A CAUTIONARY TALE OF TESTING SOFT AND VERY SOFT SOILS WITH VANE SHEAR



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ABSTRACT: Reliable undrained shear strength (Su) profiles are essential for stability assessment and staged-construction modelling in deep soft soils, embankments, mine tailings facilities, and ground engineering works. Although several methods exist for assessing Su, the down hole electronic Vane Shear Test (VST) provides clear advantages over traditional top drive systems, particularly in soft and very soft soils.

With top drive top-measure VSTs, torque applied at the surface is transmitted down a long rod string, introducing errors from torsional deformation, rod friction and mechanical energy losses. These effects increase with depth and can overwhelm the small torques characteristic of low-strength materials.

Down hole VSTs apply and measure torque at or near the vane, effectively eliminating mechanical resistance above the tool. This enables more accurate peak and remoulded strength measurements and clearer torque–rotation behaviour. Controlled rotation rates (0.1–60°/s) and direct measurement of verticality at depth further improve compliance with testing standards and result repeatability.

The higher resolution data and reduced uncertainty provided by downhole VSTs support defensible geotechnical design parameters for deep soft ground. Consistently unreliable results from top drive vanes—together with the strong agreement between down hole VST, and Cone Penetration Test data, motivate the findings presented in this paper.

Key Words: vane shear test, shear vane, down-hole, soft soils, undrained shear strength

INTRODUCTION

Peak and residual undrained shear strength are key geotechnical engineering parameters used in the design of structures founded on or within soils, particularly fine-grained, slow-draining soils. These structures include embankments, mine tailings facilities, and ground engineering systems that rely on accurate shear strength assessment.

Undrained shear strength can be assessed using mathematical approaches such as SHANSEP, developed by Ladd and Foott (1974), as well as through sophisticated laboratory testing of undisturbed samples and a range of in-situ tests of varying quality and reliability.

While laboratory testing provides controlled strength measurements, its reliability is limited due to sample disturbance occurring during sampling, extraction, handling, transportation, extrusion and preparation.

Due to these inherent limitations, the in-situ vane shear test is often considered one of the most representative methods for determining undrained shear strength. This paper reviews the reliability of the test by comparing two preferred configurations, demonstrating that results are highly dependent on the torque measurement system of the vane shear device configuration.

THE VANE SHEAR TEST TO DETERMINE SHEAR STRENGTH

The vane shear test involves inserting a four-bladed vane into the ground and rotating it at a controlled rate to induce shear failure along a theoretical cylindrical surface. The soil resistance to rotation is measured as torque, which is converted to shear strength using vane geometry. The test can provide peak, residual, and remoulded strengths depending on the degree of rotation.

ASTM D2573 specifies Equation 1 for converting torque to shear strength for a square-shouldered vane with a length-to-diameter ratio of 2:

$$Su = \frac{6T}{7\pi D^3} xK \quad (1)$$

Where:
Su = shear strength from the vane, kPa
D = vane diameter, mm
K = 1 x 10^6
T = value of measured torque corrected for apparatus and rod friction, Nm

The torque value must be corrected for apparatus and rod friction, which is difficult to quantify. This correction is often inconsistent and influenced by variables such as torsional deformation, rod imperfections, varying degrees of shaft friction, and mechanical energy losses.

VANE SHEAR TESTING CONFIGURATIONS

There are a wide variety of vane shear testing devices available. Figure 1 (ISO 22476-9) illustrates different configurations and how torque is generated and measured:

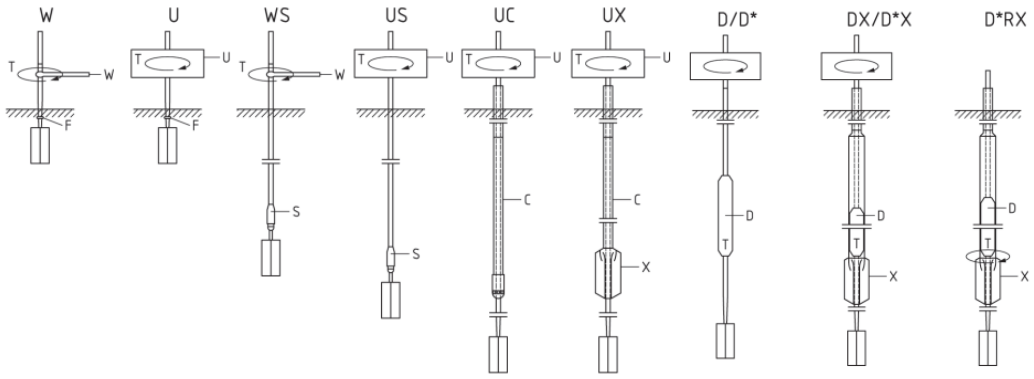


Figure 1. Vane Shear Test Configurations

where:

W = up hole measurement of maximum torque
U = up hole continuous measurement of torque versus rotation
D = down hole continuous measurement of torque versus rotation
DX = down hole continuous measurement of torque versus up hole measurement of rotation

Table 4 – "Applications of field vane test configurations", in the ISO Standard (ISO 22476-9) recognises the limitations and advantages of various device configurations. In this trial results from a D*RX (A.P. van den Berg Icone Vane) and a D*X (GTV100) style vane shear configurations are compared.

THE TRIAL SITE

A trial site was selected in New Farm, Brisbane, which is located on a pronounced bend of the Brisbane River. It is characteristic of Brisbane's riverine and estuarine setting, comprising a combination of shallow alluvial deposits overlying older volcanic and sedimentary bedrock. The surface geology is dominated by Quaternary alluvium consisting of soft, variable layers of clay, silt, and sand deposited by the meandering Brisbane River which is underlain by Pleistocene age over consolidated clay and gravelly sandy clay. The cone penetration test result from the site is shown in Figure 2 and is representative of the geological conditions in the area.

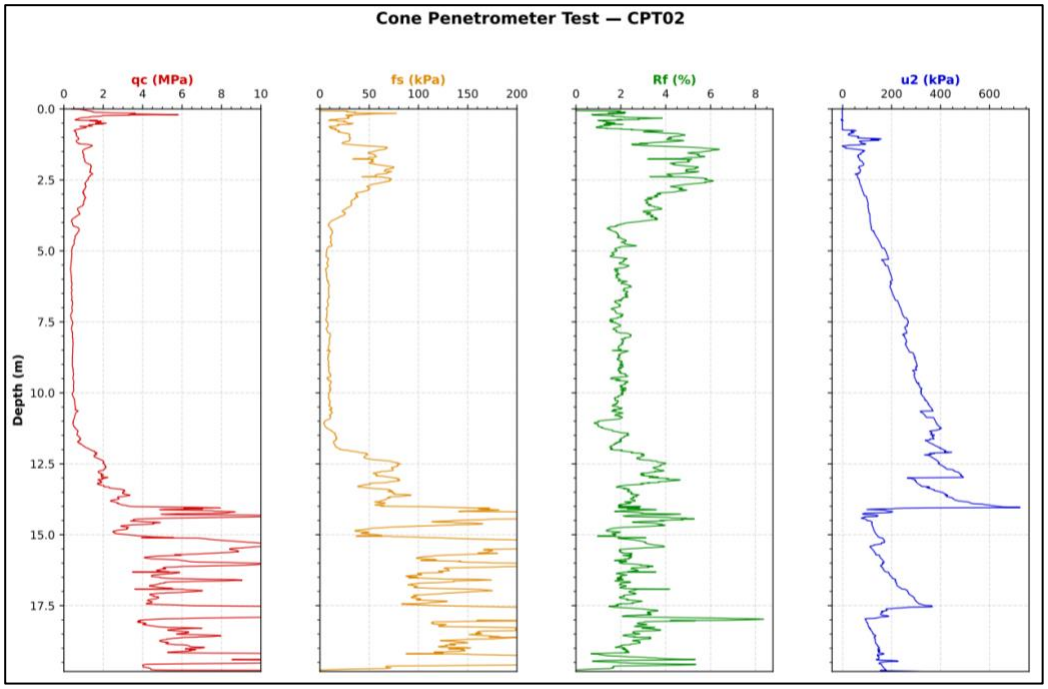


Figure 2. Cone Penetration Test Results

TESTING

Four vane shear tests were conducted at varying vertical depths with a D*X GTV100 top drive, top measure vane shear device. This device was fitted with a 15 degree slip joint. At a one metre offset, an additional four vane shear tests at the same vertical depth were conducted with a D*RX AP van den Berg Icone Vane, a Down the Hole Vane Shear which generates and measures the torque directly above the vane blade. A 50 x 100mm vane blade conforming to the requirements of ASTM 2573 was utilised for all of the tests and the vane stem considered in the vane factor calculation. The rotation rate adopted was 12 degrees per minute. Figure 3 below shows the tests conducted with the Top Measure and Bottom Measure vane configuration.

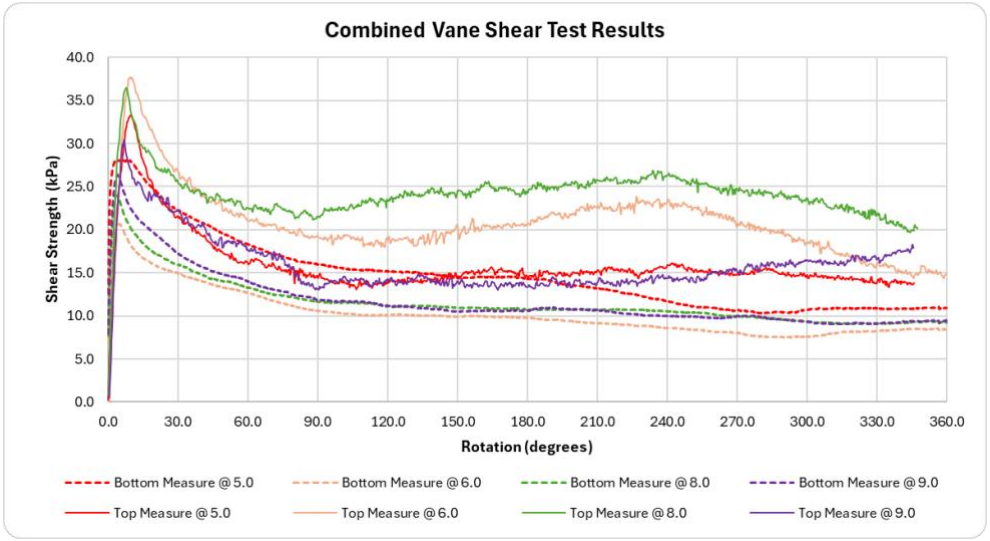


Figure 3. Combined Vane Shear Test Results

DISCUSSION

The Peak Strengths measured with the two different vane shear device configurations are plotted against the predicted shear strength from the cone penetration test. An N_{kt} of 15 has been adopted when empirically converting the cone tip resistance to shear strength with a sensitivity assessment at N_{kt} of 13 and N_{kt} of 17. At shallower depths, the cone, top measure and bottom measure vane shear devices all deliver similar shear strengths. However at greater depths, the top measure vane over predicts compared to the other two tests. This is due to the torque correction uncertainty discussed above as the rod lengths increase and which can be seen in the high variability in the results shown in Figure 4.

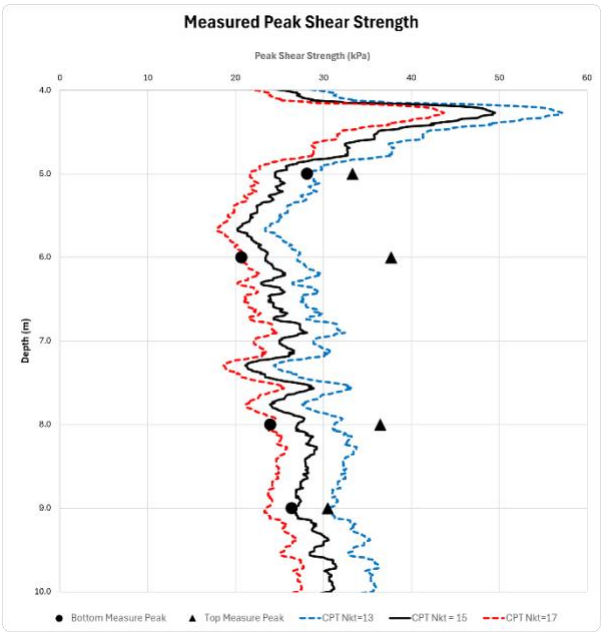


Figure 4. Measured Peak Shear Strength results compared to CPTu prediction (Nkt=13, 15 and 17)

The average Residual Strength between 120 and 360 degrees rotation measured with the two different vane configurations are plotted against the sleeve friction measured by cone. The strength measured by the cone sleeve and the down the hole vane shear match closely whilst the top measure device over predicts compared to the bottom measure device and the sleeve friction. Again this is due to the torque correction uncertainty associated with the top measure device. Residual shear strength errors of up to 230% are observed.

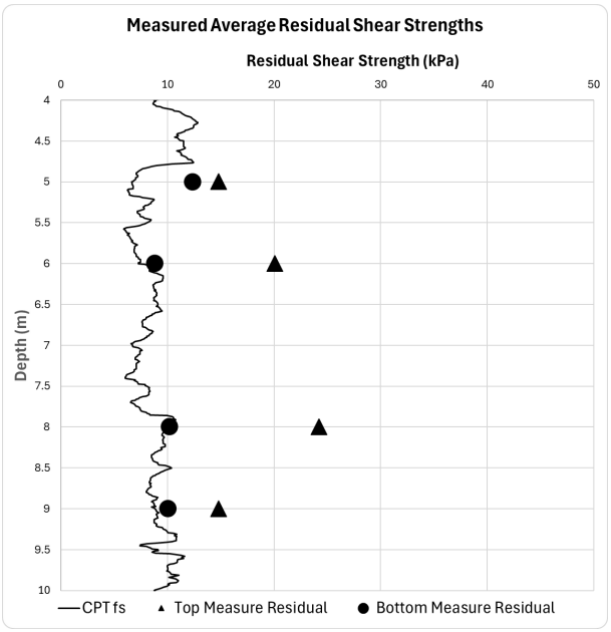


Figure 5. Measured Residual Shear Strength results compared to CPTu sleeve friction

The impact of the over measurement of the top drive devices can be significant when assessing geotechnical structure safety. As an example Rio Tinto D5 Tailings and Water Storage Facilities Standard specifies that facilities are designed with site specific residual strength parameters. The safety of facilities designed based on residual strength from top drive vanes may be significantly over estimated.

CONCLUSION

A suite of vane shear tests was conducted at a soft soil site in Brisbane to compare the performance of top-drive (top-measure) and downhole (bottom-measure) vane shear devices. The measured peak and residual undrained shear strengths were benchmarked against CPTu-derived values to assess reliability and consistency.

The results clearly demonstrate that vane shear strength measurements are highly sensitive to the method of torque application and measurement. At shallow depths, all testing methods showed reasonable agreement. However, with increasing depth, the top-drive device consistently overestimated both peak and residual shear strengths. This divergence is attributed to cumulative errors associated with torsional deformation, rod friction, and energy losses within the rod string, all of which become more pronounced with increasing rod length.

In contrast, the downhole vane shear system, which applies and measures torque directly at the vane, showed strong agreement with CPTu data across the full test depth. This configuration effectively eliminates the need for uncertain torque corrections and provides a more reliable representation of in-situ soil behaviour. The improved resolution of torque–rotation response further enhances the identification of peak and remoulded strengths.

The magnitude of error observed in top-drive measurements, particularly for residual strength, where discrepancies exceeded 200% has a significant implication for geotechnical design. Overestimation of shear strength may lead to unconservative designs, especially for critical infrastructure such as embankments and tailings storage facilities where stability is governed by residual strength parameters.

The findings of this trial support the adoption of the D*RX downhole vane shear testing configuration as the preferred method in soft soil conditions, particularly where accurate strength profiling at depth is required. Where top measure systems are used, the inherent limitations and uncertainty of torque correction must be explicitly considered in design, and supplementary testing (i.e. CPTu or DMT) is strongly recommended.

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