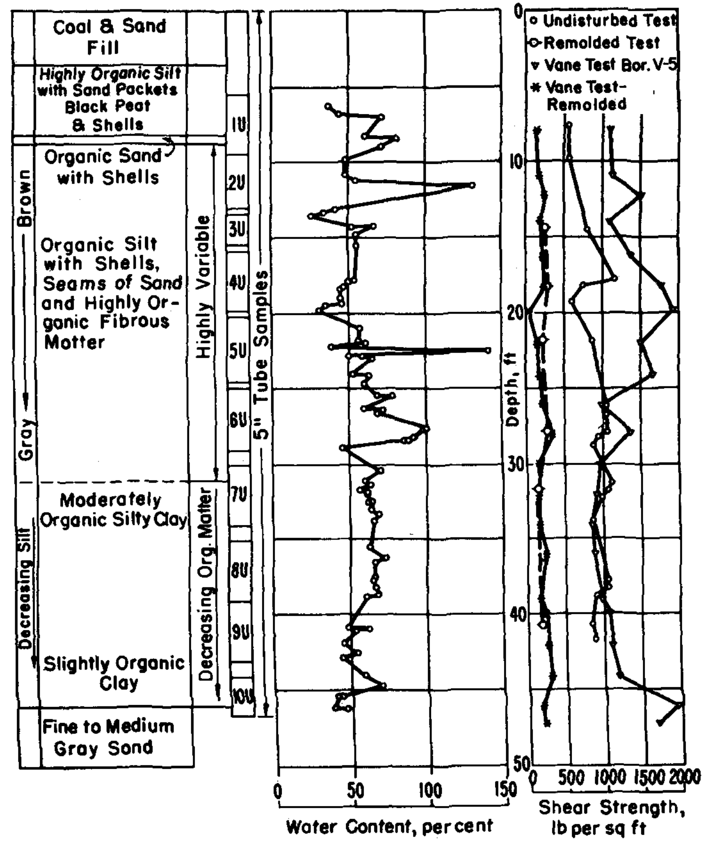

FIG. 2.—Shear Strength *Versus* Depth for a River Deposit, Milwaukee, Wis. Results of Field Vane Tests and Laboratory Unconfined Compression Tests are Compared.

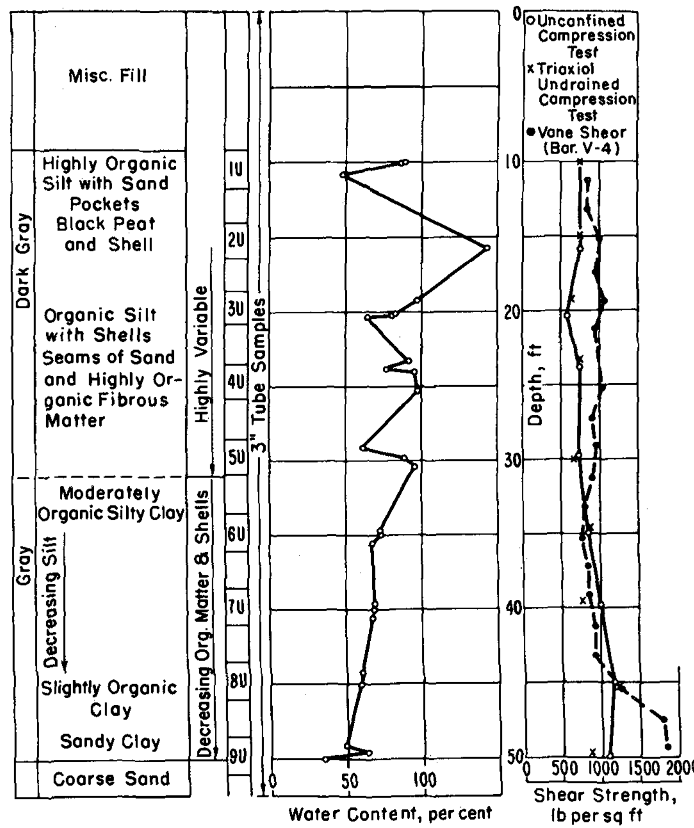

FIG. 3.—Shear Strength *Versus* Depth for a River Deposit, Milwaukee, Wis. ($\frac{1}{4}$ Mile from that of Fig. 2). Results of Field Vane Tests and Laboratory Unconfined Compression Tests are Compared.

been done to determine the in-place shear modulus by this method. Thus the vane has been limited to date to use in determining the maximum shear resistance of soil *in situ*.

Factors Limiting the Validity of the Vane Test Results:

1. As in undisturbed soil sampling, precautions must be taken to avoid disturbing the soil to be tested. If used in a bore hole, the advancing of the casing and drilling operations must not cause soil disturbance below the bottom of the casing at the depth to be tested. Also the vane itself must not cause disturbance when it is pushed into the soil to be tested. One of the virtues of this test is that it shears a cylindrical piece of soil of which only a small portion of the failure surface is near the edge of the vane blades.

2. The presence of stones in the soil near the vane or interfering with the surface of the cylinder to be sheared will of course affect the results. Similarly, silt and sand layers and lenses, will affect the test results. It is therefore important that sufficient samples are taken for inspection to provide a basis for interpreting the results.

3. It should be pointed out that the vane test measures the shear strength in a vertical direction, and therefore should not necessarily check the results of compression tests on unisotropic soils in which failure occurs on an oblique plane.

4. The vane test measures the undrained shear strength under existing stresses due to the weight of the overburden.

Results of Field Tests:

Swedish, Norwegian, and English investigators have reported that up to depths of about 40 ft, the shear strength as determined by unconfined compression tests agree reasonably well with the strength as determined by vane tests. But at greater depths the vane gives results increasingly greater with depth than the unconfined tests. This has generally been attributed to reduction in strength due to increasing sample disturbance with depth. Recently Lauritz Bjerrum[3] obtained excellent checks of both tests to depths up to 100 ft. He attributes the good results to very careful sampling and sample handling procedure.

Figures 2 and 3 show the results of some recent tests performed under the author's direction in Milwaukee, Wis. The results are from two sites in the same river valley less than one half mile apart. Figure 2 shows the results of unconfined compression tests on samples taken with a 5-in. hydraulic piston sampler (3) compared with results of vane tests taken in a boring only 3 ft away. The soil is slightly over-consolidated. It is seen that in the upper part, the vane tests yield results that are more than double the unconfined compression tests whereas in the lower part there is fair agreement between the two types of tests. On the other hand, the agreement between the vane strength and laboratory unconfined strength on remolded samples is good for the entire depth. This may be explained by the fact that the upper part had many sand seams and horizontal layers of fibrous material, thus being stronger when confined *in situ* than in an unconfined compression test, whereas the lower part was a uniform clay without sand seams. Unfortunately, no specimens remained after the testing program to test triaxial specimens, drained or undrained.

In Fig. 2, a comparison is also made with two borings only a few feet apart. The samples were taken with a similar hydraulic piston sampler except that in this case the samples were 3 in. in diameter. The soil is normally consolidated. Here also agreement is good in the lower part but poor in the upper part. In this case, a few undrained triaxial tests were made under a lateral pressure approximately equal to the overburden pressure and these tests check the unconfined tests and not the vane tests. Here again in the region where the tests do not agree, the soil has many shells, sand seams, and organic fibres.

REFERENCES

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

(2) A. W. Skempton, "Vane Tests in the Alluvial Plain of the River Forth Near Grangemouth," *Geotechnique*, Vol. 1, No. 2, p. 111, London (1948).

(3) J. O. Osterberg, "New Piston-type soil Sampler", *Engineering News Record*, April 24, 1952, pp. 77–78.