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Methodology for the Spatial Representation of the State of Compaction in Tailings Dams

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ABSTRACT

It is common today that the control of the compaction processes for tailings deposits is completed in a punctual manner, which partnered with the large volume of residual deposits, often misrepresents the quality of the construction process; therefore weak areas within the structure of the deposit are not detected, and can be generated possible zones of failures.

An analysis of the dynamic variability cone resistance parameter (q_d) is shown, which is obtained from the variable energy dynamic lightweight penetrometer test (Panda 2 ®). The assessment variability was estimated using classic statistical tools.

Estimations were performed for the qualitative characteristics as a function of the relative density (RD %), this parameter was obtained using a correlation with q_{dN1} (normalized dynamic cone resistance parameter). Then, the level of compaction, mechanical behavior and risk of liquefaction is determined showing weak zones. The data processing and geospatial modeling were made using the software Rockworks v.14 ®.

This work enabled a validation of the hypothesis regarding reconstruction of the internal structure of a tailings deposit, through the compaction test parameters whether quantitative (dynamic cone resistance parameter, q_d) or qualitative (compaction, mechanical behavior). Weak zones and corroborating the quality of the compaction test process was performed. Furthermore post compaction control recommendations were completed.

Keywords: tailings dam / Tailing density/ dynamic lightweight penetrometer / spatial variability / liquefaction risk.

INTRODUCTION

Chile is a country with long mining history, with a current annual production over 5 million tons representing his most outstanding mineral (copper) which constitutes over 36% of world production. Over time, this material extraction in Chile has resulted in a decrease in their mineral grade, a concept that refers to the amount of copper per volume of material removed for exploitation, which currently comes to the order of 1.0% copper, which brings multiple problems relating to the storage location of the waste material (Sernageomin, 2012).

Due to the above, Chile's mining history has been a problem to store these solid wastes, considering that are materials that cannot be reused with a particular use. The environmental legislation was developed the necessity to store them in specific places called tailings dams.

Deposits of tailings are classified into two main types, one where the resistant wall consists of coarse granular material and two, sands tailings; the latter being the most widely used because of its low cost, because the building of the construction is part of the tailings. However, sands tailings have some deficiencies in mechanical properties due to its composition, which has brought instability problems, causing natural disasters, human and economic losses.

Currently, the compaction control of tailings dam wall, during the operation, is performed using traditional methods with punctual results, these samplings of a very small amount of dam material versus the entire structure. Consequently, it has a poor representation of the internal behavior of the dam and not ensuring the quality of the construction process (Ojeda M., & M. Zamora, 2015).

In 2012, the NCh 3261.Of.2012 called "Deposits Control Relave-compacting with light dynamic penetrometer" (INN, 2012), which indicates the requirements and instructions for carrying out monitoring of compaction of the sand wall is made official in tailings using light dynamic penetrometer. Also, this technique is correlated with SPT $(N_1)_{60}$ values or CPT values, which are generally used for liquefaction triggering assessment. The application of this new technology has allowed for a more efficient control in terms of speed of execution of the tests, exploration depth, accuracy of results, and direct assessment of the strength of the deposited material. According to these advantages, particularly in this work Panda 2 equipment is used, which allows prospecting depths around 7.0 m as maximum value and determine the level of resistance of the new and old deposited layers. Direct measurement of the instrument is the cone resistance (q_d) (Espinace et al, 2013; Villavicencio et al, 2014).

In order to study the internal structure of a tailings dam in terms of the level of compaction, it has been raised using a geospatial modeling of the most representative variables. Computationally modeling is performed with Rockworks v.15 software, where the input variables are: parameter to simulate (degree of compaction, cone resistance, or other), spatial coordinates and date of execution exploration of each point prospected (Panda 2 ®). The spatial representation is in three dimensions; however, to show more clearly profiles are obtained in two dimensions for each control parameter.

The methodology developed to generate the modeling of compaction control parameters, will aim to structure the internal composition of the tailings dam under study. In this way, it is possible to know the variability of the features found in the dam and probable weak areas are detected in their construction. Therefore, this work develops through the following activities:

- Collection and management of dam studied, through the data obtained from the in situ test.

- Analysis of the parameters' variations that to define the compaction control identifying variation of the sands geotechnical properties. Statistical analysis and subsequently is adopted a theoretical probability density function.

- Estimation of the degree of compaction, mechanical behavior and liquefaction risk, all of these parameters depending of the dynamic cone resistance (q_d).

- Finally, the database obtained to evaluate the internal structure of the dam is modeled in 2 or 3 dimensions.

MEASUREMENTS AND DATA MANAGEMENT

In situ measurements

To measure and control of degree of compaction on the wall of sand, the PANDA test is used. This test determines the degree of compaction and dynamic cone resistance of deposited material. The maximum depth of prospecting is 7 m and in-depth exploration mode is used considering a loosed cone tip (4.0 cm^2 of effective area). Some of the technical features of the equipment are presented in Figure 1.

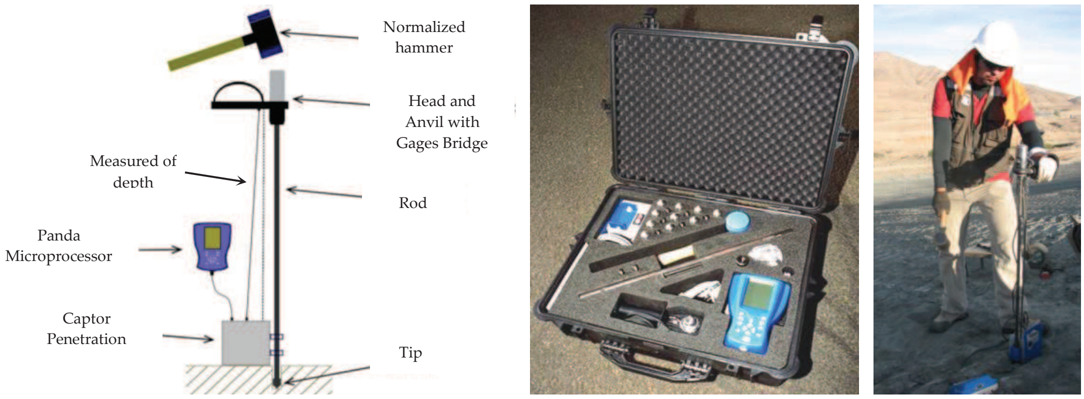


Figure 1 Description of the PANDA equipment and test performance on a tailings dam

Temporal and spatial data management

The collection and management of data generated from the process and permanent monitoring of a tailings dam allow to obtain the process information control of compaction, and thus an analysis of variability such information. The objective is to develop a spatial modeling the internal structure of the tailing dam, identifying weaknesses in the compaction process.

This methodology was applied in the tailings dams where constantly take the control of the compaction by classical methods (SPT, CPT, etc.) and light dynamic penetration tests (For instance: PANDA test). In this work, data is available from the compaction control process conducted between 2010 and 2013 including a database of 107 tests, located in several areas in the wall is generated. This database contains 40,000 specific data dynamic cone resistance (q_d), being able to perform a statistical analysis and spatial interpolations resulting in the reconstruction of the internal structure.

The collection and management of data have the following activities:

- The information compaction control process in the dam is identified, which holds regular checks and standardized construction processes.
- The location of the tests and their execution date is defined.
- Statistical analysis using correlations for qualitative and quantitative characteristics is realized.
- Modeling of the characteristics of the dam with data managed in order to rebuild and to define the internal structure of the soil mass considering all the limitations of spatial modeling.

VARIABILITY ASSESSMENT

Statistical analysis of the variables of interest

This step aims to make a statistical analysis of the data collected in order to determine whether the dam under study comprises a homogeneous material. The analysis is based on the study of the physical properties and parameters of state of the sands, which come from the same mineralogical origin, and are deposited and compacted with the same constructive approach.

In particular, the statistical analysis is performed on the dynamic cone resistance parameter (q_d), that its signals are obtained from the PANDA test performed between 2009 and 2013 years. The tests are distributed on three sections located in different areas trying to represent the global dam structure.

Probability density function

From the available data, a probability density function that best describes the behavior of the variable is adopted, in order to use it as a working hypothesis based and spatial representation model. Once defined, this function is calculated the different statistical parameters and histograms built. Subsequently adapting the function was conducted using descriptive statistical analysis by the proof of Kolmogorov-Smirnov.

Within the statistical assessment, the following parameters are obtained: arithmetic mean, standard deviation and coefficient of variation, the latter being the most important to determine the homogeneity of the dam. These parameters were determined globally as also locally, calculating for each test and by sector. In both analyzes, global and local, always coefficients of variation less than 50% were obtained.

For constructing histograms of the log data penetration resistance it is used, since it has proved that they follow a normal distribution function, as shown in Figure 2.

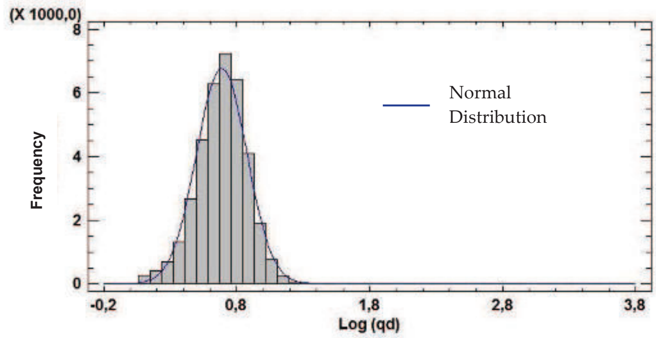


Figure 2 Frequency's histogram for dynamic cone resistance (qd) for Global analysis

The histogram shows a very regular symmetrical shape, and reduced dispersion; also the distribution graph data clearly fits with the histogram.

ESTIMATION OF GEOTECHNICAL PARAMETERS

Correlation between Relative Density (RD %) - qd_{N1}

Although the information obtained directly from compaction control contains quantitative data that can generate a study of variability of the strength properties of the dam and then a spatial modeling rebuilding the internal structure and identification of areas of possible low compaction. Often using variables soil strength is focused academically and will not hand the mining operation, which is why is needed to use variables that represent characteristics of qualities of the compaction process and possible dangers associated such as the risk of liquefaction.

To perform the estimation of the quality characteristics of the control relative density index (RD %), it is essential to know the degree of compaction of soil mass intervals parameter is used. That is why correlations have been used to obtain its value by using the standardized dynamic cone resistance (qd_{N1}) was generated by Villavicencio G. in 2009 (Villavicencio, G. 2009; Villavicencio, G. 2011) from recent calibrations performed in various Chilean dams. Then, the expression to obtain the RD index is:

$$RD(\%) = A \cdot \ln(qd_{N1}) - B \quad (1)$$

The constants A and B depend on the mineralogical origin, physical characteristics in relation to the particle size distribution, and exhibiting moisture content in situ sands tailings.

From the value of qd_{N1}, the following qualitative characteristics of in situ sands were generated:

- State of compaction: The degree or state of compaction is based on the concept of degree of bulk density of granular soil in relation to empty its contents, for this reason it is important to estimate its value to define a criterion compaction process. The characteristics exemplified between traits are (very low, low, compacted, compacted to dense, dense, and very dense).
- Geotechnical and mechanical behavior: The mechanical behavior refers to how the soil mass acts against dynamic action according to their state of compaction and geotechnical properties. Such behavior has three stages, dilatant, contractionary and limit. These steps define the potential risk of liquefaction that has the mass of soil (Verdugo, R. 2005).

These parameters are used in the spatial modeling and allow the definition of possible failures that can affect the sands tailings dam.

Spatial Modeling for control of compaction parameter

The modeling of the parameters of the compaction is done under the assumption that we can evaluate the internal structure of the tailings dam knowing their parameters and their variability. The parameters used are point resistance (q_d), relative density index (RD), compactness, mechanical behavior and risk of liquefaction.

To model the variables Rockworks v.15 software tool is used, which by iteration enables geospatial methodologies represent globally the internal structure of the solid, in this case a mass soil.

The modeling of the studied area occurs in three dimensions, using commercial software based in an algorithm anisotropic reverse, delivering various display modes; solid in three dimensions, profiles, grids, etc.

The steps presented for modeling the compaction control.

- Defining the work area.
- Compilation of background information of compaction control.
- Generation model correctly representing the internal structure of the dam, according to the variability that has, in its mineralogical origin and construction process.
- Determine the best way to visualize the model, providing for easy understanding and comprehension.
- Identification of areas with potential risks of failure, which can be verified by analyzes conducted either globally or locally.

RESULTS AND DISCUSSION

Then, in Figure 3, it is presented graphically a model based on qd parameter measured.

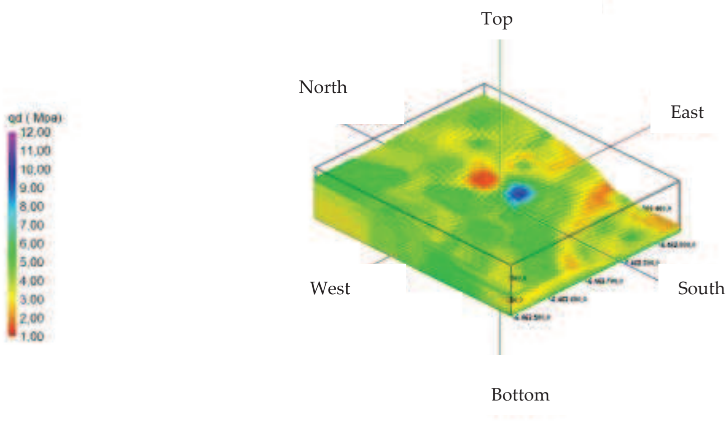


Figure 3 Sand tailing dam spatial model based on dynamic cone resistance (q_d)

It can be seen in the generated model, areas with low resistance on the tip between the ranges of 1.0 to 3.0 (MPa), which probably represents a product of a weak area of poor compaction process. In Figure 4 is shown the spatial modeling parameter qd through a display cross section.

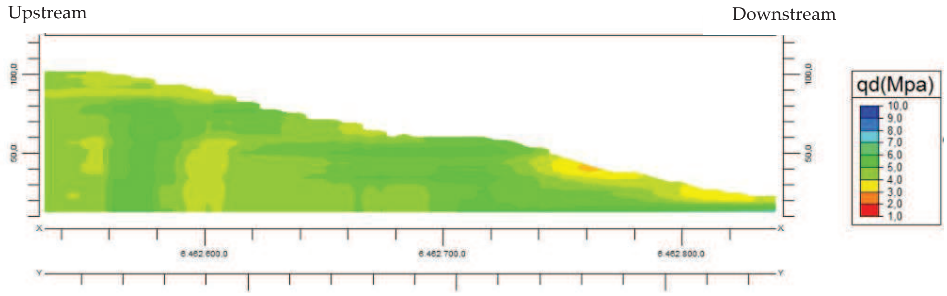


Figure 4 2D Model from cross section of a sand tailings dam

A spatial modeling based on the qualitative state of compaction parameter is presented in Figure 5. To correlate this state parameter with the measured value qd the correlation was given by Espinace R. et al (2013) and updated with recent measurements in 2014 (Figure 5). The color scale defines a particular color for each state of compaction (Figure 6).

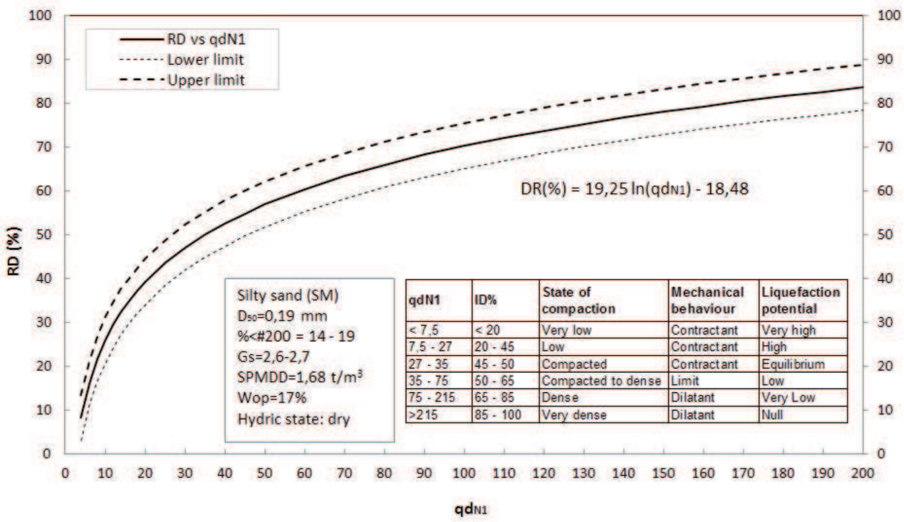
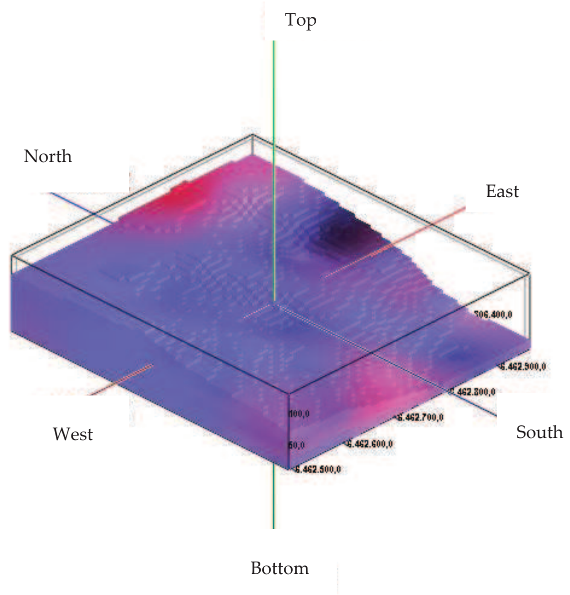


Figure 5 RD Index vs qd_{N1} correlation to estimate the state of compaction in sand tailing dams



Color	Description
	Very dense
	Dense
	Compacted to dense
	Compacted
	Low

Figure 6 Sand tailing dam spatial model based on state of compaction

It can see that the red color correspond to weak compaction, however bluish hues show higher compaction. In Figure 6, it can see that the wall of sand (very dense compacted) is globally well compacted, however it can identify specific surface or punctual areas with low compactness.

CONCLUSION

The methodology proposed in this paper has as objective to be a useful tool for operational control and diagnostic analysis in tailings dams, since it is possible to define the internal structure of years of operation efficiently and accurately. To carry out this methodology, it is necessary to have a large number of penetration tests and always georeferenced, allowing proper interpretation and spatial modeling.

Regarding the 2D and 3D models shown, it may indicate that the computational time used is quite low, meaning there would be no limitation in this kind of analysis. However, for the processing of the data obtained from the PANDA test, it will require adequate data processing, which is based on recommendations and requirements of NCh. 3261.Of.2012 normative.

For future work in this line of research is expected to maintain the proposed methodology considering new correlations between the parameter qd and other parameters relevant to the operation or other design parameters to be controlled.

NOMENCLATURE

q_d	Dynamic cone resistance
q_{dN1}	Dynamic cone resistance normalized by atmospheric pressure (1.0 atm).
A, B	Constants

RD Relative density
ID Index of density or relative density
SPT Standard penetration test
CPT Cone penetration test

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