Rate of Shear Effects on Vane Shear Strength

By Mohsen Sharifounnasab,[1] A. M. ASCE
and C. Robert Ullrich,[2] M. ASCE

Introduction

Conventionally, the vane shear test is performed using a four-bladed vane, the height of which is twice its diameter. Torque is applied to the vane at a rate of approximately 6 deg/min until failure occurs.

Studies of the vane shear test have been performed by many investigators (1,2,4,5,8,10). These studies indicate that measured vane shear strength may be affected by vane geometry (1,8), and that the measured vane shear strength of highly plastic clays tends to increase as shear rate increases (10).

In this paper results are presented for a series of laboratory vane shear tests in which different shear rates were used. Results of vane shear tests on a clay of low plasticity are used to show that partial drainage may occur in tests performed at rates as slow as 6 deg/min. Results of vane shear tests on a highly plastic clay are used to demonstrate that for completely undrained conditions vane shear strength increases as shear rate increases.

Laboratory Studies

A study was performed at the University of Louisville to investigate the effects of shear rate and vane dimensions on the measured vane shear strength of soft clays (9). A total of 222 individual vane shear tests were performed.

The soils used in this study were kaolinite and slaked Pierre shale, which differ widely in engineering properties and behavior. Index properties of these two soils are summarized in Table 1. The mechanical properties of kaolinite and Pierre shale have been studied extensively and results have been reported in the literature (3,6).

In order to avoid differences between samples due to special geologic features and sampling procedures, specimens of kaolinite and Pierre shale were prepared from thick slurries. Prior to sample preparation the Pierre shale was slaked by exposure to six cycles of wetting (immersion) and drying. Samples of kaolinite were one-dimensionally consolidated under pressures of 528 psf (25.3 kPa) and 1,056 psf (50.6 kPa), and samples of Pierre shale were consolidated under a pressure of 528 psf (25.3 kPa). Kaolinite samples were 3.5 in. (8.89 cm) in diameter by 4 in. (10.2 cm) high, whereas Pierre shale samples were 3 in. (7.62 cm) high.

[1]Civ. Engr., Esfahan, Iran.
[2]Assoc. Prof. of Civ. Engrg., Univ. of Louisville, Louisville, Ky. 40292.

Note.—Discussion open until June 1, 1985. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on January 26, 1984. This paper is part of the *Journal of Geotechnical Engineering*, Vol. 111, No. 1, January, 1985. ©ASCE, ISSN 0733-9410/85/0001-0135/$01.00. Paper No. 19391.

J. Geotech. Engrg. 1985.111:135-139.

TABLE 1.—Index Properties of Soils Tested

Soil (1)	Specific gravity (2)	Liquid limit, as a percentage (3)	Plastic limit, as a percentage (4)	Percent finer than 2 microns, as a percentage (5)	Activity (6)
Kaolinite	2.70	48%	34%	43%	0.33
Pierre shale	2.74	138%	35%	73%	1.41

When consolidation of each sample had been completed a template was used to mark three points of insertion on the surface of the sample. Vane shear tests were performed at depths of 1.5 in. (3.81 cm) and 2.5 in. (6.35 cm) for kaolinite samples, and at a depth of 1.5 in. (3.81 cm) for Pierre shale samples. During each test, readings of applied torque were taken at predetermined time intervals so that the actual rate of vane rotation could be determined.

Different pulley arrangements were devised for the motor and drive train of the laboratory vane shear device used in this study; the resulting rates of torque head rotation were 5 deg/min, 10 deg/min, 26.7 deg/min, 53.3 deg/min, and 106.6 deg/min. Three rectangular vanes with different height-to-diameter (H/D) ratios were used: The diameter of each vane was 0.5 in. (1.27 cm), and the vane heights were 0.5 in. (1.27 cm), 0.75 in. (1.91 cm), and 1.0 in. (2.54 cm).

Test Results

Results of tests performed in this study are presented in Figs. 1 and 2, in which shear strength is shown as a function of the average rate of shear. The average rate of shear was calculated by dividing the angle of rotation of the vane at failure by the time to failure. Each data point in Figs. 1 and 2 represents the average of several test results.

The measured torque at failure is related to horizontal and vertical shear strength values by the equation

$$T = \pi D^2 \left(\frac{H}{2} s_v + \frac{D}{6} s_h \right) \quad (1)$$

in which T = torque at failure; D = diameter of vane; H = height of vane; s_v = vertical shear strength; and s_h = horizontal shear strength.

In this study vane shear tests were performed for each of three vane shapes at specific rates of rotation. Thus, for a given rate of rotation it was possible to consider measured torques for pairs of vane shapes and solve simultaneous equations to determine s_v and s_h.

In Figs. 1 and 2 the vertical shear strength was normalized by dividing each value of vertical shear strength by the vertical shear strength measured at the standard shear rate (6 deg/min). Values of the vertical shear strength at the standard shear rate, s_{vo}, were 1.05 psi (7.23 kPa) for the Pierre shale consolidated under 528 psf (25.3 kPa); 0.70 psi (4.82 kPa) for the kaolinite consolidated under 528 psf (25.3 kPa); and 1.40 psi (9.65

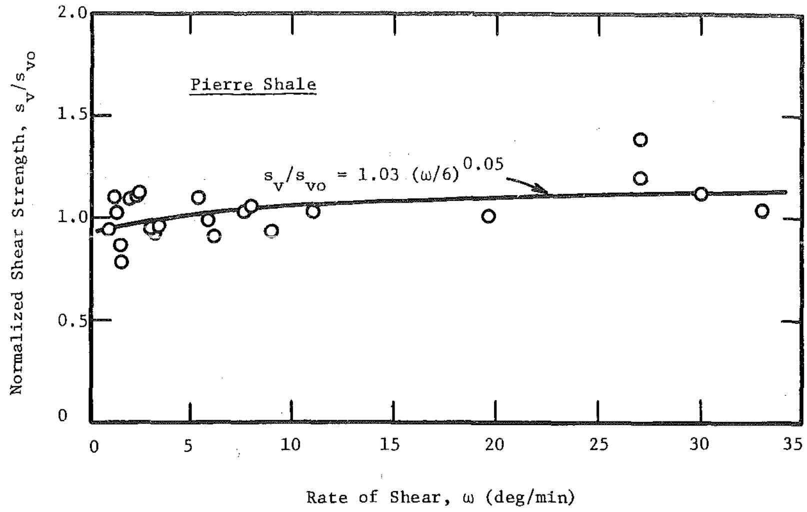

FIG. 1.—Normalized Shear Strength versus Rate of Shear for Pierre Shale

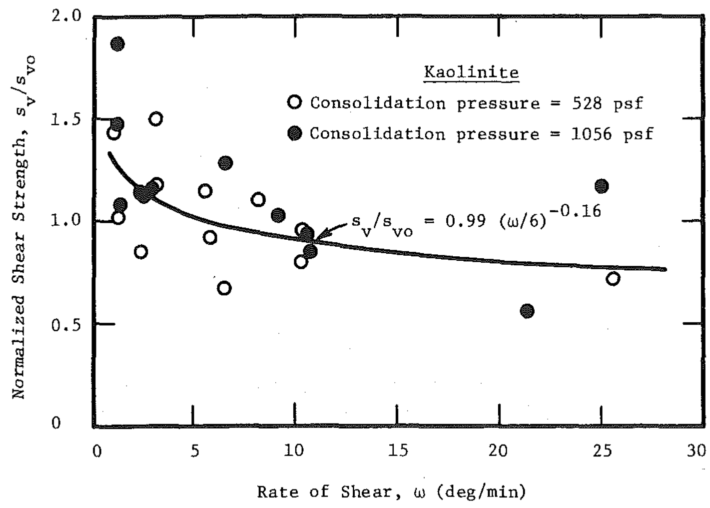

FIG. 2.—Normalized Shear Strength versus Rate of Shear for Kaolinite

kPa) for the kaolinite consolidated under 1,056 psf (50.6 kPa). Normalized shear strength values for both test series on kaolinite (both consolidation pressures) are shown together in Fig. 2.

Values of horizontal shear strength, calculated by simultaneous equations, were expressed as s_h/s_v. Values of s_h/s_v did not display any consistent pattern with changing shear rate. For the Pierre shale the average value of s_h/s_v was 1.38, whereas for the kaolinite the average value of s_h/s_v was 2.55. Richardson et al. (8) collected vane shear data from various sources and plotted s_h/s_v versus plasticity index. The values of

s_h/s_v obtained in this study are approximately 50% higher than values indicated by the relationship presented by Richardson et al.

The effect of shear rate on measured vane shear strength was studied in a series of field tests by Torstensson (10). Over 300 vane shear tests were performed on two highly plastic normally consolidated clays; in these tests time to failure was varied from 5 min to 7 days. The angle of rotation of the vane at failure was found to be independent of the time to failure. Vane shear tests results were presented in terms of normalized shear strength versus time to failure.

An equation of the form proposed by Torstensson (10) was fitted to the data shown in Figs. 1 and 2. The equation has the form

$$\frac{s_v}{s_{vo}} = \alpha\left(\frac{\omega}{\omega_o}\right)^{\beta} \quad \text{(2)}$$

in which s_v = vertical shear strength; s_{vo} = vertical shear strength, measured at the standard shear rate; ω = shear rate; ω_o = standard shear rate (6 deg/min); and α and β are coefficients which depend on the properties of the soil.

The method of least squares was used to fit Eq. 2 to data shown in Fig. 1 for the Pierre shale. The value of β describes the effect of shear rate on measured strength; the value of β determined for the Pierre shale was 0.05, which is the same as that determined by Torstensson in his study. The value of α for the Pierre shale was 1.03.

Contrary to expected behavior, shear strength values for kaolinite decrease with increasing shear rate (Fig. 2). Apparently, at relatively slow shear rates, shear-induced pore pressures are able to dissipate away from the test location and a partially-drained strength value is measured. As the rate of shear increases, less pore pressure dissipation occurs and lower values of shear strength are measured. The method of least squares was used to fit Eq. 2 to data shown in Fig. 2; the value of β was -0.16 and α was 0.99.

Perlow and Richards (7) proposed that shear rates for vane shear tests be standardized on the basis of angular shear velocity; for a 0.5 in. (1.27 cm) diameter laboratory vane, the shear rate necessary to maintain undrained conditions is about 80 deg/min. Using the equation fitted to data in Fig. 2, it may be calculated that for kaolinite the shear strength measured at 6 deg/min is about 50% higher than that measured at 80 deg/min.

Conclusions

Principal conclusions drawn from this study are as follows:

1. Results of vane shear tests on kaolinite indicate that partial drainage may occur if the shear rate is too slow.
2. The suggestion by Perlow and Richards (7) that laboratory vane shear tests be performed at 80 deg/min appears justified; for kaolinite shear rates of at least 30 deg/min are necessary to ensure undrained conditions.
3. Results of vane shear tests on Pierre shale indicae that in the ab-

J. Geotech. Engrg. 1985.111:135-139.

sence of any drainage during shearing, measured shear strength increases as shear rate increases.

4. The rate-dependent character of vane shear strength for Pierre shale may be described by a mathematical equation similar to that proposed by Torstensson (10).

Appendix I.—References

1. Aas, G., "A Study of the Effect of the Shape of Vane and Rate of Strain on In Situ Shear Strength of Clays," *Proceedings*, 6th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, Montreal, 1965, pp. 141–145.
2. Flaate, K., "Factors Influencing the Results of Vane Tests," *Canadian Geotechnical Journal*, Vol. 3, 1966, pp. 18–31.
3. Knight, D. K., "Oahe Dam: Geology, Embankments and Cut Slopes," *Journal of Soil Mechanics and Foundation Division*, ASCE, Vol. 89, No. SM2, 1963, pp. 99–125.
4. Menzies, B. K., and Merrifield, C. M., "Measurements of Shear Stress Distribution on the Edges of a Shear Vane Blade," *Geotechnique*, Vol. 30, No. 3, 1980, pp. 314–318.
5. Monney, N. T., "An Analysis of the Vane Shear Test at Varying Rates of Shear," *Deep Sea Sediments: Physical and Mechanical Properties*, A. L. Inderlitzen, ed., Plenum Press, New York, 1974, pp. 151–167.
6. Olson, R. E., and Mesri, G., "Mechanisms Controlling Compressibility of Clays," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 96, No. SM6, 1970, pp. 1863–1878.
7. Perlow, M., and Richards, A. F., "Influence of Shear Velocity on Vane Shear Strength," *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 103, No. GT1, 1977, pp. 19–32.
8. Richardson, A. M., Brand, E. W., and Memon, A., "In-Situ Determination of Anisotropy of a Soft Clay," *Proceedings*, ASCE Specialty Conference on In-Situ Measurement of Soil Properties, Vol. 1, 1975, pp. 336–349.
9. Sharifounnasab, M., "Effects of Rate of Shearing on Vane Shear Strength of Soft Clays," thesis presented to the University of Louisville, at Louisville, Ky., in 1982, in partial fulfillment of the requirements for the degree of Master of Engineering.
10. Torstensson, B. A., "Time-Dependent Effects in the Field Vane Test," in "Geotechnical Aspects of Soft Clays," *Proceedings*, International Symposium on Soft Clay, Bangkok, Thailand, 1977, pp. 387–397.

Appendix II.—Notation

The following symbols are used in this paper:

D = diameter of vane;
H = height of vane;
s_h = horizontal shear strength;
s_v = vertical shear strength;
s_{vo} = vertical shear strength, measured at standard shear rate;
T = torque at failure;
α = constant in empirical equation;
β = constant in empirical equation;
ω = shear rate; and
ω_o = standard shear rate.

J. Geotech. Engrg. 1985.111:135-139.