Evaluation of the Laboratory Vane Shear Test

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A comparison was made between the laboratory vane strength and the unconfined compression strength of several remolded soils. It was found that a constant ratio of unconfined compressive shear strength to the vane shear strength resulted for each soil and this ratio varied from 0.6 to 1.4 for the soils tested. A relationship between the ratio and the plasticity index of the soils was noted. Soils with a low plasticity index generally had a low ratio. The ratio increased and then became relatively constant with increasing plasticity indices.

The effect of vane size, rate of shear, and aging of the remolded samples before testing was studied. Pocket penetrometer tests were also made on each of the samples tested.

•WITH THE PRESENT expansion of the highway construction program, the highway engineer is frequently required to locate and build highways and, particularly, interchanges over poor, submarginal lands and sometimes even swamplands. One problem in designing interchange embankments over soft soils is the determination of the initial shear strength of the foundation soil. This shear strength may be estimated from results of the standard penetration test, obtained during subsurface investigations, or measured directly by the field vane test. In general, however, the initial shear strength of the foundation soil is based upon laboratory unconfined compression tests of undisturbed samples. In cases where the undisturbed samples are very sensitive, or so weak they fail under their own weight, another type of test is needed.

The Materials Research Division of the Bureau of Public Roads purchased a laboratory vane shear device (Fig. 1) for testing very soft soils directly in the sampling tubes. The test is made by inserting the vane into the sample, measuring the resistance to rotation, and from this, calculating the shear strength. This device was evaluated by comparing the shear strength obtained with that obtained using the unconfined compression test.

Initial tests indicated that the laboratory vane shear test and the unconfined compression shear test did not yield the same shear strengths for identical remolded specimens of soil. In an attempt to explain this difference, additional tests were run on both undisturbed and remolded soils. The effects of aging of the samples before testing, the rate of shear, and the vane size were studied for the remolded soils.

A few researchers have compared the shear strength obtained with the field vane, the laboratory vane (undisturbed sample left in the tube when tested), and the undisturbed, unconfined compression tests (1, 2). Generally, the field vane test gives the greatest strength, the unconfined compression test the least, with the results of the laboratory vane test falling in between. Gray (1) believed that for the sensitive clays he tested, the difference was due to disturbance in obtaining the samples and in preparing the unconfined compression test specimens. Fenski (2) found that consolidated undrained triaxial shear tests gave results close to the field vane test. For this reason he concluded that the difference between the field vane and the unconfined compression test was largely due to the different stress conditions created by removing the soil from the ground.

Paper sponsored by Committee on Stress Distribution in Earth Masses.

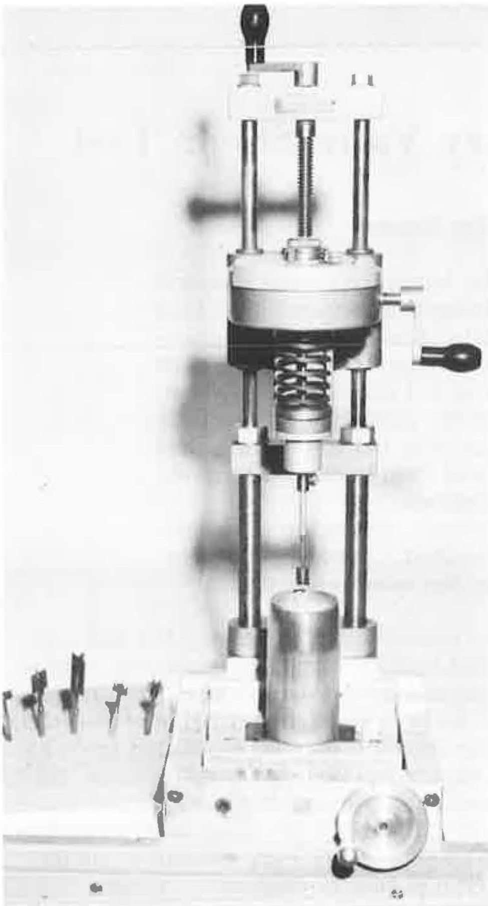

Figure 1. Laboratory vane shear apparatus.

VANE SHEAR APPARATUS

The vane shear apparatus used for this study (Fig. 1) is equipped to measure both torque and rotation of the vane in degrees. Torque is applied to the vane through a calibrated spring by rotating the crack handle. The base of the apparatus was replaced by a clamp to hold the sampling tubes. The vane normally used consists of four blades, each ½ in. high and ¼ in. wide.

CALCULATION OF SHEAR STRESS

The surface of rupture and the possibility of progressive failure for the vane test have been studied for sand and clay by Swedish researchers (3). Their study was conducted by placing wetted tissue paper, with a pattern marked on it, on the surfaces of the samples. The distortion of the pattern was observed as the vane test progressed. It was concluded that for the sand and clay tested, the surface of rupture was a circular cylinder, with the diameter, D, equaling that of the vane, and that any progressive character of failure was slight and did not appreciably affect the test results.

In calculating the vane shear strength, S, in the present study, it was assumed that the failure surface was the circular cylinder of revolution created by rotating the vane. The shear stress was assumed to be constant along the vertical surface and to have a linear distribution on the ends varying from zero at the center to maximum at the edge. The resulting formula for the shearing strength is

$$S = \frac{2\,T_{max}}{\pi D^2 (H + D/4)} \tag{1}$$

in which T_{max} is maximum torque, D is diameter or overall width of the vane, and H is height of the vane.

The unconfined compressive shear strength was computed using the conventional expression

$$S = \frac{Q_u}{2} \tag{2}$$

in which Q_u is the unconfined compressive strength, defined as the maximum applied load divided by the average cross-section of the specimen.

SOIL PREPARATION AND INITIAL TESTING

The soils tested in this study consisted of four clays, two silty clay loams, a clay loam, a loam and two sandy loams. A summary of the tests performed and the mechanical properties of the soils are given in Table 1.

The soil to be used for the remolded tests was air dried, pulverized to break up clay lumps and generally sieved through No. 10 sieve to remove coarse particles. One exception, a silty clay loam, was sieved through No. 4 sieve. Water was then added and thoroughly mixed with the soil to bring it to the selected moisture content. The mixture was stored in a moist cabinet at least 24 hr before molding and testing.

The remolded specimens were prepared in a mold 2 in. in diameter by 5 in. long. The soil was added to the mold in small increments and manually tamped with a ¾-in. diameter wooden rod. The density of duplicate specimens could be reproduced within a range of 1.0 pcf by this method. The vane shear tests were generally performed on these specimens while still in the mold. The vane was inserted into the soil until the top of the vane was approximately ½ in. below the top of the specimen. After the vane test, the specimens were pushed from the mold and trimmed to a 4-in. length for the unconfined compression test. The tests listed under Group A in Table 1 were made by this procedure. It was found that for each soil molded into test specimens at moisture contents approximately between the plastic and liquid limits, the ratio of the vane shear strength to one-half the unconfined compression strength (UC) was constant; this ratio, however, varied from soil to soil between 0.6 and 1.4 (Table 1). Typical test results for one soil, showing this constant ratio, are plotted in Figure 2. Duplicate tests were made on this soil to evaluate different vane designs and resulted in seemingly excessive replication at each of the three moisture contents at which specimens were molded.

Four possible causes for the different shear strengths measured by the vane and unconfined compression tests are: (a) nonuniformity of soil structure, that is, particle arrangement and moisture distribution within the specimen; (b) variations in pore pressure developments during shear; (c) progressive failure in the vane test; and (d) effects of testing procedures. To investigate the effects of these factors, additional tests were made.

Structure

Any nonuniformity of structure or strength within the test specimen would be reflected in the vane-UC ratio. This ratio would be greater than one because the vane shears the soil specimen along a fixed surface, whereas the unconfined compression test allows the soil specimen to shear along the weakest surface. Shearing along a fixed surface tends to give an average shear strength, whereas shearing through the weakest part gives the minimum strength.

It was hypothesized that a remolded test specimen has a less uniform structure than an undisturbed test specimen. If this were so, the vane-UC ratio for the specimens of remolded soil would be greater than that for the specimens of undisturbed soil. This hypothesis was investigated using samples of an undisturbed silty clay (Test 10a of Group B) that were obtained from a 12-ft excavation by means of 3- and 6-in. sampling tubes. Vane shear tests were run on this material while still in the tubes. Unconfined compression specimens, 2 in. in diameter by 4 in. long, were trimmed and tested. The vane-UC ratio for this undisturbed soil was found to be about 0.90. This material was then thoroughly remolded and tested (Test 10b). The resultant ratio was about 1.2. This larger vane-UC ratio for the remolded soil appears to support the hypothesis that remolded samples are less uniform than undisturbed samples.

As a further check of the effect of structure uniformity on the vane-UC ratio, the effect of age of the specimen after molding was studied. A remolded sample possibly will become more uniform with age, thereby increasing in unconfined compressive strength and lowering the vane-UC ratio. This was investigated for specimens of clay loam and clay, which were molded at one time, immediately pushed out of the mold, wrapped in aluminum foil, and stored in a moist cabinet until they were tested.

Figures 3a and 4a show strength as a function of curing time and Figures 3b and 4b show the corresponding changes in the vane-UC ratio. Both the vane and the unconfined

TABLE 1

SUMMARY OF SOIL TESTS AND PROPERTIES

Group	Type of Test	Test No.	Ratio of Vane Shear to ½ Unconfined Compressive Strength	Ratio of Pocket Penetrometer Shear to ½ Unconfined Compressive Strength	No. Samples Tested	Moisture Content, w (%)	Dry Density (pcf)	Basic Soil Properties							
								Liquid Limit	Plastic Limit	Plasticity Index	Clay (< 0.005 mm)	Silt (0.074-0.005 mm)	Sand (2.0-0.074 mm)	Classification: AASHO	Classification: USDA Texture
A	Determination of vane-UC ratio (remolded soils)	1a	1.0	1.5	54	37.0-44.0	73.5-80.6	51	30	21	44	49	7	A-7-5(15)	Silty clay loam
		2a	1.4	1.5	22	20.3-35.5	83.2-97.9	48	20	28	37	23	40	A-7-6(13)	Clay loam
		3a	0.7	2.3	6	33.6-34.3	79.3-80.6	41	35	6	4	33	63	A-5(1)	Sandy loam
		3b	0.8	2.0	3	33.6-35.1	80.7-82.9	36	28	8	22	34	44	A-4(4)	Loam
		5	1.3	1.6	3	35.9-36.0	89.1-89.8	49	33	16	83	10	7	A-7-6(12)	Clay
		6	1.4	2.1	3	47.8-47.9	71.7-71.8	88	41	47	92	7	1	A-7-5(20)	Clay
		7	1.25	1.5	3	64.0-65.0	59.6-61.1	89	34	55	77	12	11	A-7-5(20)	Clay
		8a	0.6	2.1	8	24.7-24.8	98.0-100.7	30	24	6	15	18	67	A-2-4(0)	Sandy loam
		9a	1.3	1.7	3	33.9-34.0	85.9-87.0	55	25	30	83	13	4	A-7-6(19)	Clay
B	Determination of vane-UC ratio (undisturbed soil)	10a	0.9	1.1	5	46.2-47.9	109.7-112.0	46	24	22	46	52	2	A-7-6(14)	Silty clay loam
		10b	1.2	2.0	7	44.8-46.3	110.4-118.5	46	24	22	46	52	2	A-7-6(14)	Silty clay loam
C	Rate of shear	2f	1.4	—	10	25.0-31.6	89.7-98.7	41	19	22	37	23	40	A-7-6(10)	Clay loam
		8b	0.5-1.0	2.3	8	22.1-22.6	101.9-102.7	30	24	6	15	18	67	A-2-4(0)	Sandy loam
D	Effect of age	2d	1.3-1.4	—	6	26.2-26.7	95.5-96.3	41	19	22	37	23	40	A-7-6(10)	Clay loam
		2e	1.4-1.5	—	9	24.9-25.8	96.9-97.5	41	19	22	37	23	40	A-7-6(10)	Clay loam
		9b	1.2-1.4	—	11	32.0-33.0	87.7-87.9	55	25	30	83	13	4	A-7-6(19)	Clay
E	Effect of vane size	1c	1.1	1.7	18	38.1-38.9	78.2-82.9	51	30	21	44	49	7	A-7-5(8)	Silty clay
		2b	1.3	1.3	54	24.9-34.8	84.3-98.9	41	19	22	37	23	40	A-7-6(10)	Clay loam
F	Effect of testing procedure	2c	1.3-2.7	1.3-2.2	8	19.0-21.4	102.3-107.3	41	19	22	37	23	40	A-7-6(10)	Clay loam

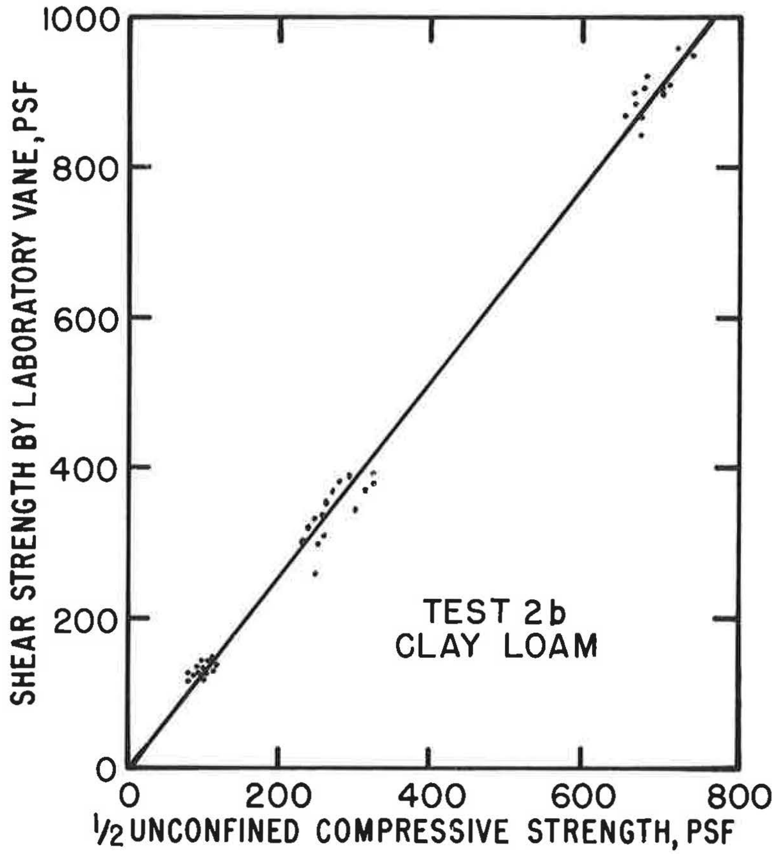

Figure 2. Vane shear vs one-half unconfined compressive strength.

compressive strengths tend to increase with curing time. However, the unconfined compressive strength increases at a more rapid rate, resulting in a decreasing vane-UC ratio. This tendency is more pronounced for the clay loam than for the clay. The strength ratio decreases from about 1.47 at zero time to about 1.33 at 39 days for the clay loam (Test 2e) and from about 1.37 at zero time to about 1.22 at 39 days for the clay (Test 9b). Based on these results, it appears that a remolded soil does gain in uniformity with age and thereby reduces the difference between the shear strengths measured by the two tests.

Pore Pressure

The second factor investigated was the possibility of pore-pressure buildup during shearing. This was investigated indirectly by studying the effect of rate of shear. The rate of shear for the vane test was maintained constant by rotating the crank handle approximately 1 rpm. This resulted in an almost constant rate of stress increase and very little strain as the load increased. As the load approached the shear strength of the soil, a constant rate of strain of approximately 0.2° per sec resulted.

The effect of shear rate was investigated by varying the rate of shear at failure between 0.1° and 1.0° per sec (Group C, Table 1). A clay loam (Test 2f) showed no measurable differences in strength for this range of shear rates. However, Figure 5 shows that a loam (Test 8b) gave a vane-UC ratio of 0.6 at 0.2° per sec and 1.0 at 1.0° per sec. At rates slower than 0.2° per sec, a constant ratio of slightly lower than 0.6 resulted. This apparent constant ratio could be due, in part, to the difficulty

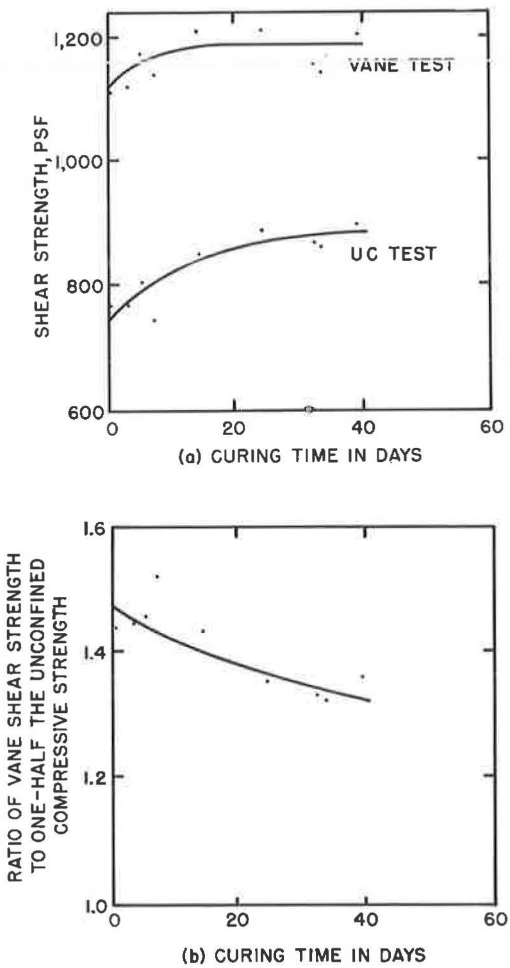

Figure 3. Effect of curing time on shear strength of remolded clay loam specimens (Test 2e).

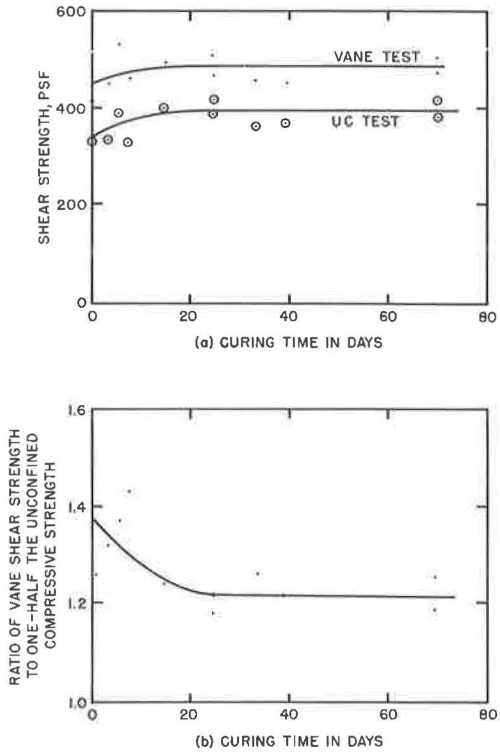

Figure 4. Effect of curing time on shear strength of remolded specimens (Test 9b).

in manually rotating the crank at a constant rate at these slow speeds, resulting in a variability in readings. Because 0.2° per sec rotation gave the minimum strength, this rate was considered satisfactory for all tests.

Because the loam is a dilatant soil, negative pore stresses may be induced during shear deformation. The negative pore-water stresses would create or increase normal pressure on the rupture surface. This would, in turn, possibly increase an intergranular friction force, resulting in an increased shear strength with increased rate of shear.

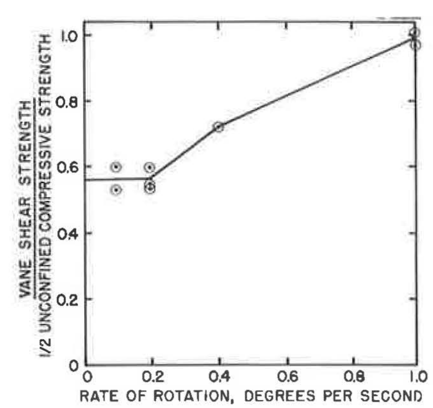

Figure 5. Effect of rate of rotation on vane-UC ratio for sandy loam (Test 8b).

Progressive Failure

The third factor, the possibility of progressive failure in the vane test, was also studied indirectly. If a progressive failure was taking place in the vane test, a six-bladed vane would create a larger shear surface and result in a higher shear strength than a two- or four-bladed vane.

The vane supplied consisted of four blades, each with a height of ½ in. and a width of ¼ in. Two- and six-bladed vanes were also constructed and tested. The six-bladed vane gave average strength values 9 percent greater than the two-bladed vane, whereas the four-bladed vane gave values 2 percent greater. In soft silty soils, the six-bladed vane caused significant compression of the soil during insertion. The effect of this disturbance on the measured strength is unknown. The effect of length of blades was also studied. Vanes with blades 1.0 and 2.0 in. long were built and the strength values were compared with those obtained with the original vane with ½-in. blades. The calculated shear strength values were essentially equal.

Because the six-bladed vane did give strength values slightly greater than the four- and two-bladed vanes, some progressive failure seemed to be taking place.

Effect of Testing Procedure

The fourth factor that possibly affects the shear strength as measured by the vane and the unconfined compression test is the testing procedure used.

Because the vane and the unconfined compression tests both were often run on the same test specimen, there was a possibility that disturbance by the insertion of and testing with the vane would reduce the unconfined compressive strength. To investigate this, duplicate samples not tested by the vane were periodically tested using the unconfined compression test. Strengths obtained by the two methods checked very closely and indicated that the insertion of the vane made no significant difference.

To determine any changes in strength due to removing the soil from the mold, duplicate specimens were tested with the vane in the mold and after removal from the mold. The specimens removed from the mold prior to testing were wrapped in aluminum foil and held by hand while the vane test was run using the normal procedure. No measurable difference in shear strengths was observed for the soils tested inside and outside the mold at moisture contents between the plastic and liquid limits.

Although the vane-UC ratio was constant for each soil within its plastic range, it increased as the moisture content decreased below the plastic limit. This may be due to crumbling of the soil and subsequent reduction of the unconfined compressive strength. When the vane test was conducted on these drier specimens after removal from the mold, the specimens tended to crack, resulting in a reduced vane shear strength. The vane-UC ratio then approached the constant value obtained for the soil at higher moisture contents.

POCKET PENETROMETER TESTS

In conjunction with the laboratory vane test evaluation, shear strength values were obtained using a commercially manufactured "pocket penetrometer." This pocket-size device is used to measure the resistance of a soil mass to the penetration of a 0.245-in. diameter rod at ¼-in. penetration. Pocket penetrometer tests were usually made with each vane shear test. The ratios of the average shear values obtained from the pocket penetrometer to the values obtained from the unconfined compression tests varied from 1.3 to 2.3 (Table 1). The relationship between this ratio and the plasticity index is shown in Figure 6.

MODE OF FAILURE

The wide variation in the vane-UC ratio, from 0.6 to 1.4, indicates that there is a basic difference in the mode of failure between the two tests. Figure 7 shows that the vane-UC ratio is related to the plasticity index. As the plasticity index increases, the vane-UC ratio increases to a value of about 1.4. For a plasticity index of 14, the ratio is 1.0.

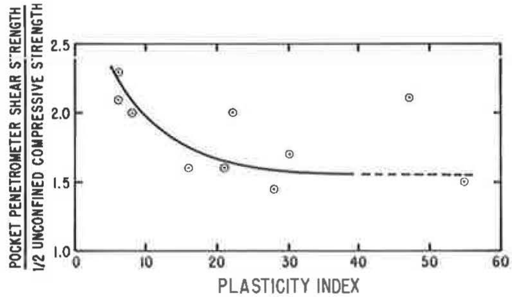

Figure 6. Pocket penetrometer-UC ratio vs plasticity index.

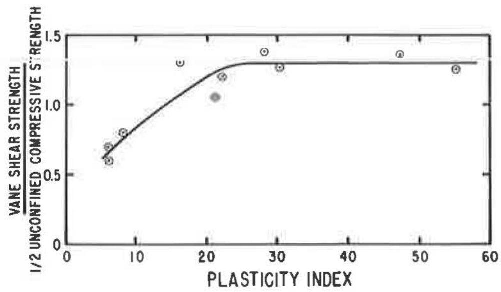

Figure 7. Vane-UC ratio vs plasticity index.

Test specimens with nonuniform structure, water content and density tend to give vane-UC ratios greater than 1.0. It is likely that as the plasticity index of the soil increases, the uniformity of the molded test specimen decreases. For highly plastic soils, the average strength measured by the vane exceeds that measured by the unconfined compression test by 40 percent.

The vane-UC ratios less than 1.0, indicating greater shear strengths by the unconfined compression test, may be due to the inclusion of an intergranular friction component mobilized in the unconfined compression test but not in the vane test. Figures 8a and 8b represent the theoretical mode of failure for the vane and the unconfined compression tests, respectively. In the vane test, if the normal pressure, σ, induced during shear is zero, the shear strength would be a function of cohesion only and would not be affected by intergranular friction. In the unconfined compression test, the shear strength is a function of both cohesion and friction. It is reasonable to expect that as the plasticity index of the soil becomes smaller, the frictional component will increase in significance and result in smaller vane-UC strength ratios.

If the vane measures cohesion only, a useful Mohr diagram can be plotted using results of the vane and the unconfined compression tests. By using the vane-measured strength at a zero normal stress and the Mohr circle determined by the unconfined compression test, the envelope was established as shown in Figure 9.

To check the validity of these envelopes, the resistance to penetration of the penetrometer was compared with that computed using the envelopes. The penetrometer resistance was calculated by Terzaghi's formula (6),

$$F_{Dr} \leq \pi r^2 \; (1.3\, c N_c + 0.6\, \gamma r N_\gamma) \qquad (3)$$

in which

F_{Dr} = critical load on a circular footing in lb;
r = radius of footing in ft;
c = cohesion in psf from vane shear test;
N_c, N_γ = bearing capacity factors dependent upon angle of internal friction, ϕ, from unconfined compression test; and
γ = unit weight of soil in pcf.

The theoretical mode of failure for the pocket penetrometer is shown in Figure 8c. A comparison of the computed penetration resistance with the measured forces is given in Table 2. The reasonably good agreement indicates that the Mohr envelopes may be correct.

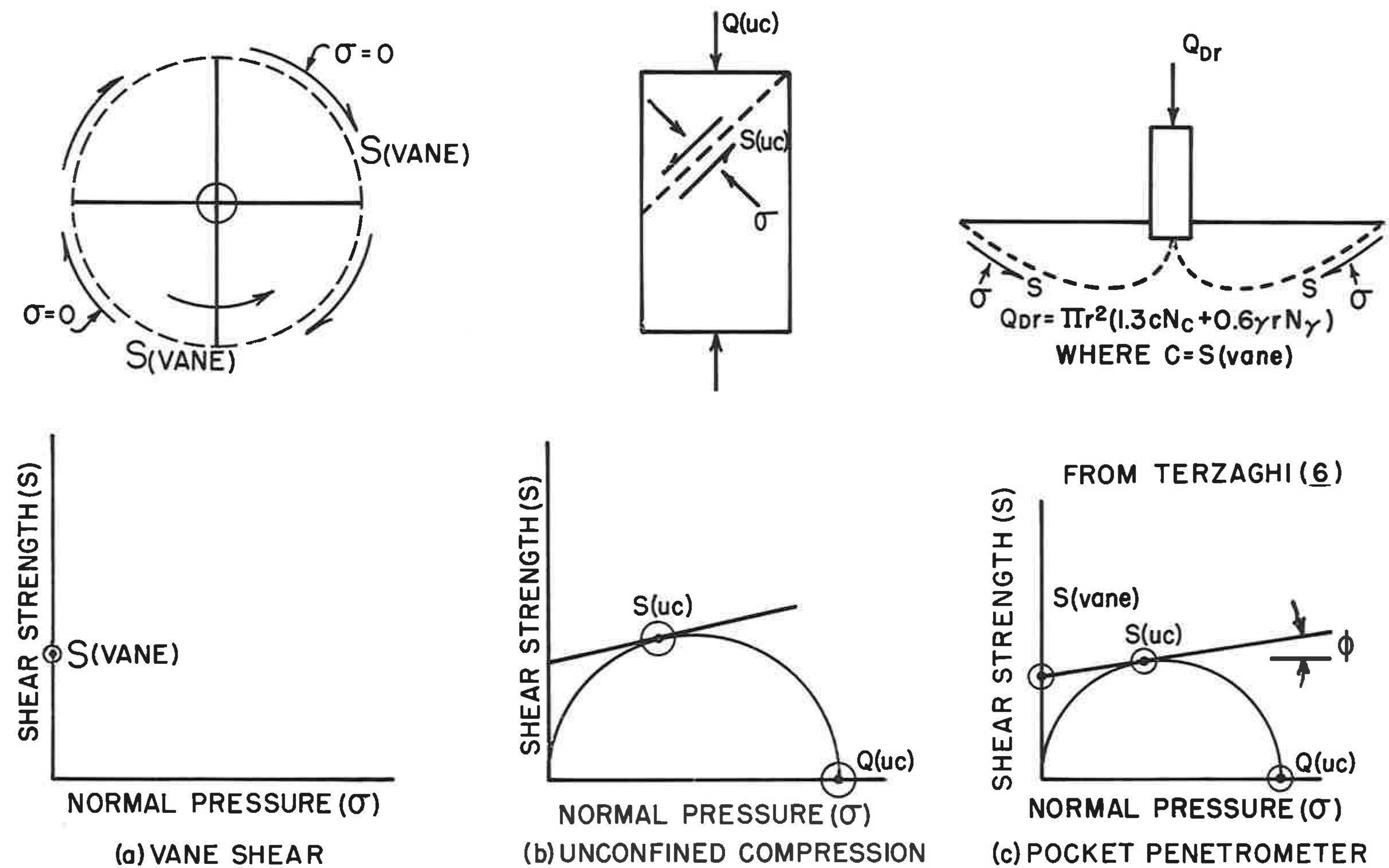

Figure 8. Theoretical modes of failure.

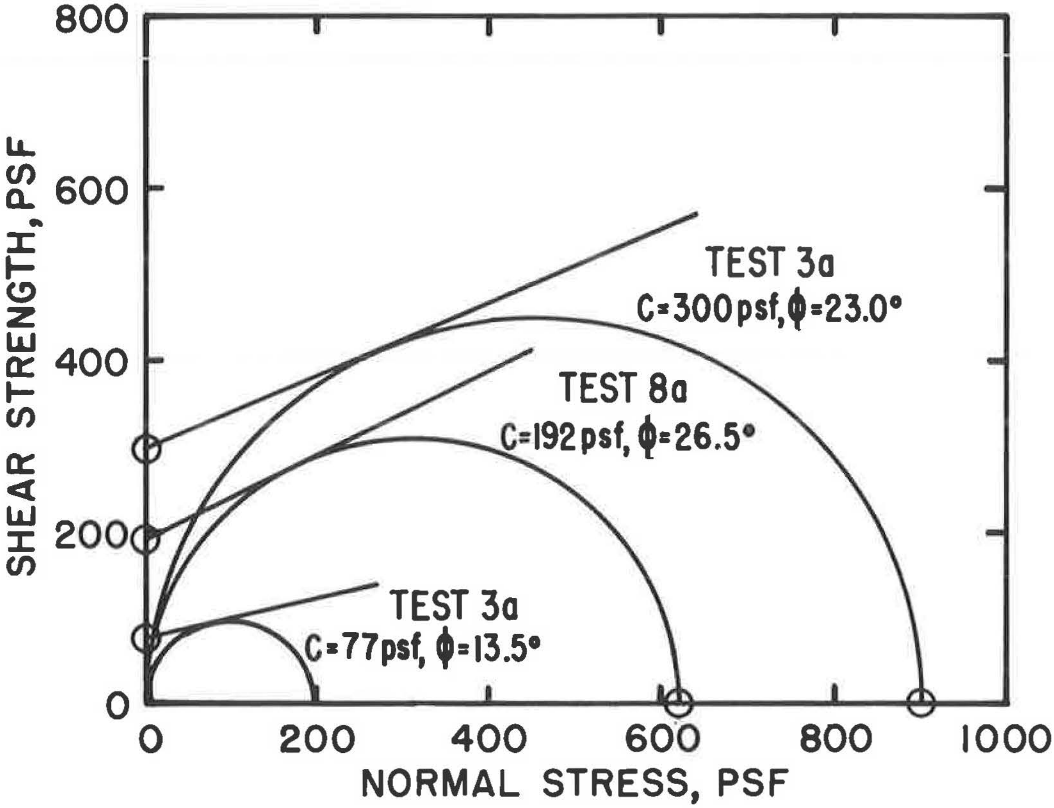

Figure 9. Graphical interpretation of shear strength measured in vane shear and unconfined compression tests.

TABLE 2

MEASURED AND COMPUTED FORCE TO INSERT POCKET PENETROMETER

Soil Test No.	Cohesion, c (psf)	Angle of Inter-granular Friction, φ (deg)	Required Force (lb)	
			Measured	Computed[a]
3a	300	23.0	3.50	3.00
3b	77	13.5	0.62	0.43
8a	192	26.5	2.27	2.24

[a]From Terzaghi's formula.

SUMMARY

Laboratory vane shear and unconfined compression tests on a variety of fine-grained soils, molded into test specimens at moisture contents between the plastic and liquid limits, showed that the ratio of the vane shear strength to one half the unconfined compressive strength for a given soil was constant. This vane-UC ratio varied from soil to soil, ranging from 0.6 to 1.4. Soils with plasticity indices of less than 14 had vane shear strengths less than the unconfined compressive shear strengths, whereas soils with plasticity indices greater than 14 had vane shear strengths greater than the unconfined compressive shear strengths. Possible reasons for this include:

1. A remolded soil with a high plasticity index probably has nonuniform structure. Because the specimen in the vane test fails along a fixed surface and that in the unconfined compression test fails in the weakest area, nonuniformity of structure causes the vane strength to be higher in relation to that of the unconfined compression test. The vane-UC ratios of the undisturbed soil increased from 0.9 before remolding to 1.20 after remolding. The vane-UC ratio also decreased as the age of the specimen increased. The structures of undisturbed specimens and specimens aged after remolding probably were more uniform than those of specimens immediately after remolding, causing the lower vane-UC ratio.
2. A soil with a low plasticity index probably has an intergranular friction force that is mobilized in the unconfined compression test but not in the vane shear test. This results in low vane-UC ratios for such soils.

The buildup of pore-water pressure in the vane test was studied indirectly by the effect of shearing rate on the vane-UC ratio, but the results were inconclusive. However, increasing the rate of rotation of the vane for a soil with a low plasticity index did cause an increase in the shear strength. Because the soil tested was dilatant, negative pore-water stresses were probably induced during the shear deformation. This negative pore-water pressure contributed to the increase in shear strength. No such effect was noted for clays.

The length and the number of blades made little difference on the results of the vane test for the soils tested.

The difference noted by other researchers between the unconfined compressive shear and the vane shear strengths may be due to differences in the modes of failure rather than in the actual shear strength of the soil.

The shear strength values obtained with the laboratory vane shear device appear to be reliable. The ease of testing and the relatively small degree of disturbance to the specimens make this a desirable test, especially for soft, sensitive soils.

REFERENCES

1. Gray, H., "Field Vane Shear Tests on Sensitive Cohesive Soils." ASCE Proc., 81: paper 755 (July 1955).
2. Fenske, C. W., "Deep Vane Tests in the Gulf of Mexico." ASTM Spec. Tech. Publ. 193, Symposium on Vane Shear Testing of Soils (Nov. 1957).
3. Cadling, L., and Odenstad, S., "The Vane Borer, an Apparatus for Determining the Shear Strength of Clay Soil Directly in the Ground." Royal Swedish Geotechnical Inst., Stockholm, Proc., 2 (1950).
4. Darienzo, M., and Vey, E., "Consistency Limits of Clay by the Vane Method." Proc., HRB, 34: 559-566 (1955).
5. Skempton, A. W., "Vane Tests in the Alluvial Plain of the River Forth near Grangemouth." Geotechnique, 1: 2 (Dec. 1948).
6. Terzaghi, K., "Theoretical Soil Mechanics." John Wiley & Sons, New York (1943).

Discussion

NYAL E. WILSON, McMaster University, Canada.—Goughnour and Sallberg proposed two hypotheses regarding the research work on the laboratory vane shear test. These hypotheses are concerned with (a) the influence of pore-water pressures and (b) the effects of progressive failure. Some interesting research work has been conducted on the laboratory vane shear test and the results of this work substantiate the findings of Goughnour and Sallberg.

This research involved using the laboratory vane shear apparatus in dilatant soil; the soil used was a medium-fine silt. The rate of testing was accurately controlled by a variable-speed motor and the vane blade was instrumented so that pore-water pressures could be measured on the shear surface (Fig. 10). The pore-pressure measurements were taken by welding hypodermic tubing to the edge of one of the vane blades; the end of the tubing was slotted and covered by a No. 200 mesh screen.

Influence of Pore-Water Pressures

As in the research by Goughnour and Sallberg, it was found that the torque applied to the vane shaft was dependent on the speed of testing. Figure 11, showing torque vs testing speed for vane tests in silt, indicated that a higher torque was associated with higher testing speeds. The value of the torque was overestimated by about 25 percent when tested at the usual speed in the laboratory. This overestimation was related to the particular torsion spring used in the test. The deformation of the soil was dependent upon the speed of testing, i. e., the angular velocity of the torque dial, was related to the rigidity of the torsion spring, and varied with each apparatus. This is one of the disadvantages of the laboratory vane test that is neither rigorously stress nor strain controlled.

To investigate the influence of pore-water pressure on the torque applied to the vane shaft, a series of tests was conducted in silt (Fig. 12). These tests, conducted at constant speed, also indicated that a change in testing depth from 2 to 3 in. had no significance. The results show that induced pore-water pressures can be in either the neg-

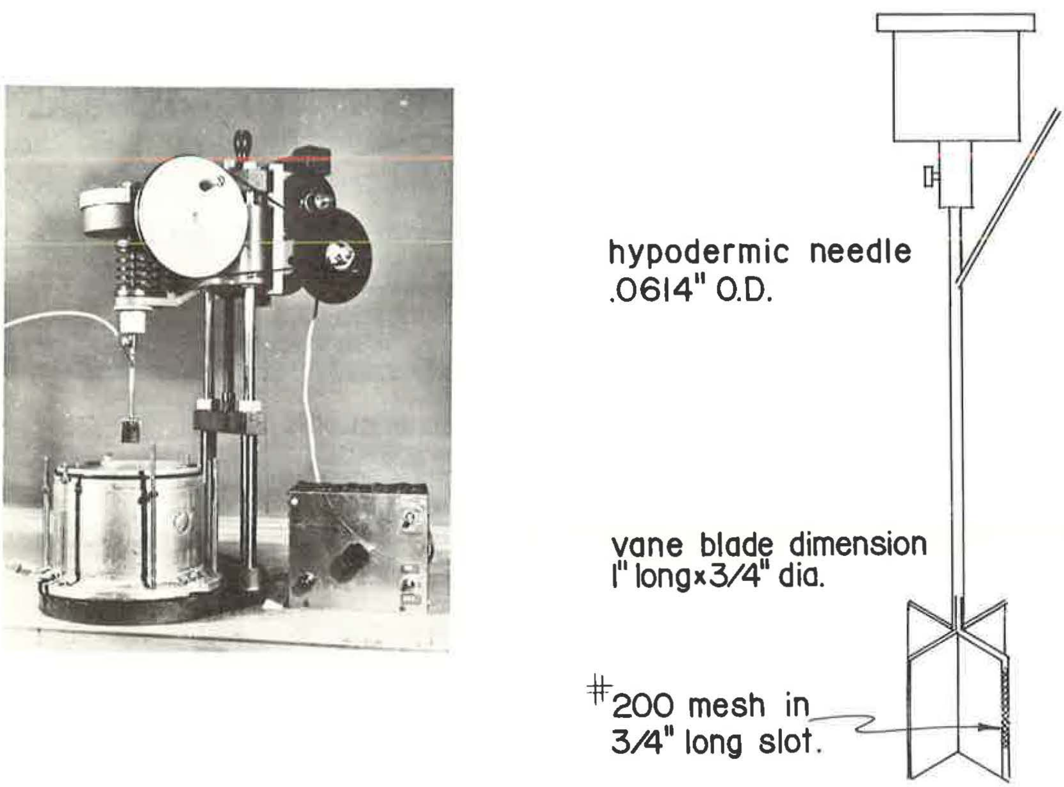

Figure 10. Laboratory vane, with provision for pore-pressure measurements.

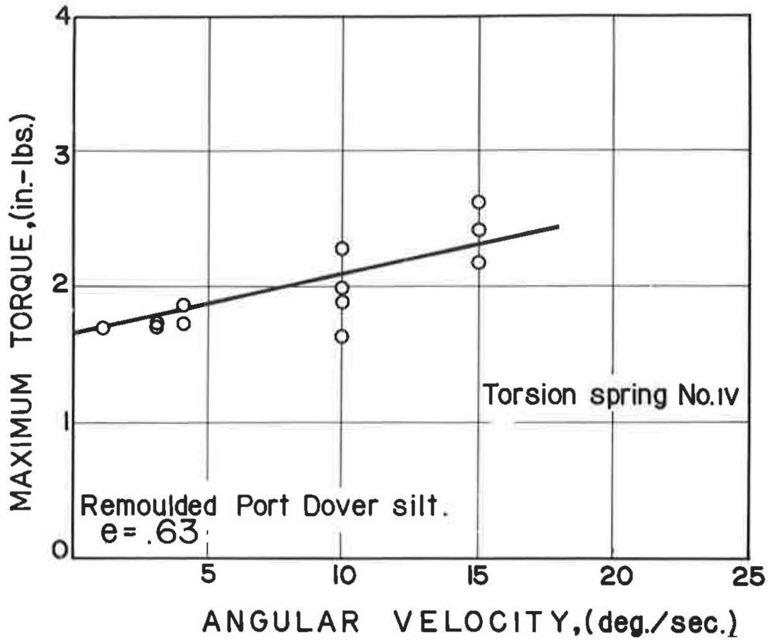

Figure 11. Vane tests in silt—dependence of maximum torque on angular velocity of torque dial.

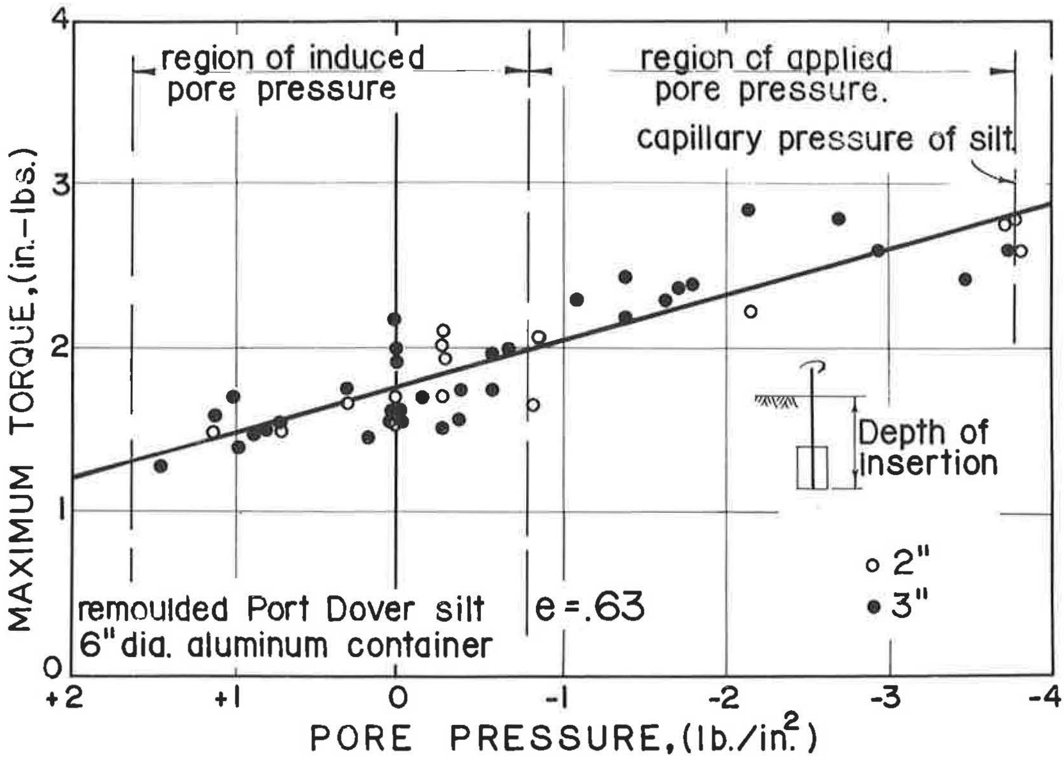

Figure 12. Vane tests in silt—maximum torque vs pore-pressure.

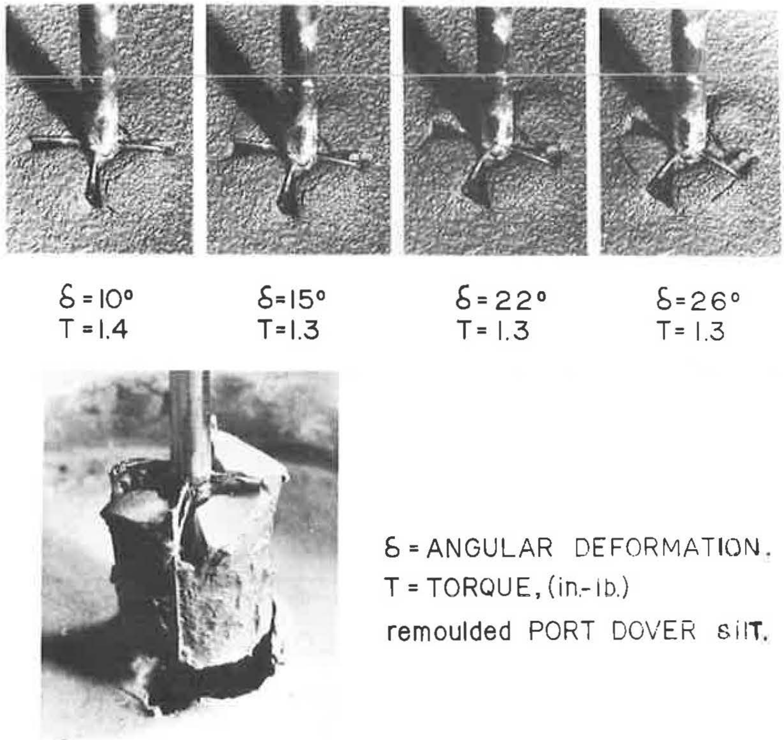

Figure 13. Vane tests in silt—generation of rupture surfaces during test.

ative or positive range, depending on the formation of the meniscus at the start of the test. Negative pore-water pressures were applied to the soil to determine the influence over a greater range. The sloped line indicates that the laboratory vane test, commonly considered as an "undrained" test, acquired the characteristics of a "drained" test in dilatant soils. This anomaly also has been found for triaxial tests on dilatant soils.

Progressive Failure

During the tests progressive failure was investigated. The vane was inserted to the depth of the vane blades and photographed as the torque was applied and as the angular deformation took place (Fig. 13). At a strain of 10°, and when the maximum torque occurred, shear surfaces were generated at the tips of the blades and at right angles to them. At this stage in the test, the shear surface was not cylindrical but almost rectilinear. As the angular strain increased and the torque decreased, the shear surfaces extended until, ultimately, a cylindrical failure surface was formed. During these stages of the test, voids were formed behind the vane blades and the shearing resistance was zero at these voids. Although the ultimate shearing surface was cylindrical, it was not necessary for the shear surface at maximum torque to be cylindrical or the stress distribution on the walls of the cylinder to be uniform. As the stress distribution at the shearing surface and along the vane blades was unknown, it was not possible to use the vane with any accuracy in this type of soil.

References

7. Golder, M. Q., "Techniques of Field Measurement and Sampling." 5th Internat. Conf. on Soil Mechanics and Foundation Eng., Paris (1961).

8. Wilson, N. E., "Techniques of Field Measurement and Sampling." 5th Internat. Conf. on Soil Mechanics and Foundation Eng., Paris (1961).
9. Cadling, L., and Odenstad, S., "The Vane Borer." Royal Swedish Geotechnical Inst. Proc., 2 (1950).
10. Wilson, N. E., "Laboratory Vane Shear Tests and the Influence of Pore-Water Stresses." ASTM Shear Testing Sym. (1963).

R. D. GOUGHNOUR and J. R. SALLBERG, Closure. —The authors are grateful to Prof. Wilson for his interesting and informative discussion. His development of the pore-pressure device results in a welcome contribution. It would be of interest to continue the study of pore-pressure on a variety of soils with a wide range of plasticity indices.

Prof. Wilson refers to the "usual speed" of vane testing, but in Figure 11 shows values up to 15° per sec angular velocity of torque dial. These values appear to be much higher than values of normal testing.

In regard to Prof. Wilson's last sentence, it should be pointed out that the stress distribution is not known for any type of test and, therefore, the vane test could be considered as accurate as any other of the commonly used tests.