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Developing a vane shear test with pore-water pressure measurement capability for in-situ monotonic and cyclic shear strength assessment

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ABSTRACT: Evaluating soil shear strength is of paramount importance for any infrastructure development project. Field testing methods, such as the Cone Penetration Test (CPTu), allow for an indirect estimation of soil shear strength based on measurements of tip resistance and sleeve friction, though with some inherent uncertainty. The only tool that allows for in-situ direct measurement of soil shear strength is the Vane Shear Test (VST), under the assumption of undrained soil behavior. However, this test does not provide the pore-water pressure variation in the soil to confirm this assumption. This article describes the design and application of a vane shear test with pore-water pressure measurement capabilities during vane rotation, referred to as the VSTu. This apparatus is an extension of the VST, incorporating a wireless pore-water pressure transducer inside the vane stem, and conduits extending from the transducer through each of the four blades, enabling pore-water pressure measurement at the edge of the blades, where soil shearing occurs. Results comparing the VSTu and CPTu measurements conducted at the same location in a tailings storage facility confirm the validity of the VSTu measurements. Additionally, the results of cyclic vane shear tests (CVSTu) are included, envisioning the possibility of measuring the soil cyclic shear strength in-situ.

KEYWORDS: Vane shear test, undrained shear strength, cyclic shear strength, pore-water pressure, in-situ testing.

1 INTRODUCTION

Today, the evaluation of soils properties is primarily carried out through in-situ testing, mainly using the CPTu tool (cone penetration test with pore-water pressure transducer) which provides measurements of tip resistance, sleeve friction, and pore-water pressure response. However, this tool cannot directly measure the soil shear strength, it can only be estimated from tip resistance and sleeve friction.

The vane shear test (VST) is, perhaps, the only in-situ test that allows for the direct measurement of soil shear strength. Historically, this test has been applied only to clayey soils, where undrained conditions during testing can be reasonably assumed. However, since 2015, ASTM D2573 (ASTM International, 2015) has extended its application to tailings, which often contain silty soils where undrained conditions are not guaranteed. One of the main limitations of the conventional VST is the absence of pore-water pressure (PWP) measurement, making it impossible to verify the assumption of undrained conditions during the test.

This article presents an extension of the conventional VST by adding PWP measurement capabilities during testing. This new apparatus and its application, named the VSTu test, was partially developed at Universidad Técnica Federico Santa María in Chile.

2 CONVENTIONAL VST

2.1 *Development of the VST*

The VST apparatus is shown schematically in Figure 1a. It consists of four thin blades attached to a central stem. The apparatus is inserted into the ground, and torque is applied to generate vane rotation at a constant angular velocity. This produces cylindrical shearing in the soil, with height H and diameter D, matching the vane dimensions (Figure 1b). It is assumed that shearing occurs in a fully undrained manner. The undrained shear strength from the field vane, $(S_u)_{fv}$, can be calculated from the measured torque, T, and vane geometry using Equation (1).

$$(S_u)_{fv} = \frac{6T}{7\pi D^3}\ valid\ for\ \frac{H}{D} = 2 \quad (1)$$

This equation can be used to evaluate the peak and remolded shear strength of the soil (Figure 1c).

Osterberg (1957) speculates that the vane shear test was developed simultaneously in Sweden by John Olsson in 1928, and in Germany, as evidenced by a 1929 German patent.

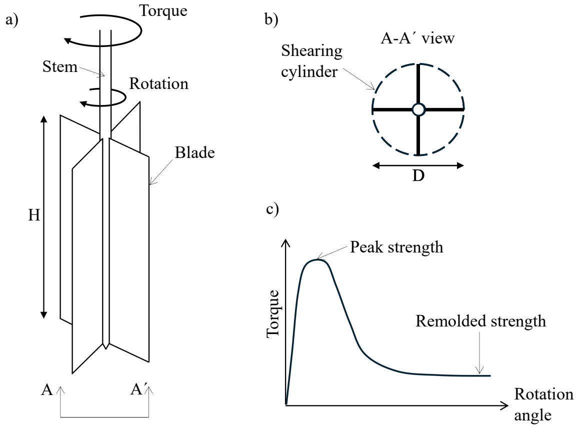

Figure 1. a) Schematic design of a VST apparatus. b) Shearing cylinder in section A-A′. c) Typical result of VST.

Carlson (1948) and Skempton (1948) used the vane to investigate clay strength, showing close agreement with laboratory tests and slope failure back-analyses. After that, the VST gained popularity, and many characteristics and procedures included today in ASTM D2573-18 (ASTM International, 2018) derives from research conducted in the 1950s and 1960s.

Cadling and Odenstad (1950) performed tests using vanes with diameters of 5.5, 6.5, and 8.0 cm, and ratio H/D = 2. Their tests indicated that neither the vane dimensions nor the H/D ratio had any effect on the shear strength measurements on clay. The vane ratio H/D = 2 has been commonly adopted since.

The vane area-ratio is defined as the cross-sectional area of the vane (blades and stem) expressed as a percentage of the cross-sectional area of the shearing cylinder (Figure 1b). A low area-ratio is preferred to minimize soil disturbance during vane insertion, particularly in sensitive clays (LaRochelle et al. 1973; Roy and Leblanc, 1988; Cerato and Lutenegger, 2004). However, shear strength measurements in soils with low sensitivity may be relatively unaffected by the vane blade thickness (Cerato and Lutenegger, 2004). ASTM D2573-18 recommends an area ratio of less than 10%.

Flaate (1966) presented $(S_u)_{fv}$ measurements in Norwegian marine clays conducted between 3 to 480 minutes after vane insertion. The results show a general tendency to increase the shear strength with increasing time delay, from 1.55 t/m^2 (3 minutes) to 1.85 t/m^2 (480 minutes). This difference is attributed to the dissipation of pore-water pressure generated during vane insertion and reconsolidation of the clay around the vane. Flaate (1966) recommends conducting the test no later than 5 minutes after vane insertion, and the same indication is included in ASTM D2573-18.

Cadling and Odenstad (1950) studied the effect of the rate of vane rotation and concluded that 6 deg/min was sufficiently slow rate and adopted this for general use, in agreement with Carlson´s (1948) and Skempton's (1948) findings. ASTM D2573-18 indicates a rate of 6 deg/min, with permissible variations in the range of 3 to 7 deg/min.

Bjerrum (1973) discussed a discrepancy between the soil shear strength measured with the vane test and the soil shear strength estimated from failure back-analyses of embankments constructed on soft clays, which were considerably lower than the values obtained from the vane tests. This discrepancy was attributed to the failure rate effect and to the anisotropy of soft clays. Bjerrum (1973) proposed a correction factor which reduced the vane shear strength to reach agreement with the mobilized strength during embankment failures.

Later studies suggested that Bjerrum´s correction factor may not be required for soils with low plasticity index (Aas et al., 1986), or for soft clays (Leroueil et al., 1990). Kouretzis et al. (2017) concluded that there is no need for the correction factor if the strength is normalized by the horizontal confining effective stress, perpendicular to the vane shearing cylinder (Figure 1b), and the rate effects are properly considered. Nevertheless, a correction factor developed by Chandler (1988), as an extension of the factor proposed by Bjerrum (1973), is included in ASTM D2573-18, stating that: "*The ASTM committee does not recommend or endorse any single method for adjusting the data*".

There have been efforts to measure the pore-water pressure associated with vane shear tests through physical models using small vanes in consolidation chambers, as well as through numerical and analytical methods (Matsui and Abe, 1981; Kimura and Saitoh, 1983; Morris and Williams, 1993). The general findings show a significant increase in pore-water pressure during vane insertion, as well as an increase during vane rotation, the latter often accompanied by pore-water pressure dissipation. Furthermore, Atkinson & Jessett (1990) and Charlie et al. (1995), developed vane apparatus with an integrated pore water pressure (PWP) transducer, known as the piezovane. They presented test results obtained from calibration chamber experiments. However, it remains unclear why this innovation did not progress to field applications or why the piezovane is not commercially available today.

2.2 *Application of VST in tailings*

Since 2015, ASTM D2573 has extended the use of VST to mine tailings, which commonly corresponds to silt and sand mixtures. In this context, the undrained conditions of the VST become uncertain, especially with a slow rotation rate of 6 deg/min. The need for higher angular velocities in tailings has been widely discussed (Olguín and Ortúzar, 2015; Reid, 2016; Harvey et al., 2023; Hogan et al., 2025).

Incorporating the capability to measure PWP generated during vane rotation represents a significant improvement to the VST test. The design of this new apparatus, referred to as VSTu, is detailed below.

3 DESIGN OF THE VSTU APPARATUS

3.1 *General concept*

The VSTu was developed to measure PWP during vane rotation. The following requirements were established:

- The PWP must be measured at the edge of the blades, where soil shearing occurs.
- The PWP sensor must be wireless, to prevent cable interfere with vane rotation.
- The VSTu apparatus must fit within a standard HQ3 borehole casing, commonly used in geotechnical engineering.
- The vane area ratio must be minimized, to reduce soil disturbance during vane insertion.

3.2 *Dimensions*

Figure 2 shows the design and dimensions of the VSTu apparatus, machined from a solid aluminum cylinder. The vane has a height of H = 120 mm and a diameter D = 60 mm, so the ratio is H/D = 2. This vane diameter is compatible with standard HQ3 boring. The stem is hollow to house the wireless PWP sensor. This space is also filled with glycerin used as saturating fluid.

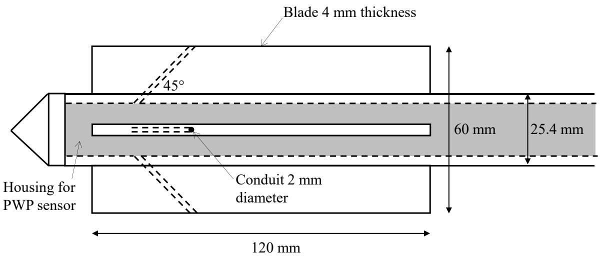

Figure 2. Dimensions of VSTu apparatus.

The thickness of each of the four blades is 4 mm and includes a 2 mm diameter conduit, hydraulically connecting the PWP sensor to the edge of the blades. The conduits are filled with glycerin, and they are angled 45° with respect to the axis of the stem to prevent glycerin leakage and desaturation during vane insertion into the ground.

3.3 *Instrumentation*

The PWP sensor is hosted in the hollow vane stem. It is wireless, meaning that the sensing hardware, data acquisition, power supply, and data storage occurs within the sensor. This represents a significant difference from the piezovane designs developed by Atkinson & Jessett (1990) and Charlie et al. (1995), whose PWP sensors included a wire connected to an external data acquisition system, potentially hampering vane rotation.

The PWP sensor must be preprogrammed to define the time frame for recording and the sampling rate. Once the test is completed, the vane is retrieved, and the data can be downloaded and visualized. The main disadvantage of this configuration is that no PWP readings are available to the user during the test. It is desirable for future developments of VSTu apparatus to allow real-time data transmission.

The instrumentation also includes a torquemeter and encoder, located above the ground level and connected to a computer, allowing for real time logging and visualization of the torque and angle of vane rotation.

3.4 *Laboratory and field testing*

Several VSTu tests were conducted in the laboratory and in the field. All tests described herein were performed in copper mine tailings at a relatively shallow depth, manually rotating the vane using T-shape crank.

For the laboratory test a 1 m diameter container was built (Figure 3a), divided into rings which allowed placing the tailings with a controlled density. A cover (not shown in the figure) was used to seal the container, generate vacuum, inject CO_2, and then insert deaired water, which permitted the saturation of the tailings.

One set of field tests were conducted at the impoundment of a large copper tailings storage facility (TSF) in Chile, near the water pond to ensure fully saturated tailings at shallow depth, as shown in Figure 3b. Another set of field tests was conducted at the impoundment of an inactive copper TSF located in Chile, as described later in this article.

Figure 3. a) 1 m diameter container for VSTu test. b) Field VSTu test on tailings impoundment, near the water pond.

3.5 *VSTu area ratio*

The dimensions of the VSTu apparatus results in an area ratio of 28%, exceeding the ASTM D2573-18 maximum of 10%. To evaluate its impact, a standard VST vane was built with a 10% area ratio, but without PWP measurement capabilities. Figure 4 presents both devices.

Figure 4. Photography of the VSTu apparatus and comparison with the conventional VST apparatus (ASTM D2573).

Side-by-side VST and VSTu tests were performed on the tailings impoundment shown in Figure 3b, two meters apart at different locations and depths. Figure 5 presents the results of each pair of tests, VST and VSTu. The testing followed the procedure described later in this article.

The results indicate that the peak and remolded shear strengths measured with VST and VSTu apparatus are similar, and no clear trend indicates that one is greater than the other. It is speculated that the small differences between the VST and VSTu results are due to the natural tailings heterogeneity.

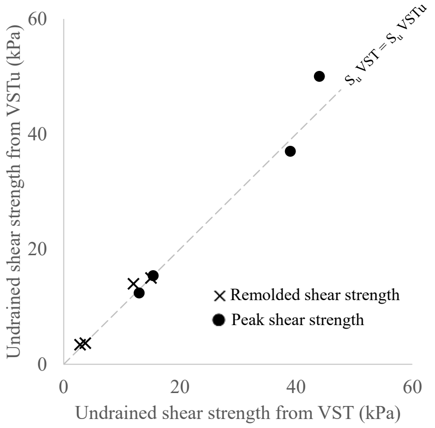

Figure 5. Comparison of VST and VSTu tests.

It seems that the relatively large area ratio of the VSTu apparatus does not have a significant effect on the shear strength measurement. This may be because the tailings tested have low sensitivity (Chandler, 1988; Cerato and Lutenegger, 2004), however, more research is needed on this topic.

4 VSTU TESTING PROCEDURE

4.1 *PWP dissipation after vane insertion*

ASTM D2573-18 recommends testing within 5 minutes after vane insertion. This is to avoid dissipation of the excess PWP generated due to vane insertion and prevent reconsolidation of the disturbed soils.

Several tests have been conducted using the VSTu apparatus. In all cases the vane insertion into the ground produces a large excess of pore-water pressure, as described by Kimura and Saitoh (1983), Chandler (1988), Morris and Williams (1993), Wilson et al. (2016), among others.

Figure 6 presents the PWP measured with the VSTu apparatus during a test conducted in the field at a depth of approximately 0.5 m, from vane insertion to vane retrieval, over a lapse of close to 2 hours.

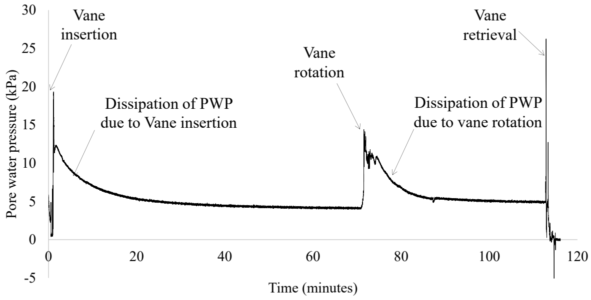

Figure 6. Pore-water pressure measured with VSTu apparatus.

To distinguish insertion-related excess PWP from that caused by vane rotation, it was deemed necessary to allow sufficient time for PWP dissipation after insertion; otherwise, the excess PWP from both insertion and rotation would be coupled.

For all the VSTu tests carried out in tailings, a dissipation time between 40 to 60 minutes ensured a consistent hydrostatic reading of PWP prior to vane rotation.

4.2 *Vane rotation rate*

ASTM D2573-18 recommends a vane rotation rate in the range of 3 to 7 degrees per minute, with a target of 6 degrees per minute. This aspect of VST testing has been debated in the framework of tailings testing (Olguín and Ortúzar, 2015; Reid, 2016; Hogan et al., 2025). Based on the tailings tests conducted as part of the VSTu development, a much faster angular velocity appears to be more appropriate.

In the context of comparing CPTu soundings with VSTu results, such as calculating the N_{kt} cone factor needed to estimate the peak undrained strength from piezocone tip resistance, or comparing the remolded undrained strength obtained from piezocone sleeve friction with vane strength measurements at large strain (Robertson and Cabal, 2022), and considering that the vane rotation rate influences the shear strength measurement (Reid, 2016), it seems reasonable to select a vane rotation rate such that the tangential velocity at the edge of the blades matches the standard piezocone push velocity of 2 cm/s (ASTM International, 2020).

In the VSTu tests, the attempted angular velocity is in the range of 38 deg/second, equivalent to 6.3 RPM. This corresponds, approximately, to 2 cm/s of tangent velocity at the edge of the blades, which matches the CPTu push rate. It is important to note that Robertson and Cabal (2022) indicate that, for CPTu soundings, the push rate of 2 cm/s generates a fully drained response in granular soils, a fully undrained response in fine-grained soils, and a partial drainage may occur in silty soils, such as tailings. A comparison between CPTu and VSTu measurements is described next.

5 COMPARISON BETWEEN CPTU AND VSTU

5.1 *Field conditions*

A field investigation campaign was conducted to assess the stability of a tailings storage facility, located in Chile, which has been inactive for a long time. As part of this campaign, several CPTu soundings were completed, and Figure 7 presents one of the CPTu results.

The tailings were primarily composed of sand and silt mixture, in an unsaturated condition, a natural unit weight of 19 kN/m³ was measured. However, layers of saturated clayey tailings with low to medium plasticity (CL and ML) and very low resistance were identified. Figure 7 shows a clayey tailings layer, with about 0.8 m thickness, between 2.9 and 3.7 m depth. This layer of clayey tailings produces pore-water pressure, u_2, measured by the piezocone. From undisturbed samples it was established that this layer is fully saturated with a saturated unit weight of 17 kN/m³.

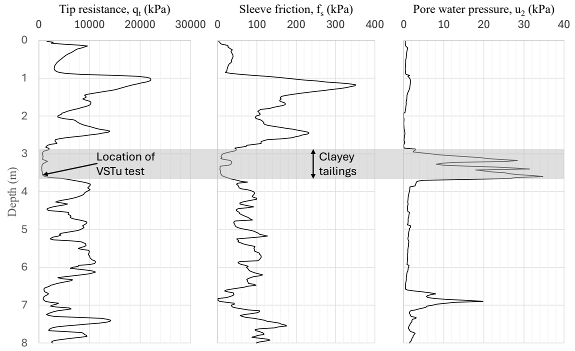

Figure 7. Results of CPTu test and location of VSTu test on clayey tailings layer.

A VSTu test was carried out in the clayey tailings layer, at a depth of about 3.7 m, with a total vertical confinement pressure of 69 kPa. Representative results of the CPTu test at this depth are:

- Tip resistance, $q_t = 570$ kPa
- Sleeve friction, $f_s = 6$ kPa
- Pore-water pressure, $u_2 = 20$ to 30 kPa

5.2 *CPTu and VSTu comparison*

Figure 8 presents the results of the VSTu test carried out at the location shown in Figure 7, including undrained strength and pore-water pressure. The vane was manually rotated, completing 10 revolutions over a lapse of 1.2 minutes. This is equivalent to about 8.3 RPM corresponding to a tangent velocity of about 2.6 cm/s at the edge of the blades, similar to the push velocity of the piezocone.

The shear strength in Figure 8 was calculated using Equation (1), without including the vane correction factor described in ASTM D 2573-18.

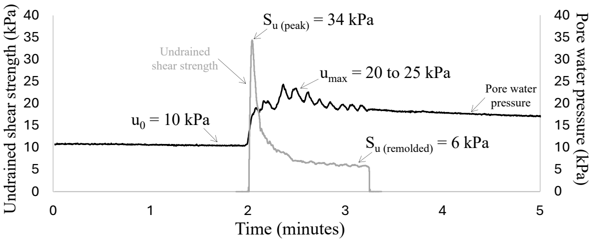

Figure 8. Results of VSTu test.

Representative results of the VSTu test are:

- Peak undrained strength, $S_{u\,(peak)} = 34$ kPa
- Remolded undrained strength, $S_{u\,(remolded)} = 6$ kPa
- Hydrostatic pore-water pressure, $u_0 = 10$ kPa
- Maximum pore-water pressure, $u_{max} = 20$ to 25 kPa

The peak undrained strength from the CPTu test can be estimated from the tip resistance, q_t, the total vertical stress σ_{vo}, and the cone factor N_{kt} using Equation (2):

$$S_{u\,(peak)} = \frac{q_t - \sigma_{vo}}{N_{kt}} \tag{2}$$

Given the peak undrained strength from the VSTu test, the $q_t = 570$ kPa from the CPTu test, and that the total unit weight of the soils that produces a total vertical confinement of $\sigma_{vo} = 69$ kPa at 3.7 m depth, Equation (2) results in $N_{kt} = 15$ which is within the range expected for this parameter (Robertson and Cabal, 2022).

The remolded undrained strength measured using the vane after 10 complete rotations was 6 kPa, the same as measured as the sleeve friction, f_s, of the CPTu test. It is expected for the remolded strength to be equal to the CPTu sleeve friction, since both occur at large strains under similar shearing rates (Robertson and Cabal, 2022). Furthermore, since the remolded undrained strength is a function of the void ratio, this result means that the insertion of the VSTu apparatus did not significantly affect the tailings void ratio, consistently with the results presented in Figure 5, or it did in a similar manner than the insertion of the piezocone.

Figure 8 presents the pore-water pressure measured during the VSTu test. The vane rotation started 1 hr after the vane insertion, and a near stable hydrostatic reading is observed before the test. The initial PWP is around 10 kPa, which approximates the expected hydrostatic pressure at the base of the 0.8 m thick clayey layer.

Figure 8 also shows the increase in pore-water pressure due to manual vane rotation. The maximum values are in the range of 20 to 25 kPa, similar to the 20 to 30 kPa measured during the CPTu sounding. The wavy shape of the curve is attributed to inadvertent variations in angular velocity caused by manual vane rotation.

Some PWP dissipation occurs as the undrained shear strength approaches its remolded value. This is consistent with

Robertson and Cabal (2022), who indicated that, for CPT soundings with a push rate of 2 cm/s, similar to the tangent velocity of the vane, a partial drainage may occur in silty soils.

A reasonable agreement is observed between the VSTu and the CPTu tests, which indicate that the VSTu measurements are meaningful.

5.3 *PWP dissipation*

Figure 9 presents the rest of the PWP record measured with the VSTu apparatus shown in Figure 8, including the dissipation following rotation and the PWP generation due to vane retrieval. The dissipation takes about 40 minutes to reach the hydrostatic condition.

A dissipation test was also carried out as part of the CPTu sounding, near the top of the same clayey layer where the VSTu test was carried out (Figure 7). The CPTu and VSTu pore-water pressure dissipation tests are presented in Figure 10.

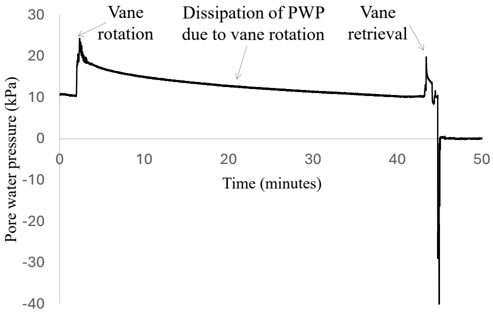

Figure 9. Dissipation of pore-water pressure after VSTu test.

A much faster dissipation occurs in the CPTu test, when compared with the VSTu test. Teh and Houlsby (1991) showed that the PWP dissipation measured behind the cone, u_2, is faster than the dissipation measured at the sleeve of the piezocone, u_3, because the PWP gradient is greater around the tip of the piezocone than its sleeve.

In Figure 10 the CPTu pore-water pressure readings corresponds to u_2. However, given the location of the VSTu conduits shown in Figure 2, it is speculated that the VSTu pore-water dissipation would be comparable with the CPTu u_3 readings. If that is the case, the results presented in Figure 10 would be consistent with the analysis in Teh and Houlsby (1991).

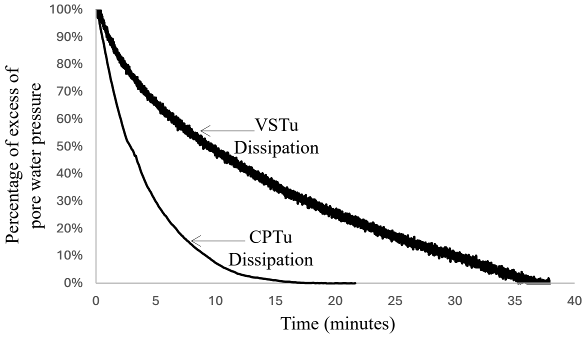

Figure 10. Comparison of CPTu and VSTu dissipation tests.

A level of consistency is observed between the CPTu and VSTu dissipation tests. However, more research is needed to relate a VSTu dissipation test with the soil hydraulic conductivity.

6 CYCLIC VSTU TESTS

The possibility of conducting cyclic VSTu tests (CVSTu) has been explored. Currently, the only option to study the cyclic behavior of soils is in the laboratory, through cyclic triaxial or cyclic simple shear testing, among others, requiring undisturbed soil sampling which is a significant challenge.

A limited number of CVSTu have been completed. Figure 11 shows a representative result of laboratory tests conducted in the container shown in Figure 3a, filled with saturated copper tailings. The figure also shows the test setup.

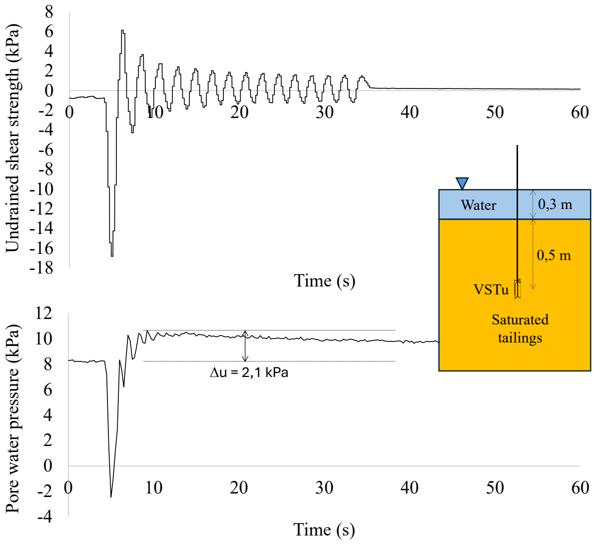

Figure 11. Results of cyclic VSTu test (CVSTu) carried out in tailings.

The vane was manually rotated through 15 cycles, each with an amplitude of 50 degrees, 25 degrees clockwise and 25 degrees counterclockwise, at an average rate of one cycle every two seconds. The results can be divided into three stages:

- Initially a large value of undrained shear strength is observed, accompanied by a significant reduction in pore-water pressure, indicative of dilative behavior,
- Then a pore-water pressure build-up occurs reaching an increase of about 2.1 kPa above the hydrostatic value, which is maintained for a few cycles as the amplitude of the undrained shear strength is rapidly reduced. This is the behavior that would be expected at the onset of liquefaction.
- Finally, a reduction in shear strength amplitude is observed, along with partial dissipation of pore-water pressure during cycling.

The tailings were placed in the container at a saturated unit weight of γ_{sat} = 18.5 kN/m³, which is equivalent to an effective unit weight of γ_{eff} = 8.5 kN/m³. Considering an estimated coefficient of horizontal earth pressure at rest, K_0 = 0.5, the initial horizontal effective stress, σ_h', at the soil depth of the CVSTu test h = 0.5 m, is:

$$\sigma_h{}' = \gamma_{eff} * h * k_0 = 2.1\ kPa$$

This means that the increase in PWP measured during the CVSTu test matches the initial horizontal effective stress at the depth of the test. This is what would be expected in PWP increase when the soil reaches a full liquefaction condition, and it is consistent with the analysis presented by Kouretzis et al. (2017), indicating that the vane shear strength should be normalized by the horizontal effective stress.

Figure 12 schematically presents this analysis, considering observations of Menzies and Merrifield (1980) and Kimura and Saitoh (1983) indicating that the shear distortion of the soil during shearing by a vane is concentrated in a narrow band at the edges of the vane.

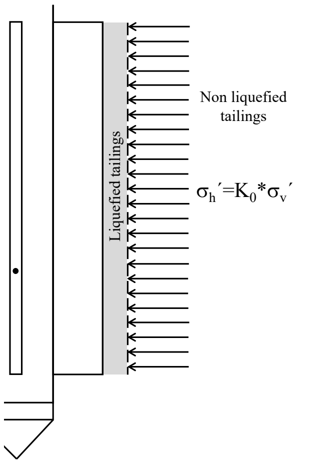

Figure 12. Zone of liquefied tailings during CVSTu test.

Significant work is still required to determine whether a CVSTu is a viable tool to study the cyclic strength of tailings in-situ, but the limited number of tests conducted shows promising results.

7 CONCLUSIONS

An extension of the conventional VST, named VSTu, is proposed, which allows measuring the pore-water pressure generated during vane rotation. Preliminary results are presented, showing that:

- Comparison between CPTu and VSTu tests shows agreement in terms of peak and remolded shear strength, as well as pore pressure development during the tests and dissipation after the tests.
- The possibility of carrying out in-situ cyclic vane shear tests (CVSTu) is explored, the results show the expected pore-water pressure build-up, reaching a maximum value matching the initial horizontal confining stress, as in a fully liquefied state.
- The VSTu relatively large area ratio does not seem to significantly affect the shear strength measurement.

The VSTu test offers a direct measurement of soil shear strength, coupled with the pore-water pressure response under both monotonic and cyclic loading conditions. While additional research is required to fully validate the VSTu apparatus and its testing methodology, the results obtained to date are encouraging.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

Aas, G., 1986. Use of in situ tests for foundation design on clay. In *Proceedings of the ASCE Specialty Conference In Situ'86, Use of In Situ tests in Geotechnical Engineering*.

ASTM International, 2015. ASTM D2573, Standard test method for field vane shear test in saturated fine-grained soils. West Conshohocken, PA: ASTM.

ASTM International, 2018. ASTM D2573, Standard test method for field vane shear test in saturated fine-grained soils. West Conshohocken, PA: ASTM.

ASTM International, 2020. ASTM D5778, Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils. West Conshohocken, PA: ASTM.

Atkinson, J. H., & Jessett, C. A. 1990. Measurement of relative density of saturated sand using a piezovane. *Geological Society, London, Engineering Geology Special Publications, 6(1)*, 229-233.

Bjerrum, L., 1973. Problems of soil mechanics and construction of soft clays. *Proc. 8th ICSMFE, Moscow*, pp.109-159.

Cadling, L. and Odenstad, S., 1950. Vane borer. An apparatus for determining the shear strength of clay soils directly in the ground. *Statens geotekniska institut*.

Carlson, L., 1948. Determination in situ of the shear strength of undisturbed clay by means of a rotating auger. In *Proceedings of the 2nd International Conference on Soil Mechanics and Foundation Engineering* Vol. 1, 265-270.

Cerato, A.B. and Lutenegger, A.J., 2004. Disturbance effects of field vane tests in a varved clay. In *Proceedings of the 2nd International Conference on Site Characterisation, Porto, Portugal. Millpress, Rotterdam, the Netherlands* (Vol. 1, pp. 861-867).

Chandler, R.J., 1988. The in-situ measurement of the undrained shear strength of clays using the field vane. *Vane shear strength testing in soils: field and laboratory studies*, *1014*, pp.13-44.

Charlie, W. A., Scott, C. E., Siller, T. J., Butler, L. W., & Doehring, D. O., 1995. Estimating liquefaction potential of sand using the Piezovane. *Geotechnique, 45(1)*, 55-67.

Flaate, K., 1966. Factors influencing the results of vane tests. *Canadian Geotechnical Journal*, *3*(1), pp.18-31.

Harvey, J.W., Hogan, A.A., Obeidat, D.N., Contreras, I.A. and Kelly, S.A., 2023. Establishing a Site-Specific Standard of Practice for Field Vane Shear Testing in Mine Tailings.

Hogan, A.A., Kelly, S.A., Sharp, J.T. and DeJong, J.T., 2025. A Comprehensive Review of Field Vane Shear Testing in Mine Tailings and Recommendations for Tailored Standards. *Geotechnical Testing Journal*, *48*(1), pp.80-91.

Kimura, T., & Saitoh, K. 1983. Effect of disturbance due to insertion on vane shear strength of normally consolidated cohesive soils. *Soils and foundations*, 23(2), 113-124.

Kouretzis, G., Pineda, J., Krabbenhøft, K. and Wilson, L., 2017. Interpretation of vane shear tests for geotechnical stability calculations. *Canadian Geotechnical Journal*, *54*(12), pp.1775-1780.

LaRochelle, P., Roy, M., and Tavenas, F. 1973. Field measurements of cohesion in Champlain clays. *Proceedings of the 8th International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1.1, pp. 229-236.

Leroueil, S., Rochelle, P.L., Tavenas, F. and Roy, M., 1990. Remarks on the stability of temporary cuts. *Canadian Geotechnical Journal*, *27*(5), pp.687-692.

Matsui, T., & Abe, N., 1981. Shear mechanisms of vane test in soft clays. *Soils and Foundations*, *21*(4), 69-80.

Menzies, B. K., & Merrifield, C. M. 1980. Measurements of shear stress distribution on the edges of a shear vane blade. *Geotechnique*, *30*(3), 314-318.

Morris, P. H., & Williams, D. J. 1993. A new model of vane shear strength testing in soils. *Géotechnique*, *43*(3), 489-500.

Olguín, R. and Ortúzar, M., 2015. Desarrollo e implementación de una veleta de corte a alta revolución para sondajes. *Obras y proyectos*, (17), pp.89-95.

Osterberg, J. O. 1957. Introduction. Symposium on In Place Shear Testing of Soil by the Vane Method. *ASTM Special Technical Publication No 193*, Atlantic City, NJ, USA, 22 June 1956, 1-7.

Reid, D., 2016. Effect of rotation rate on shear vane results in a silty tailings. *Proceedings of Geotechnical and Geophysical Site Characterization*, *5*(1), pp.369-374.

Robertson, P.K. and Cabal, K., 2022. Guide to cone penetration testing. Seventh Edition. Signal Hill, California: Gregg Drilling LLC.

Roy, M. and Leblanc, A., 1988. Factors affecting the measurements and interpretation of the vane strength in soft sensitive clays. In *Vane shear strength testing in soils: Field and laboratory studies*. ASTM International.

Skempton, A.W., 1948. Vane tests in the alluvial plain of the River Forth near Grangemouth. *Geotechnique* 1(2), 111-124.

Teh, C.I. and Houlsby, G.T., 1991. An analytical study of the cone penetration test in clay. *Geotechnique*, *41*(1), pp.17-34.

Wilson, L. J., Kouretzis, G. P., Pineda, J. A., & Kelly, R. B. 2016. On the determination of the undrained shear strength from vane shear testing in soft clays. *Australian Geomechanics Society, Sydney*.