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Increase in Undrained Shear Strength Measured with Shear Vane in Tailings Due to Desiccation in Time

Aumento de la Resistencia al Corte no Drenada Medida con Veleta de Corte en Relaves Debido a la Desecación en el Tiempo

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ABSTRACT: The shear vane test is a in situ test designed to determine the undrained shear strength of fine soils, whose use is convenient due to its flexibility, speed of execution, easy application and even allows obtaining sensitivity in the case of clays. This test technique has been used in the basin of a tailings storage facility located in Chile to measure the increase in shear strength over time due to drying of tailings. This research presents the time variation of the strength through the geotechnical data of 46 measurements, obtained superficially around 0.5 m depth by manual methods in a period of approximately one month. In addition to the field measurements, moisture contents were obtained through laboratory tests on samples taken at the same points where the vane tests were executed. The results of the study lead to the conclusion that, as time of drying goes by, the undrained shear strength of the tailings increases while the moisture content and total density decrease.

KEYWORDS: Undrained shear strength, vane test, moisture content, time, tailings.

1 INTRODUCTION

Tailings storage facilities in Chile generally are the materials left over after the process separating the valuable fraction from the extracted ore and are usually described as non-plastic or low plasticity soils with high void ratio. These features make it difficult to extract undisturbed samples for laboratory shear strength testing and, therefore, geotechnicians prefer in situ techniques when characterizing tailings of a storage facility (Harvey & Contreras, 2023).

One of the widely used apparatus to estimate shear strength in cohesive soils is the Vane Shear Test, whose flexibility, speed of execution and ease of application allows geotechnical engineers and specialists to measure the undrained response of the soil at a specific depth. Given the abovementioned advantages, the hand vane tester has become widely used in projects associated with the growth of tailings dams (Olguín & Ortúzar, 2015).

However, this in situ method also has limitations, which refer mainly to the control of the conditions under which the sample or measurement is taken (Harvey & Contreras, 2023). This makes it necessary to analyze and verify other geotechnical parameters, ideally obtained from laboratory tests on samples taken at the same points where the vane shear tests were carried out.

The objective of this paper is to analyze the geotechnical data from 46 measurements of a tailings deposit located in Chile. These measurements were obtained at 0.5 m depth over a period of approximately one month, based on the application of Hand Vane Tester (ASTM, 2008) for estimating undrained shear strength and through the Sand Cone method (ASTM, 2000) for assessing total density. In addition, from field samples, moisture content and fines content were obtained by laboratory tests to correlate the results and evaluate their variability over time.

2 METHODOLOGY

The field exploration campaign of a tailings storage facility located in Chile comprised in-situ and laboratory tests; the relevant geotechnical data for this research comprised a total of 46 measurements, which were taken from mid December 2021 to January of 2022 according to MC (2012).

Measurements collected include:

- Undrained shear strength (Peak, Su) in kPa, obtained from the Hand Vane Tester,
- In-place wet density (D.M.C.H) in g/cm^3, obtained through the Sand Cone method,
- Tailings natural moisture content (ω) in %, obtained from laboratory tests, and
- Fines content (FC) in %, obtained from laboratory tests.

The data records and site visits were registered in days; therefore, this is the time unit that will be used for comparison.

2.1 *Location of the measurement points*

Seven measurement points were taken within the basin and labeled P-1 through P-7 (see Figure 1). For the purposes of this paper, the measurement points were grouped into sectors depending on the tailings disposal (discharges) and the sequence that tailings wetting occur.

Thus, it was possible to monitor sectors that have the same discharge-drying cycle. Four study sectors were defined:

- Sector A, consisting of the measurements at point P-1,
- Sector B, corresponding to the measurements taken in an area of 0.90 km^2 in the area west of the tailings pond (P-7), in addition to the measurements taken at point P-4. Most of the data are grouped here.
- Sector C, composed of random measurements taken at points P-2 and P-5, and
- Sector D, composed of measurements taken at points P-3 and P-6.

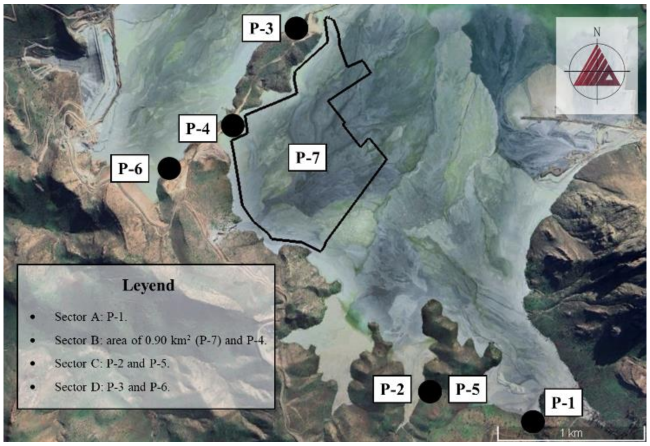

Figure 1. Location of the measurement points.

2.2 *Material characterization*

The material is characterized predominantly as fine soil of low to very low consistency, with fine contents ranging between 50% and 60% mixed with sands, which is essentially tailings coming directly from the thickeners (not processed by the cyclone stations). Figure 2 shows the grain-size curve of 20 samples.

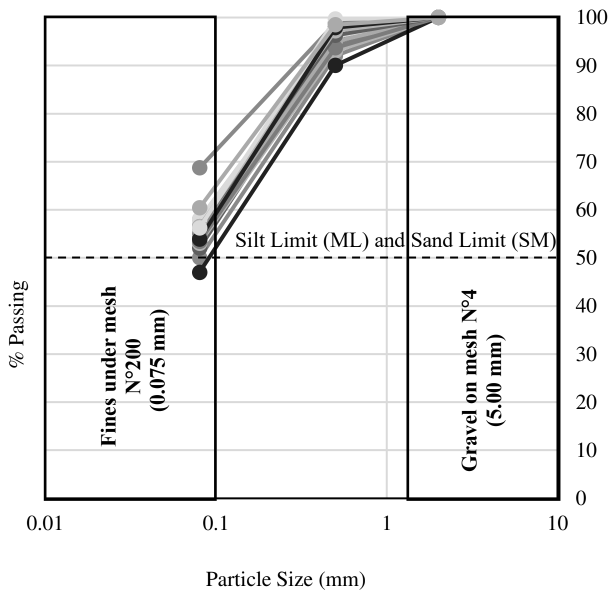

Figure 2. Particle size distribution of 20 samples.

2.3 *Measurements obtained from in situ tests*

2.3.1 *Undrained shear strength*

Shear strength values were obtained using the Hand Vane Tester at 0.5 m depth in undrained tailings, where there was no evidence disturbance coming from people or equipment passing through the surface.

A filtering of the measurements was performed, in which data that were affected by the limitations of the vane shear test and/or its location were discarded. Thus, from the total of 46 data, only 39 measurements of Su were considered along with their measurement date to analyze their behavior over time.

In addition to the readings coming from the hand vane tester, the measurement date was also recorded. This information made it possible to identify a point cloud of undrained shear strength (Su) variations over time for each measurement sector, as shown in Figure 3. These measurements ranged from 1.00 to 30.00 kPa, with an average of 8.80 kPa.

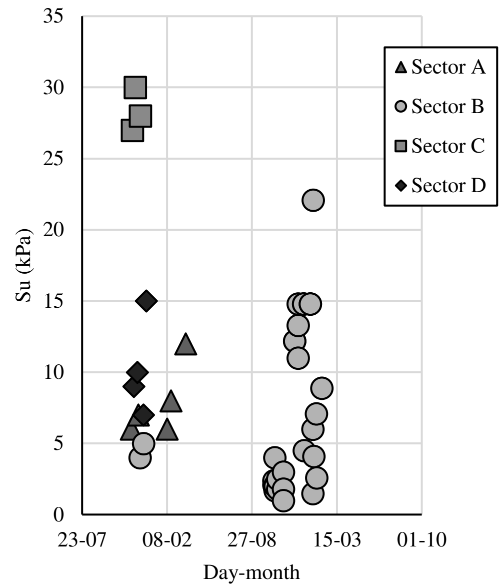

Figure 3. Variation of the undrained shear strength (Su) over time (day – month).

Based on these results and the field observations, it was estimated that each decrease in the undrained shear strength is related to a new tailings discharge cycle, and the drying process occurs from the end of the hydraulic discharge, leading to an increase in the undrained shear strength.

2.3.2 *In-place wet density*

The in-place wet density measurements (DMCH, in g/cm^3), obtained with the Sand Cone method 18 times in the field, provided values ranging between 1.34 and 2.04 g/cm^3 with an average of 1.88 g/cm^3 (see Figure 4). In this case, it is estimated that the total density will have an increasing trend with respect to the measurement date for the same time cycle (before hydraulic discharge).

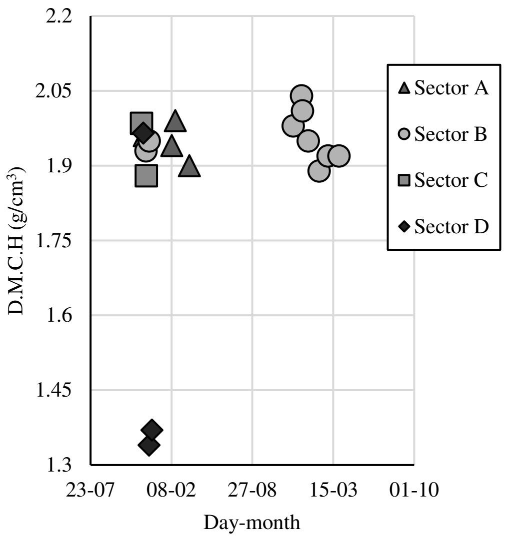

Figure 4. Variation of in-place wet density over time (day – month).

2.4 Laboratory test results

2.4.1 *Moisture content*

Moisture content measurements obtained in laboratory tests range from 16.4% to 36.5%, with an average of 27.7% for 35 samples (see Figure 5).

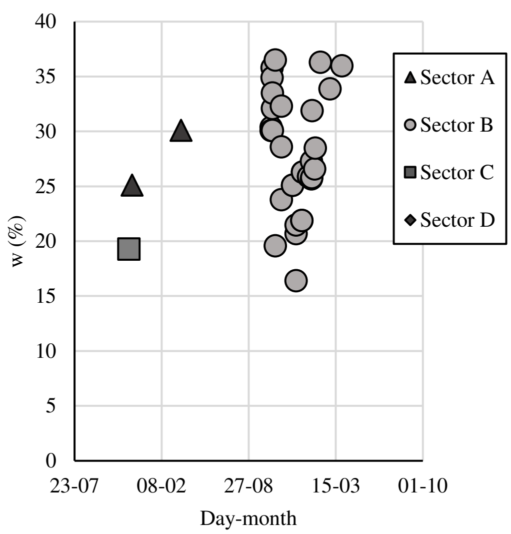

Figure 5. Variation of moisture content over time (day – month).

2.4.2 *Fines content*

The fines content was obtained for 23 of the 46 measurements recorded. This feature of the material samples allowed to correlate the fine content (FC) with the undrained shear strength and moisture content.

3 RESULTS AND DISCUSSION

3.1 *Variation of undrained shear strength and moisture content over time*

The variability of shear strength and moisture content over time was evaluated, considering the date and location of the measurement points within the tailing's basin. From the obtained results, it is worth noticing that the undrained shear strength (Su) increases as the days go by of tailings drying, regardless of the evaluated sector. Figure 6 shows the variation of Su over time according to the discharge-drying cycles of 32 Sector B samples, location where most of the measurements were grouped.

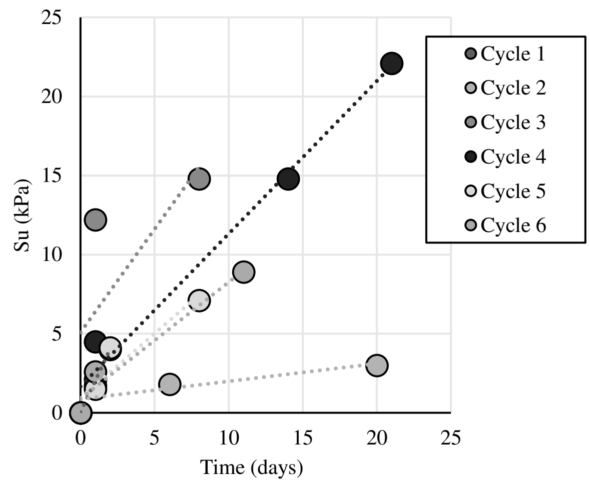

Figure 6. Variation of Su shear strength over time (days) according to the discharge-drying cycles of 32 Sector B samples.

In relation to the moisture content and, considering that the measurements were taken at the same points where the undrained shear strength tests were carried out, it is evident that for tailings drying to occur, the moisture content must decrease. Figure 7 shows the follow-up of moisture content (%) versus time (in days), where 4 drying tailings cycles from Sector B loose water content as part of the drying phase of the cycle.

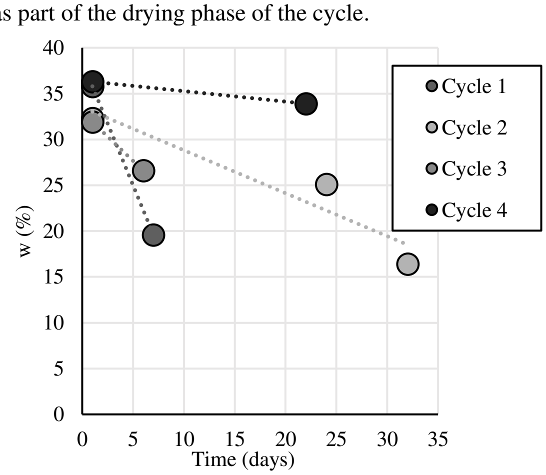

Figure 7. Variation of moisture content over time (days) according to the discharge-drying cycles of 32 Sector B samples.

The study of both graphs (Figure 6 and Figure 7) allows to conclude that there is an inversely proportional relationship between undrained shear strength and moisture content as time goes by for the same tailings discharge cycle.

It is observed that, in case the moisture content is low (less than 25%), the measurements of Su are scattered, so the behavior of Su will depend not only on the time elapsed, but also on the range of values in which the natural moisture content is found.

Given this, the variability of Su has been studied over time with different moisture contents, the result of which is presented in Figure 8. It also shows some measurements that were not only carried out in the same area, but also at the same point at different times. This allows us to infer the behavior of the shear strength measurement over time during summer season.

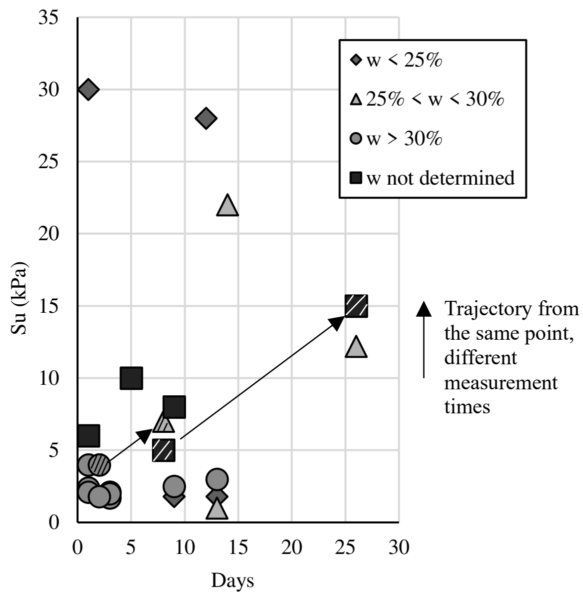

Figure 8. Variation of undrained shear strength over time (in days) considering different moisture contents.

3.2 *Fines content and undrained shear strength considering different moisture contents*

Finally, due to the predominance of fine particles in the tested material, the influence of the fines content on the behavior of the shear strength and the measured moisture content was analyzed. For this purpose, the data along with trendlines are plotted as a chart in Figure 9, where all these variables are considered, and zoning is carried out according to the most marked trends of the measurements.

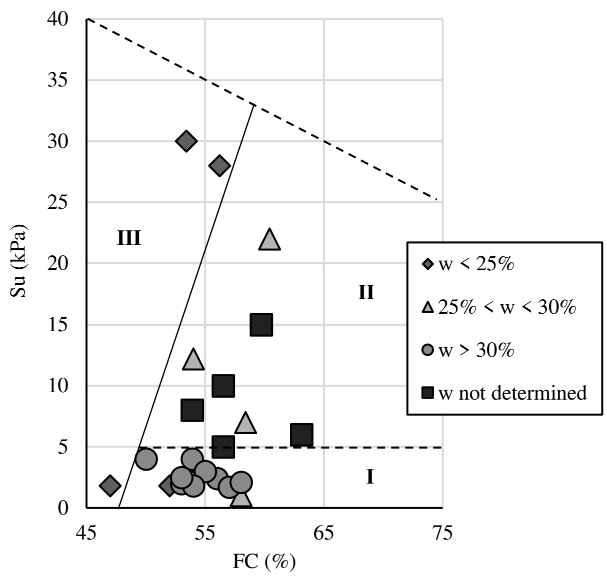

Figure 9. Undrained shear strength versus FC for different moisture content ranges.

4 CONCLUSIONS

This study presented the registered changes of the shear strength in tailings measured in situ with a hand vane tester in the basin of a tailings dam, during the execution of a geotechnical campaign. The results of the field work complemented with laboratory testing indicate that the magnitude of the undrained shear strength of tailings can show significant changes depending on the moisture content; in particular, it was estimated that the decrease in the undrained shear strength is related mainly to the tailings disposal cycle, whilst the increase in the undrained shear strength is most closely associated with the drying process that occurs after tailings are discharged.

The follow up and analysis of shear strength and moisture content variability over time of monitoring zones previously defined allowed to conclude that that there is an inversely proportional relationship between undrained shear strength and moisture content as time goes by, which is conditioned in this specific case for the tailings discharge cycle of the storage facility. Notably, it is worth mentioning that during the increase of the shear strength and consequently the loss of moisture content, the former can be amplified by two or more in a ten-day time.

The results also suggest that it is possible to make a reasonable estimation of the mechanical properties of tailings. A relationship between Undrained shear strength versus FC considering different moisture contents gathered in quadrants is proposed, where it can be seen a clear trend for samples with moisture content over 30% in terms of undrained shear strength and, inversely, scattered data for samples with moisture content below the previously mentioned threshold. In this regard, additional data is required to improve estimations in the latter data set.

Although the results are subjected to error during testing the shear vane test, sampling, statistical analysis and refer to a specific study case, they allow to carry out a quantitative analysis of tailings properties and provide a starting point of discussion in relation to the changes these properties experience in time. In terms of practical application for the industry, this research article could be a reference as input for projecting earthworks on top of the tailings basin, such as excavations and the construction of berms. Further studies are suggested to gather more data and generate a more robust database to improve the conclusions drawn from this work.

5 ACKNOWLEDGMENTS

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