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Geotechnical characterization of saline soils

Caractèrisation geotechnique des sols salins

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ABSTRACT
A conjunction of field and laboratory tests demonstrates to be more effective than conventional tests in the proper characterization of saline soils. This paper presents a methodology for the study of these soils, which are predominant in regions of the north of Chile and where urban constructions and industrial plants, associated to mineral activities, are important. Test results show the importance of the soil structure of saline soils in their static and dynamic behaviour.

RÉSUMÉ
Un strategie combinée des essais du terrain et de laboratoire montre être plus éficace pour une correcte caractèrisation des sols salins que des essais conventionelles. Ce travail présente une métologogie appliquée a l´étude des ces sols, dont existence est dominant dans les régions du nord du Chili, où la présence des implantations urbaines et industrielles associés à la explotation mineures est important. On montre l'influence de la estructure du sols salins dans la réponse estatique et dynamique.

1 INTRODUCTION

The northern Chilean territory between parallels 17°30 S and 27° S presents saline deposits which are aligned in a north south orientation as a result of the barriers developed through geological processes by the action of Nazca Plate on a deserted area with active evaporation (Fig.1). Nazca Plate acting in subduction against South America plate generates a very intense seismic activity which has to be included in all analysis and design of civil works in the north of Chile.

These salts, which are constituted mainly by chlorides, sulfates, carbonates and nitrates, have been originated at different geological times by various agents, as the marine invasion into the Coastal and Central Depression in the case of chlorides, the intensity of electric storms at the altiplano region in the case of nitrates and by the "saline weathering" of volcanic, metamorphic and sedimentary rocks for all types of salts.

Saline soils are constituted by different percentages and quantities of salts which reach critical conditions when concentrated in crusts of crystallized chloride that after dissolution produce severe damages in structures and pavements.

The ephemeral equilibrium reached in natural conditions is disrupted by human settlements which at the coast are concentrated in urbanized cities, while at the interior, in several mineral industries. Water coming from irrigation, car and truck washing and failure in underground pipes are commonly responsible of the break out of this phenomenon. Mining activities require great quantities of water which, with the use of different acids coming from heap leaching, becomes even more active in the dissolution of salts.

Saline soils present high rigidity and high shear strength in natural conditions, but they change radically in front of water action triggering huge localized settlements in civil works, which can reach even additional settlements under dynamic action. Besides, the salts can act on the structures as very harmful corrosion agents from the natural foundation soils and fills, as well as when used as quarry material for concrete. Among the different salts, the most harmful corrosive agent are the sulfates.

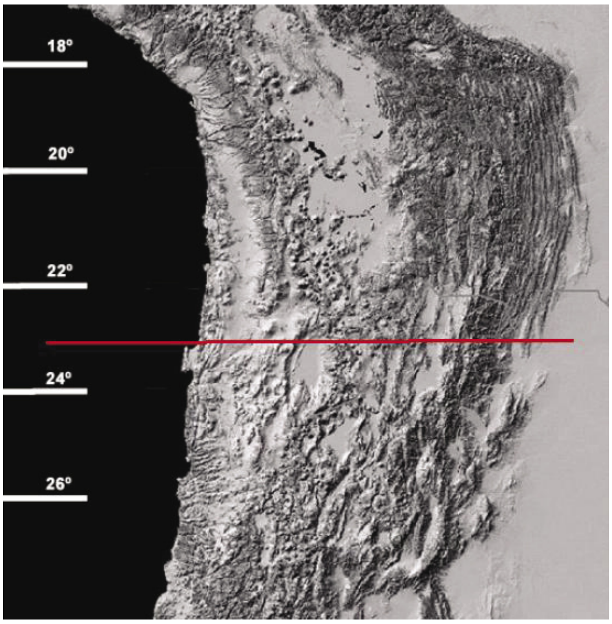
In this paper, the different salt deposits are described and grouped according to their geomorphological features to characterized separately their geotechnical potential risk as foundation materials. Some of these groups are studied in detail for the understanding of the parameters that condition their behaviour before and after salt dissolution, since salinity - defined as the weight of salts referred to the weight of insoluble grains - is unquestionably insufficient.

2 WATER ACTION DURING GENESIS AND DISSOLUTION

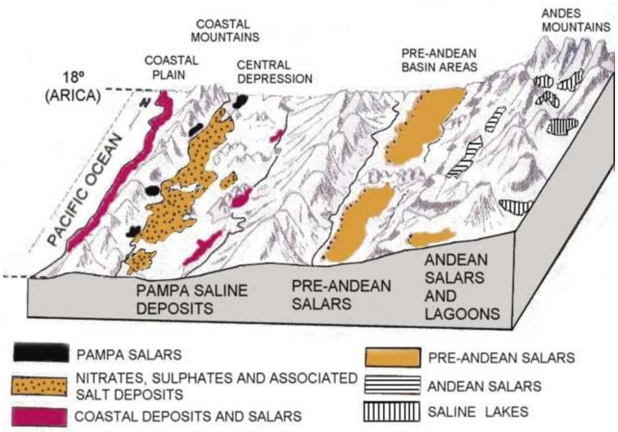
The deposition and preservation of salts on basins and microbasins and also in different landscapes, is determined by local geomorphology and structural features. Salts are carried by superficial and underground waters, being the more soluble salts (chlorides) deposited in flat areas, while less soluble salts as sulfates and carbonates are displaced and deposited closer to the their sources in areas of more inclined topography. The main geomorphological barriers that repressed the movement of water is the Coastal Range as can be observed in Figure 1. The only significant drain of the Central Depression is River Loa with a long and sinous path bordering the Coastal Range after eroding weak rocks and finally draining to the Pacific Ocean.

For understanding the geotechnical process it is imperative to relate the genesis of these deposits with the difficulties or facilities to the access of new waters that saline soils can present. There is a clear relationship between how saline soils were deposited in a given site and the final structure that they present.

The geomorphology of the north of Chile is a result of a chain of geological events which include intense tectonic, magmatic and seismic activities. These processes were initiated by the formation of Paleozoic rocks that gave shape to the Coastal Range with intense volcanic activity, followed by the formation of the Andes Range and the Pre-Andean basins (Fig.1). Thereafter, sedimentary processes occurred in a superficial sea which invaded the Central Depression together with the raising up of the Coastal Range with the deposition of a band of nitrates and associated salts as shown in this figure.



a. Satellite view and geomorphology of close basins



b. Schematic profile of distribution of saline soils in longitudinal bands.

Fig. 1 General view and profile

Saline deposits are classified according to their location related with the movement of free and capillar water. At the coast, where main cities have been settled, salts are commonly encountered mainly as chlorides embedded in the soil, as well as concentrated in a so called crust located in the colluvial sediments at depths ranging between 1 to 2 m. In the colluvial material, the final structure of the saline soil would depend on the relative percentages of soluble salts that come into the water and the salts carried by the colluvial clods themselves.

The salty crust results from a process of deposition initiated by salt precipitation in depth as a result of the reduction of temperature but enriched by capillarity action from salty waters coming from below.

3 SALINE SOIL GROUPS AND CLASSIFICATION

Classification of saline soils is necessary for geotechnical engineering use. A practical classification requires a definition of basic parameters associated with the engineering behavior of saline soils that have to be quantified by rather simplified procedures which can be attainable by existing laboratories. Since conventional geotechnical tests are not covering these needs, it is necessary to establish new parameters and procedures to define these soils. In this paper, certain parameters are defined and the correspondent procedures are described in their basic characteristics.

On the other hand, the type of deposition produces different characteristics among saline deposits which differ radically from colluvial and sedimentary soils. These variations include differences in fabric, structure, mineralogy and salt distribution. Furthermore, each deposit can be associated to particular hydrogeological characteristics whose differences have also to be considered.

Figure 1 shows the main different groups of saline soils according to their structural, volcanic and morphological location, ordered in north south bands but differentiated by the salt types in the transversal direction. These groups are:

(a) Dry lakes of salty water (Gran Salar de Atacama)
(b) Underground lakes (Pampa del Tamarugal)
(c) Nitrate deposits
(d) Colluvial and alluvial deposits
(e) Eolic sandy layers
(f) Marine deposits
(g) Sedimentary rocks
(h) Saline deposits in fractured coastal rocks

4 SALINE SOIL STRUCTURE

From the observation and analysis of different saline soil deposits it becomes clear that the saline soil structure plays an important role in the behavior of these materials. The main argument to support this idea is that the movement of the water through the soil in saturated and capillar conditions is controlled by the type of structure itself. On the other hand, border conditions have to be also considered, because the structure of a saline soil deposit in a micro basin will be stable in natural conditions while a colluvial deposit will modify the salt distribution in depth by the action of water movements.

Soil structures observed in saline soils are complex. They are constituted by inert particles of primary and secondary minerals which are insoluble, plus air and soluble salts which can be present in crystallized and amorphous forms.

In this study, two types of structures are defined. They establish the limits of all observed structures recognized on these saline soils. These structures are:

(a) Macro-Porous Structure (Fig.2)
It is characterized by a continuous open connection of pores that favors the circulation and dissolvent action of the water. The structure consists of particles of granular size (primary minerals) bonded by cement agents which allows the existence of macro porous.

(b) Micro-Porous Structure (Fig.3)
As a difference with the previous structure, it is characterized by a matrix structure, where the voids of the saline soil have been filled with fine soils (secondary minerals). Its permeability is radically reduced as compared with the macro-porous structure.

5 FIELD AND LAB TESTS

Conventional laboratory tests are not applicable for saline soils since the unusual behavior of these soils comes from the dissolution of the salts. It is necessary to concentrate in all factors that influence this phenomenon. Atterberg limits and even grain size analysis appear as irrelevant when characterizing these soils in their natural state. Nevertheless, when dealing with materials that will be used as fills in foundation terraces or earth fills, these tests acquires validity for leached materials.

The behavior of saline soils will be determined by the solubility, content and distribution of the different types of salts. Solubility is mainly controlled by the type of salt and its degree of crystallization. On the other hand, the natural soil structure and the border conditions that control the water flow, are also fundamental.

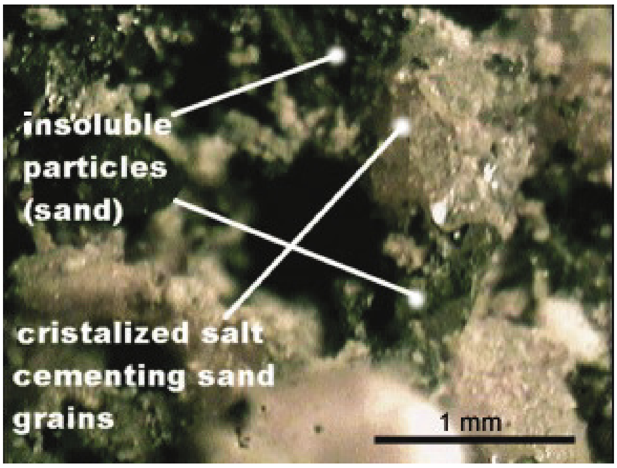


Fig. 2 Macro-porous structure

Fig. 3 Micro-porous structure

An exhaustive inspection and recognition of the following aspects at the site are of outmost importance:

i. visual and careful observation of saline soil structures with emphasis in water conductivity across the different layers and drainage conditions defined by border characteristic of the micro basin,
ii. sampling oriented to obtain a representative salinity profile in depth,
iii. measurements of pH for each layer sampled

The field test that has demonstrated more validity and representation of actual condition is the pseudo plate load test. This test was applied by Skorin, 1971, on a coastal saline crust at parallel 23° S (Fig.4). The steps include excavating an open pit, extracting all materials with salinity less than 3% or down to a given design foundation level, then a precast concrete block is horizontally placed and static load is applied on the block in dry conditions; the pit is then flooded and settlements are measured using precision topographic level on a central vertical bar anchored in the base block; finally, using the bar as an axis, a dynamic load similar to the one used in SPT is applied several times to reproduce a dynamic effect. Figure 5 shows the same pattern in the results obtained in the oedometer at the lab for dry and saturated samples.

In Figure 6 results of several oedometer tests under dry and saturated conditions on saline soil samples with representative macro and micro structures show that salinity does not suffice to explain the significatively different behavior of saline soils, which make unavoidable to include the soil structure in the study of the behavior of saline soils.

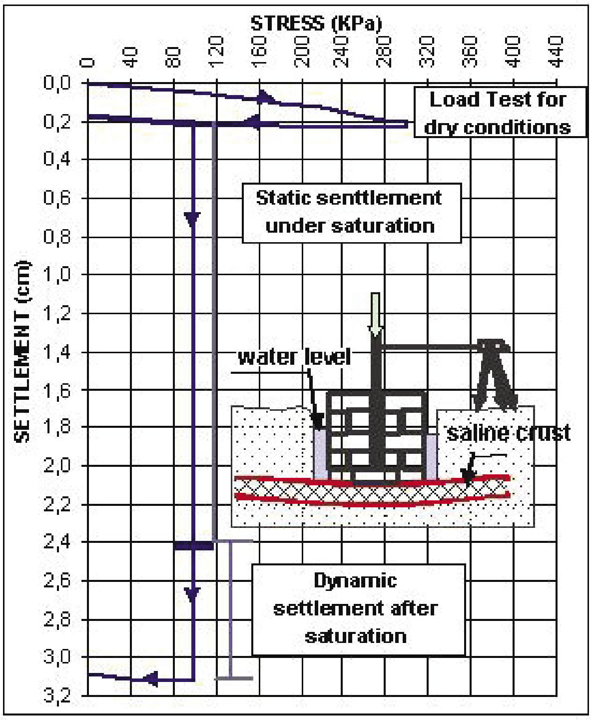


Fig.4 Settlement in load test before and after saturation.

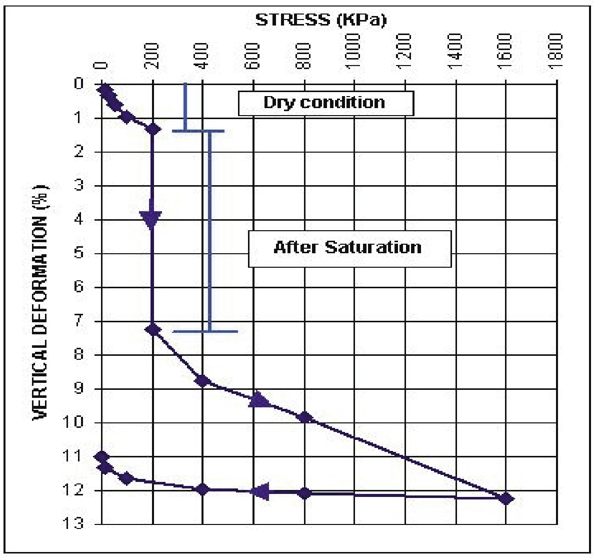


Fig. 5 Oedometer test on saline sample before and after saturation

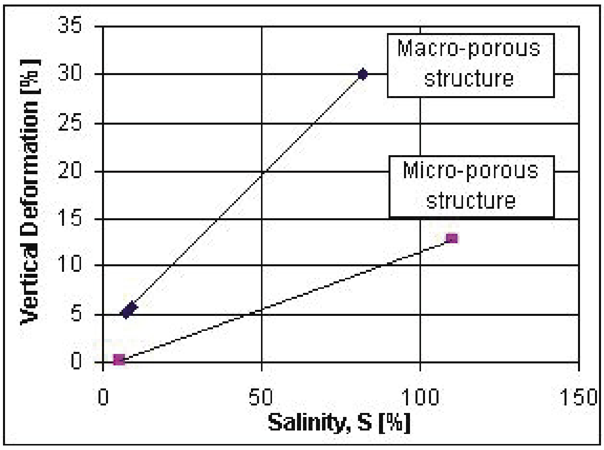


Fig. 6 Influence of structure on deformation after saturation in oedometer tests.

6 CONCLUSIONS

Saline soils in the north of Chile show different characteristics according to their locations and distribution in north south bands. In each site, they present a log of salinity which has to be studied for geotechninal behavior and design. There are differences coming from the potential solubility of each type of salt group, salt content and hydrological and drainage conditions.

Potential settlements are associated to the rapid dissolution of chlorides. Corrosion on foundations is related to the aggressive action of chlorides and sulfates, among which gypsum is the more harmful.

The worst geotechnical conditions are associated to artificial fills constituted by saline soils since salinity, dispersed in the soils, is rapidly dissolved degrading the soil structure, process activated by the water that can percolate in all directions with extreme facility.

Oedometer tests show the same type of behavior observed in in-situ load tests, with clear indication of a significant collapse after saturation. Salinity, as defined, is not enough for evaluating the saline soil response to saturation in terms of vertical deformation. The importance of the fabric of saline soils is demonstrated in the results of tests shown in figure 6, where the macro and micro structure of two natural materials present strong differences for same salinities.

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