Overview

This overview summarizes the results of the International Symposium on Laboratory and Field Vane Shear Strength Testing that was held in Tampa, FL, in Jan. 1987. The objectives of the symposium were to review the state of knowledge of the vane shear test (VST) and to provide the latest information on test theory, methods, and interpretation for the purpose of improved standardization of the field and laboratory vane tests. The need for a symposium at this time was based on the fact that the brief published results of the previous ASTM vane symposium appeared over two decades ago [*1*]. The vane literature since then has been extensive, including a short Australian overview of field vane testing and standardization by Walker [*2*] and an extensive overview by Aas et al. [*3*].

The field vane test was standardized by the ASTM for land testing in 1972 (ASTM Method for Field Vane Shear Test in Cohesive Soil [D 2573]), the laboratory vane test was standardized in 1987 (D 4648), and the offshore vane test has not yet been standardized by ASTM. Consequently, the time appeared auspicious to overview the entire subject of vane testing by holding an international symposium. It was also intended to help provide guidance to the ASTM Committee D-18 on soil and rock subcommittees concerned with the different problems of standardization using the various vane tests.

This Special Technical Publication (STP), presenting 22 papers from the symposium, has been organized into seven parts for simplicity of use as follows: Part I provides state-of-the-art reviews of the vane test on land and offshore. Part II is concerned with field vane theory and interpretation, while Part III covers the same topics for the laboratory vane. Part IV provides information on new laboratory test methods. Part V compares field vane testing to laboratory testing and other methods of in-situ testing. Part VI presents papers on the practice of vane testing on land, and Part VII does the same for vane testing offshore.

The 22 papers are intended for both theoreticians and practitioners involved with vane shear strength testing. They also should be useful to geotechnical engineers, geologists, and others concerned with laboratory and in-situ testing of soft soil, or sediment, and the application of test results to foundations, problems of soil instability, calibration of in-situ testing equipment, and other purposes.

The symposium was organized to include consideration of a number of problems in vane shear strength testing. These can be expressed as a series of questions: What is the range of soils suitable for vane testing? What are the principal advantages and disadvantages of the vane test? Does the field vane test yield data of the same or different reliability compared to other in-situ tests? In addition, What is the engineering significance of peak and residual (post-peak) strength? What corrections, if any, are appropriate for field vane testing? Does the method of soil remolding significantly influence the calculation of sensitivity? Most of these problems have been dealt with in a number of the symposium papers.

Recommendations from the symposium papers for standardization improvement are grouped and summarized for the ASTM D-18 subcommittees and others responsible for writing standards on vane testing. Suggestions for future work, based on information presented in many of the papers, are summarized following the recommendations. These summaries are intended to assist the reader interested in vane standardization or in the possibilities for future research in vane shear strength testing.

Symposium Contributions

In the following summary of some of the important points contained in the papers included in this book, the use of symbols follows the use given by the authors of the papers.

Chandler, in his state-of-the-art paper on the use of the field vane on clays, reported international acceptance of vane dimensions and test procedures resulting in what he called a "standard test." The standard test should result in undrained vane strengths in almost all uniform clays using a recommended relationship of $c_{uv} = 0.91\ M/\pi D^3$, where M is the maximum recorded torque. An approximate ratio of the field vane strength to CK_0UC triaxial strength, $V_r = 0.55 + 0.008\ I_p$ was stated to be only marginally dependent on the overconsolidation ratio (OCR) of the clay. Finally, the field vane strength, with an accuracy of about $\pm25\%$ of the measured value, may be given for "normal" clays ($m \approx 0.95$) by the relationship of $c_u/\sigma'_v = S_1\ (\text{OCR})^m$, where S_1 is the undrained strength ratio at OCR = 1.

Young, McClelland, and Quiros, in their state-of-the-art paper, summarized the results of an international survey they conducted on the practice of offshore vane testing. They found that the predominant use of the vane test was with the offshore petroleum industry, where measurements have been reliably and efficiently made in water depths exceeding 1000 m and with penetration depths as great as 440-m subseabed. In normally consolidated clay deposits (s_u/σ'_{vo} from 0.2 to 0.3) recommended adjustment values of the undrained shear strength are 0.7 to 0.8 for the design of axially loaded piles, 1.0 for development of *p-y* curves for laterally loaded piles, and 0.8 to 0.9 for bearing capacity and slope stability problems. The field vane was particularly useful to determine the strength of marine deposits having gas (low fluid saturation) or of high sensitivity. In these soils, the undrained shear strength may be significantly understated if it is obtained from tests on samples collected using high-quality samplers. The authors concluded that the vane shear test should become a standard test for offshore geotechnical investigations.

Becker, Crooks, and Been, in their interpretation of the field vane test in clays, presented evidence that strength ratios normalized using vertical preconsolidation pressures do not provide a good basis for comparison because they are not sufficiently refined. They suggest that a more rational comparison results from using strength ratios based on horizontal yield stresses, although they are not yet prepared to recommend that s_u/σ'_{hy} be established as the basis for developing alternative vane correction factors.

Silvestri and Aubertin discussed anisotropy and field vane testing. In sensitive clay deposits, the degree of strength anisotropy, or s_{uh}/s_{uv}, was found to vary between 1.14 and 1.41. They corroborated the Davis and Christian elliptical failure criterion.

Ortigão and Collet found that the Aas and others field vane corrections for the Rio de Janeiro clay were too conservative. Other cases of embankment failures in highly sensitive clays in which the Aas et al. corrections were found to be too conservative are also reported. The authors state that a correction factor was not necessary to obtain a safety factor near unity. They had no explanation to account for the differences between the results of their investigations and those reported by Aas et al.

Roy and LeBlanc performed field and laboratory vane tests in clay. They found that vane insertion produced disturbance and generated pore pressures that resulted in a reduced shear strength and that time effects led to an increased strength. A better designed vane blade, they suggested, would reduce disturbance and result in a 5 to 10% increase in the measured strength. They further recommended that not more than 1 min elapse between the time of vane insertion and the commencement of testing.

Karube, Shibuya, Baba, and Kotera used a cylinder shear test apparatus for the purpose of making vane test analyses in the laboratory. Reconstituted clays were tested. They found that the shear strength mobilized on the horizontal vane shear surface was larger than on the vertical shear surface. The difference was attributed to the different magnitudes of the effective normal stress acting on the two shear surfaces.

De Alencar, Chan, and Morgenstern performed a finite-element analysis of the laboratory vane test using an elasto-plastic constitutive relationship with strain-softening behavior. They showed that the peak torque is dependent upon the peak strength, the residual strength, and also on the rate of post-peak softening of the soil. The effect was reported to be particularly strong in very strain sensitive soils. The authors concluded that progressive failure has to be empirically corrected in practice, which requires a knowledge of the complete stress-strain curve obtained from laboratory testing to interpret the vane test and other in-situ tests involving shear failure.

Chaney and Richardson examined residual and remolded vane shear strength measured in the laboratory. They believed that the residual strength was reached after a 180° revolution of the vane. The remolded strength was dependent upon the method of remolding. The authors recommended a minimum of three vane revolutions to remold using the field vane, which yields a higher strength than either laboratory vane or hand remolding. Vane remolding was shown to be related to anisotropy, while hand remolding did not show this relationship.

Veneman and Edil, in the last symposium paper on the theory and interpretation of laboratory testing, studied shear structures developed during vane rotation using optical thin-section techniques. In soft and very soft clays of low plasticity, they found that the failure surface was a shear zone about equal to the vane diameter. The authors concluded that calculations of the undrained strength based on a fully developed cylindrical surface tend to underestimate the actual soil strength, and that the type of soil determines the magnitude of the deviation.

Pamukcu and Suhayda used a triaxial vane device equipped with a computer-aided data acquisition system for the detection of low strain shear deformations. They reported that the ratio of maximum static shear modulus to maximum dynamic shear modulus was about 0.85 in artificially prepared soft kaolinite specimens.

Almeida and Parry performed miniature vane and cone penetration tests in a bed of Gault clay overlying kaolin, which had been consolidated from slurry, in a centrifuge operating at 100 *g*. They found that the vane strengths compared well to theoretical strengths and that curves of point resistance with depth were similar to curves of vane strength with depth.

Tsutsumi, Y. Tanaka, and T. Tanaka used the laboratory vane test in a novel way to study the hardening characteristics of cements intended for soil stabilization in Japan. If the cement hardens too rapidly the blades used for mixing soil and cement cannot be extracted from the mixture. The authors found that the laboratory vane test could be successfully used to detect slight differences in early age hardening of the treated soils.

Lefebvre, Ladd, and Paré compared field vane strength with the undrained shear strength measured by triaxial and simple shear methods in the laboratory on marine clay specimens cut from block samples. The authors found very good agreement between the field vane strength and the laboratory test results for two clay deposits of low plasticity, high sensitivity, and medium to low OCR. Average correction factors were found to be unity, in agreement with the Bjerrum correction and in disagreement with the correction factors proposed more recently by Aas et al. The authors conclude that the field vane appears to be a reliable tool for profiling the undrained strength of low plasticity and sensitive clays for embankment stability, and they corroborate the use of the Bjerrum correction factors for these soils.

Greig, Campanella, and Robertson compared field vane test results at sites composed of soft organic clays, clayey silts, and sensitive clays to test results using the dilatometer, pressuremeter, piezocone, and screw plate. All of the in-situ test results were in reasonable agreement, despite the differences in failure mechanisms. At three of the sites the dilatometer results were different in value, compared to the results from other test methods, but similar in profile. A conclusion of the authors was that the piezocone and dilatometer provide continuous profiles of data that are equivalent to the field vane data if locally evaluated empirical correction factors are applied appropriately to the dilatometer and piezocone data.

Garga, in the first of the symposium papers on vane testing on land, investigated soft clays having variable amounts of sand, silt, and organic matter. At the site of a new port near Rio de Janeiro, field vane strengths were found to be similar to unconfined compression and UU triaxial tests. The Aas method to determine the anisotropy ratio S_h/S_v was not corroborated, and the strength anisotropy at the site could not be determined using vanes having different height to diameter ratios. Garga reported that the vane strength increase at the site was not the same as the effective stress increase underneath the test fills, and that the vane test could not be reliably used to monitor the consolidation progress of the soil.

Nagarkar, Rode, Shurpal, and Dixit used the field vane in soft, sensitive normally consolidated clays near Bombay to obtain strength profiles for the design of embankments. Conventional sampling and laboratory tests on samples from the same site also were undertaken. Laboratory strengths were found to be 40 to 60% lower than the field vane test results. The use of a vane guard resulted in strength values about 12% higher than when a guard was not used and the soil was more disturbed. Calculated and observed settlements were essentially the same, leading the authors to conclude that the field vane test, especially with the vane guard, is a highly reliable method for soft soil investigations.

Johnson, Hamilton, Ebelhar, Mueller, and Pelletier, in the first of the symposium papers on field vane testing offshore, compared results from the vane and cone penetrometer tests to results from laboratory vane, UU triaxial, and CU triaxial tests. The purpose of their study was to obtain a stress history and normalized soil engineering properties (SHANSEP) shear strength for the Gulf of Mexico deepwater clays, as part of the American Petroleum Institute's recommended practice to use normalized shear strength for static pile foundation design. The authors reported that UU triaxial strengths deviate significantly from SHANSEP and the in-situ shear strength at deeper depths, probably caused by stress relief during sampling. They concluded that in-situ strength and SHANSEP provide a means of interpreting shear strength for pile design, at least for the Gulf of Mexico deepwater clays.

Quiros and Young repeated approximately the same approach for the slightly overconsolidated Pleistocene clays of the Santa Barbara Channel, CA. They found that laboratory vane tests on specimens from pushed wireline samples had strengths about 30% less than field vane tests, and that the UU triaxial tests on specimens from pushed samples were about the same as the field vane $\pm 10\%$. The UU triaxial and field vane data were found to be in good agreement with the SHANSEP profile.

Geise, Ten Hoope, and May reported on the design, construction, and use of the Fugro field vane for wireline and seabed operations. They concluded with a number of recommendations relative to the ASTM field vane standard (D 2573): (1) For soils having shear strengths of less than 20 kPa, conventional heave compensation is inadequate and a hard-tie system should be used if the recommended vane test 1 m below the drillbit is to be followed; otherwise, vane tests should be performed at a minimum distance of 1.5 m, or five times the borehole diameter, for these soft soils. (2) Two or three vane rotations at 1.0°/s are adequate for remolded tests offshore. (3) ASTM Type A1 (rectangular and tapered) and G1 (rectangular) vane blades should not be used offshore because of their excessively high area ratios. The blades need to be redesigned to have an area ratio of 12% or less. (4) The ASTM D 2573 field vane standard is considered to be satisfactory for offshore testing without further modification other than the above recommendations.

Kolk, Ten Hoope, and Ims compared field vane tests on normally consolidated silts and clays, which had various amounts of carbonate, with the field piezocone and UU triaxial tests, laboratory vane, and Torvane tests. For soils from the North Sea and off the west coast of India, the field vane strength without correction factors compared well to the UU triaxial test results. The remolded UU triaxial strength compared well to the residual field vane strength (called the "post-peak" strength in the paper) at one site; data were unavailable from two other sites. The laboratory vane and the Torvane strength results were generally lower than results from the field vane; however, when piston sampling using the hard-tie heave compensation system, there was less divergence of data than when using push sampling without the hard-tie. The authors believed that K_0 could be estimated from field vane strength data together with triaxial results.

Silva and Wyland, in the final symposium paper, discussed their latest results using a remotely operated seabed field vane to obtain shear strength profiles in water depths of 6000 m and to a penetration depth of 1.5 m. The authors reported that the in-situ strengths were considerably greater than the strengths obtained from laboratory vane tests on core samples collected nearby. Field and laboratory vane strength profiles were found to be similar.

Recommendations for Vane Test Standardization

Three papers contained recommendations relevant to the various ASTM vane shear test standards. These are briefly listed in Table 1.

Midway through the symposium there was a panel discussion on standardization of the VST. Before the meeting, a panel steering committee put together a series of suggestions for VST standards (Table 2). There appeared to be no disagreement to these suggestions following their presentation to the participants.

Directions for Future Research and Development

A number of papers contained suggestions for future work. These are given in Table 3. The research and development suggested is that determined by the present author from information presented in the papers. He assumes responsibility in the event that he has misinterpreted the original authors, who are listed for the purpose of assisting a reader desiring to obtain additional information.

Summary and Conclusions

The standardization panel, referred to previously, posed some questions for discussion (Table 4) at the end of the first day that were considered to be important to the VST. At the end of the symposium most of these questions were put to the participants together

TABLE 1—*Recommendations for vane test standardization.*

Authors	L = Land O = Offshore	Recommendation
Roy and Leblanc	L	A maximum of 1 min should elapse from the time of insertion of the vane until the beginning of a test. Vane blades redesigned to cause less soil disturbance would be preferable over those specified.
Young et al.	O	Use their stated correction factors for normally consolidated Gulf of Mexico or similar offshore soils for piles, *p-y* curves, and bearing capacity and slope stability problems. Monitor or control the following for quality testing: vane blade geometry, vane rotation rate, bottomhole test penetration, drilling fluid weight and pressure, and torque calibration.
Geise et al.	O	A hard-tie heave compensation system should be used for quality testing when the soil shear strength is 20 kPa or less. Only in this case can the recommended test depth of 1 m below the drillbit be considered; without the hard-tie, the minimum test depth should be not less than 1.5 m below the drillbit. Two or three vane revolutions, made at a rotation speed of 1.0°/s, are considered adequate for the remolded strength test. Some of the vane blades specified by the ASTM need redesign to reduce the area ratio to 12% or less, while at the same time maintaining structural integrity for use in very stiff soils. The field vane standard is satisfactory if these recommendations are included.

TABLE 2—*Panel suggestions for field vane test standards.*

Hardware details
- dimensions: rectangular, with $H/D = 2$
  - $H = 125 \pm 25$ mm
  - $D = 62.5 \pm 12.5$ mm
  - blade thickness $\approx$ 2 mm (area ratio $\approx$ 12%)
- sleeved rods to avoid friction on rods
- geared drive

Procedural details
- depth below base of borehole: $\geq 5 \times$ hole diameter
- rest period before vane rotation: ≤ 5 min
- rate of rotation: 6 to 12°/min
- interpretation: $c_u = 0.86\ M/\pi D^3$ (M = max torque, and D = vane blade diameter)
- sensitivity should be reported, procedure requires standardization
- for offshore testing, specification is also required for mud pressure, motion compensation, and so forth
- the above procedural details apply to "uniform" soils having $S_t \leq$ 10 to 15 and $c_d \leq 100$ m^2/year; thus, vane test data must be accompanied by geological data

TABLE 3—*Suggested future VST research and development.*

Authors	R & D Suggested from Paper
Young et al.	Investigate how to be able to determine K_0, G, and E as part of the offshore VST.
Becker et al.	Further study the stress-strain characteristics of the soil for better interpretation of the VST. Refine the $S_u/\sigma'p - I_p$ approach for comparing vane strength and the strength operational in field failures by knowledge of horizontal stress components. Evaluate the assumptions needed to obtain σ'_{hy}.
Silvestri and Aubertin	Investigate uncertainties restraining the anisotropic analysis presented. Evaluate vane test stress relief effects. Determine the stress path generated by the VST for all stress directions.
Roy and Leblanc	Continue investigations of the failure mode in the VST.
De Alencar et al.	Obtain stress-strain curve, and relate it to the VST for the interpretation of results. Further investigate the relationship of the peak strength and progressive failure in high sensitivity soils.
Chaney and Richardson	Evaluate relationships of peak vane strength, remolded laboratory vane strength, and remolded field vane strength with vane orientation. Determine the relationship among the hand remolded strength, the laboratory vane remolded strength, and the I_L of the soil, especially with regard to the calculation of sensitivity.
Ortigão and Collet; also, Lefebvre et al.	Investigate further the problems in applying the Bjerrum and the Aas et al. VST corrections related to embankment failures with respect to resolving disagreement between the two methods.
Greig et al.	Extend comparisons among the different in-situ tests and the standard laboratory tests to the full range of applicable soil types in engineering practice.
Garga	Propose a universally correct method for analyzing the VST.
Johnson et al.	Extend procedures relating to SHANSEP, the VST, and laboratory tests for the same types of soils for confirmation, as well as to other soil types and geographic regions.
Geise et al.	Evaluate the extent of disturbance below the drillbit in different soil types and under different operating conditions relative to quality testing and sampling offshore.
Kolk et al.	Continue studies into obtaining K_0 reliably from the VST and triaxial strength data.
Silva and Wyland	Further evaluate stress relief effects, particularly when soil samples are raised from great water depths.

TABLE 4—*Panel proposed questions for discussion by participants.*

1. Do standards need to differ onshore and offshore?
2. What rotation is required to define the remolded shear strength for the calculation of sensitivity? What rotation rate should be used?
3. What "back-up" geological data are required? (For instance, plasticity index, natural water content, overconsolidation ratio, and soil profiles.)
4. When should or should not use be made of the field vane?
5. What is the field vane shear strength to be used for?

with answers that arose out of the symposium papers and discussions to learn if there was any disagreement. There appeared to be none; consequently, the following summary may be considered to represent the conclusions of the symposium participants. It has been slightly modified in this paper to take into account information contained in the revised symposium papers.

Standardization of the vane shear test is well established in both Europe and North America. With regard to the ASTM VST standardization, it is suggested that the existing D 2573 field vane standard be augmented by adding to it the differing test methods required for offshore use. In addition, the D 2573 standard needs further elaboration and clarification, and suggestions for this have been given in Tables 1 and 2. There appears to be no need at this time to have a separate field vane standard for offshore testing.

All types of field vane test methods appear to yield data of about the same degree of reliability and repeatability compared to other types of in-situ tests. The vane is particularly useful because it can be used to obtain the sensitivity of soil in situ. However, sensitivities calculated from field vane and laboratory measurements may be different, and a relationship between the two has not been standardized. The definitions of the post-peak or residual shear strength, the different types of sensitivity calculations, and perhaps other terms, need to be standardized.

Obtaining vane data is easy, but what to do with the data is more difficult. It was expressed during the symposium that the field vane shear strength is useful as a benchmark. In particular, the vane strength may be used to determine the cone factor for the cone penetrometer and piezocone tests. It is more appropriate to calibrate the various cones using shear strength data from in-situ measurements than from strength measurements made in the laboratory.

The suitability of the field vane to the type of soil appeared to be partly related to the user's experience with regard to the soil type, familiarity with the test method, and comprehension of the particular problem under investigation. While there was general consensus for the use of the VST in normally consolidated clays, opinion was divided on the suitability of the VST for other soil types. After so many decades of vane testing, this uncertainty still has not been resolved.

There was a difference of opinion among the symposium participants whether or not to correct field vane test results and, if corrections are to be applied, what the magnitude of the correction should be. In this regard, there was a concern expressed regarding comparison of VST results with routine and sophisticated laboratory results because of the sampling problem and attendant disturbance that usually affects the quality of strength data from the laboratory tests. Clearly, this is an area needing further investigation.

Bjerrum established a linkage between vane strength and embankment failures. A comparable linkage to other types of foundations appears not yet to be attained, except for some offshore applications. Several papers presented at the symposium pointed out disagreement between the Bjerrum and the Aas et al. methods of relating VST results to embankment failures. This area, also, would appear to be appropriate for further study and analysis.

There was general agreement that the laboratory vane test provided a simple and convenient index of shear strength. Everyone also agreed that the field vane test provided data that can be related to foundation design.

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