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Swell Characterization of Expansive Clays from Comodoro Rivadavia - Argentine

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Abstract. Expansive soils from Comodoro Rivadavia (CR) city (Argentine) cause significate damages in houses and civil infrastructure. A laboratory investigation was carried out over three clays from different parts of the city to study the volume change and swell pressure develop during wetting. Experimental program consists on the physical, chemical and mineralogical characterization. The volume changes were studied with the standard free swelling test, constrains swelling tests and swell pressure tests. The microstructure was studied by mercury intrusion porosimetry (MIP) to evaluate the porous changes for compacted samples for different water content. These investigations show the correlations between volume changes and swell pressures for different water contents and compaction efforts. Interpretation of the laboratory results is presented in the framework of simple models of swelling deformation and swelling pressure. Furthermore, a simple evaluation of the micro and macro porosities to evaluate the expansion potential is calculated for the clay studied.

Keywords. Swell pressure, free swelling, mercury porosimetry.

1. Introduction

The wetting and drying cycles to which a clay can be subjected due to change in climatic conditions produce volumetric changes that can generate important problems in structures or civil constructions such as roads, retaining walls and houses. This behaviour depends mainly on the physical-chemical characteristics of the clay, the history of tensions and suctions to which it was subjected [1-2]. In soils composed by minerals that are susceptible to changes in moisture content, expansions can produce swell pressure higher than that transmitted by the foundation, resulting in a differential lift that can damage the structure [3].

The study of expansive soils has a vast international bibliography. it is possible to find works in which investigators worked to obtain relationships that allow to quantify the potential of expansion in function of the index properties of soils [3-5], studies that depend on the laboratory techniques to measure swelling pressures [6] and analysis of the microstructure of clays subjected to wetting and drying cycles by electron microscopy and mercury porosimetry techniques [7].

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In the Argentine Republic, the studies of the problem of expansive soils focused on the soils of the metropolitan area of the city of Buenos Aires [8-9] and more recently on the expansive soils of Greater Buenos Aires [10]. Specifically, There are some studies in Comodoro Rivadavia city conducted by the National University of Patagonia San Juan Bosco (UNPSJB) in relation to the slide of Cerro Chenque [11], and recently, there have been carried on some studies about the potential of expansion of regional soils [12-14]. In order to study the active soils of Comodoro Rivadavia city, there have been identified different places with soils that have presented pathologies associated to volumetric changes that affected different constructions in the city. The present work presents a series of tests carried out in two sites inComodoro Rivadavia city that presented problems of expansive clays. This study characterizes the expansion potential in term of swelling deformation and swelling pressure. Furthermore, a simple evaluation of the micro and macro porosity to evaluate the expansion potential is calculated for the studied clays.

2. Materials

The samples belong to a surface formation of strongly fissured overconsolidated clays found between 0.80 and 2.20m deep. Two types of samples were taken: one in irregular blocks that were adequately preserved to maintain the conditions in situ in order to carve specimens for the different tests. The other group of samples were air-dried and pulverized to remould specimens at different moisture and compaction pressures. In Figure 1, photos of the materials under natural conditions are shown.

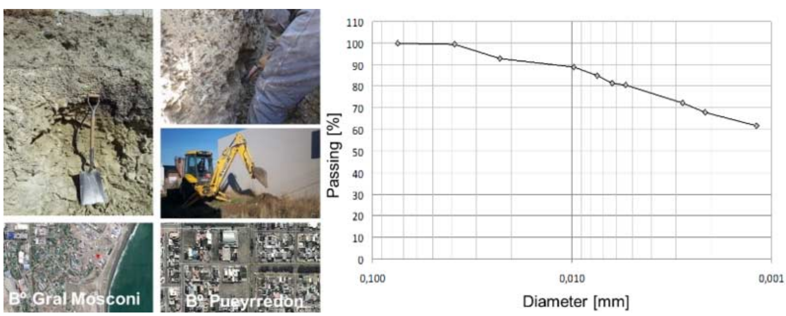

Figura 1. Materials obtained for different location in Comodoro Rivadavia City - Example of grain size distribution for 084/12 sample – Bº Gral Mosconi-.

2.1. Physical properties and mineral composition

A series of identification tests were carried out to characterize the physical properties of this material: granulometry by sedimentation, Atterberg limits, bulk density and specific gravity. Grain size distribution is observed Figure 1 and a summary of the different properties is presented in Table Nº1. The two soils classified as a silty clay of high plasticity (MH) that contains 58.2% to 68.1% of clays fraction (smaller particles 2μm) with a plasticity index equal to 112.7% and 64% and a liquid limit 159.2% and 105% for the two type of soils: 084/12 and 226/13, respectively. The minerals were identified through X-ray diffraction; the clay mineral corresponds to 100% montmorillonite for 084/12 and 113/13 samples. Some impurities were found as quartz, calcite and feldspar. The cation exchange capacity and bound cations were determined following Black

(Black, 1965) and Richter et al. (Richter et al., 1982). 084/12 clay is Ca Smectite and 226/13 clay is a Na Smectite.

Table 1. Physical properties of the clay soil.

Samples City area	084/12 Bº Gral Mosconi	226/13 Bº Pueyrredon
Liquid limit	159	105
Plastic limit	46	40
Plastic index	112	64
Contraction limit	14.0	18.6
% Clay	58.2	68.2
#200	96	95
SUCS	MH	MH
DRX	100% smectite	80% smectite, 20% illite
Superficial area [m2]	648	549
CEC [meq/100g]	49	54
Activity	1.93	0.93

Table 2. Expansion degree for different authors.

Expansion degree	Colloids content	Contraction limit	Free swelling [%]	Swelling pressure [kPa]	LL [%]	IP [%]	Activity
	Holtz & Gibbs (1956)		Seed et al. 1962	Thomas et al. 2000	Chen (1975)		Skempton (1953)
Low	<17	>18	0-15	<81	<30	0-15	0,75
Medium	12-17	8-18	1,5-5	81-153	30-40	10-35	0,75-1,25
High	18-37	6-12	5-25	153-225	40-60	20-55	1,25
Very high	>27	<10	>25	>225	>60	>35	

There are several criteria for classifying the expansion potential of a soil as a function of index properties as is shown in Table 2. Activity of the clays are 1.93 and 0.93. According to table 2, the two clays have a very high expansion potential (LL> 60 [3], IP> 32 [3], Ac> 1.25. [5]).

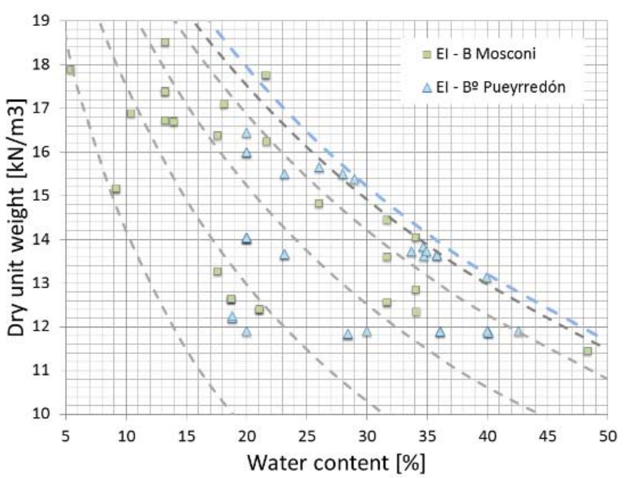

Figure 2. Statically compacted initial states for three clays: 084/12 (Bº Mosconi) and 226/13 (Bº Pueyrredon).

3. Experimental program

3.1. Samples preparation

The specimens for the different tests were obtained by two methods. The specimens carved from the soil blocks obtained in situ (only for 084/12 Clay) and specimens statically compacted. The soils for compacted specimens was air dried, pulverized and sieve by 425μm. Distilled water was added to reach the target water content and then it was homogenized for 24hs in bags. The compaction of the samples was performed by static loading in order to obtain different unit weight as is shown on Figure 2.

3.2. Free swelling and swelling pressure

The tests carried out consist of free swell tests in odometer (FS) (UNE 103-601.94), swelling pressure (SP) in odometer (UNE 103-602.94), and swelling pressure in Lambe´s apparatus (SPL) (UNE 103- 600.94).

Free swelling odometer: In this test, the cell was flooded and measurements of vertical deformations were taken until reaching 24 hours for some samples and also some samples the swelling was measured for several days until reaching cero volumetric strain. The calculation of the percentage of swelling of the sample was determined as a function of the height variation of the sample referred to the initial height.

Pressure swelling in odometer: This test consists of flooding the sample and restricting the swelling through the incorporation of weights in the bench maintaining as much as possible the deformation in +/- 0.02mm. Given the expansiveness of several of the samples tested, and especially at night, this procedure was difficult to maintain.

Swelling pressure in Lambe´s apparatus: Lambe´s apparatus consistson a rigid metal frame with a base where a cell, similar to the cell of the odometer, is located. The sample is confined and submerged in water and in direct contact with the frame through a loading cell. The sample is lightly charged to ensure the sample-hoop contact. Tests carried on using this method measure direct expansion force but have the disadvantage that small vertical deformations occur in the sample and depend on the rigidity of the load cell used. Once the sample is flooded, readings of the expansion force are taken until it reaches 24 hours.

4. Results analysis

Results of of free swelling tests (FS) in odometer for clays 084/12 and 226/13 as a function of water content and dry unit weight are observed in Figure 3. Swelling deformation increase for samples with lower initial water content and with higher initial dry unit weight. For an initial water content and similar dry unit weight, the swelling ratio between the compacted samples (FS = 13.8%) and the caved samples (FS = 28.2%) is close to 2. Samples compacted to dry unit weights between 11-13 kN / m^3 show percentages of free swelling between 10 and 12% depending on water content for 084/12 clay.

Swelling pressure (SP) values measured at 24 hrs performed on oedometer and Lambe's apparatus as a function of the initial dry unit weight of the samples tested is presented in Figure 4. The general trend indicates that there is an increase in the SP for compacted samples when the dry unit weight is higher.

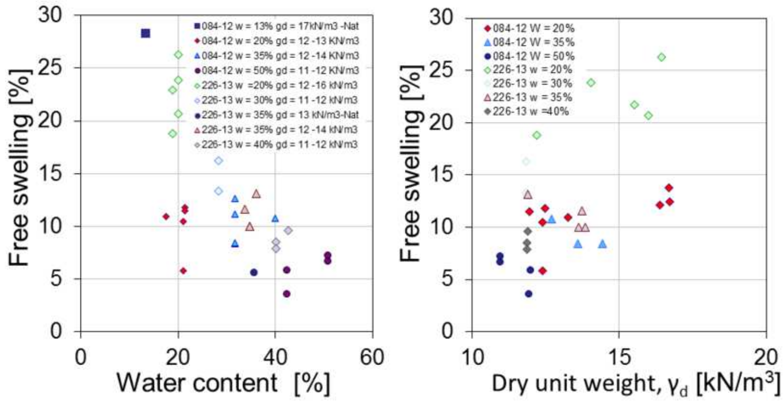

Figure 3. Results of tests of free swelling in oedometer for different water content and dry unit weight for samples of 084/12 and 226/13 clays.

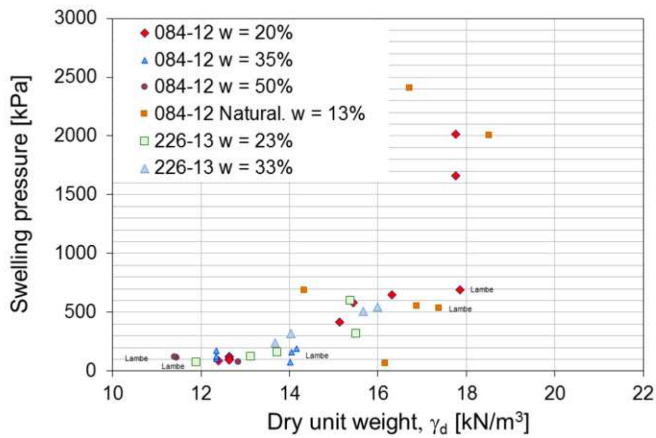

Figure 4. Results of the swelling pressure measured at 24hs and the initial dry unit weight of the samples in carved samples and compacted samples at different water content for 084/12 and 226/13 clays.

The samples compacted at 20% moisture content and γd = 17kN/m^3 reach SP between 1600 and 2000kPa. While the samples compacted to γd = 12-13kN/m^3 reach SP of 100 - 150kPa for the 084/12 clay. The carved samples with natural water content (13%) show an increase in the swelling pressure with the dry density and reaching the maximum values of 2000 kPa. If we observe the value of swelling pressure obtained with the Lambe´s apparatus for similar dry unit weight, the value is reduced to 531kPa. The compacted specimens of 226/13 clay present lower values of swelling pressure (100kPa to 600kPa) for both water content studied (23% and 33%).

Results of free swelling deformation and swelling pressure were plotted in semi-log scale in Figure 5 for compacted samples at different water contents and dry weight between 11-15 kN / m^3. Samples with 35% moisture content have generally somewhat higher dry unit weights, which may be the cause of the higher values of FS and SP with respect to the samples compacted with 20% moisture content of the 084/12 clay specimens. In the case of compacted 226/13 clay specimens, the swelling deformation and swelling pressure presented higher values than 084/12 for similar conditions. These simple semi-logarithmic correlations could be first approach for the design of foundation and retaining walls in these highly expansive soils of Comodoro Rivadavia city.

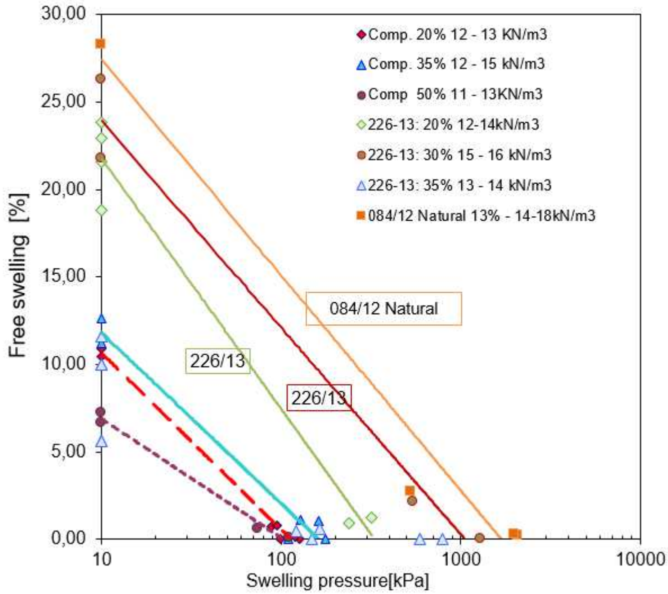

Figure 5. Relationship between free swelling and swelling pressure measured at 24hs for 084/12 and 226/13 clays specimens.

4.1. Mercury intrusion porosimetry (MIP)

Mercury Intrusion Porosimetry (MIP) test were performed only in specimen of 226/12 clay compacted (γ_d = 12.25kN/m^3) at a water content of 20%, 30% and 40% too. The specimens were lyophilized using the freeze-drying method prior to MIP analysis to preserve the microstructure [15]. Cumulative intrusion pore volume increase as the pore size decreases. The volume of pores between two diameters is given by the incremental intrusion between these two diameters. Samples compacted higher initial water content seem to have less volume of pores higher than 100nm than samples compacted at lower water content. For pore size below 100nm occurs exactly the opposite as is shown in Figure 6.

Clayey soils form aggregates dividing the void ratio in microvoids (inside the aggregate) and macrovoids (between aggregates) [1] which can be obtained by MIP as the difference between intrusion and extrusion [15]. MIP underestimates the void volumes since a small quantity of material is used.

An alternative approach is to calculate the macrovoids assuming that air volume is located in macrovoids [19] using the air void ratio $e_{M,0}=e_{air}=e-G_sw$. Therefore, the microvoids (the aggregate) contain only water and are saturated ($e_{m,0}=G_sw_0$). The void ratio after swelling e_f is plotted in Figure 7 as function of both initial void ratio (left) and initial air void ratio (rigth) for two water content (20.6% and 35.9%) of 226/13 clays specimens. Linear relationship in the right plot can be expressed as $e_f=ae_{M,0}+b$ where $e_f=e_{M,f}+e_{m,f}$ .The microvoids could be expressed by the origin ordinate: $e_{m,f}=b$ and the macrovoids are proportional to macrovoids at the initial state (before swelling): $e_{M,f}=ae_{M,0}$. For the 226/12 clay the best fit is $e_f=0.714\ e_{M,0}+1.3$.

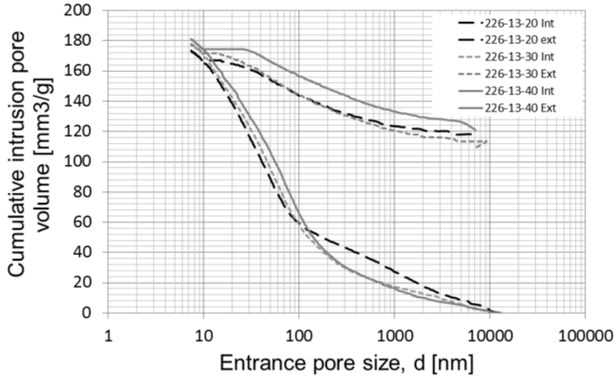

Figure 6. Cumulative intrusion and extrusion pore volume for specimens of 226/13 clay compacted at 20%, 30% and 40% water content.

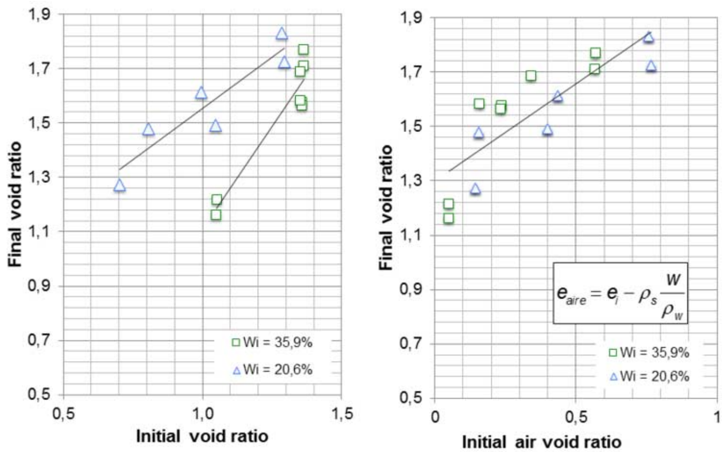

Figure 7. Final void ratio after swelling as function initial void ratio (left) and initial air void ratio (right) for 226/13 Clay.

5. Final remarks

Conventional test performed (index properties, DRX and free swelling and swelling pressure test) for two clays from Comodoro Rivadavia City indicate that we are facing with extremely high expansive soils. Results show the influence of the initial water content and dry unit weight of compacted and carved samples. Data analysis show a semi-logarithmic between swelling deformation and swelling pressures which could be first approach for the design of foundation and retaining walls in the city. Analysis of the micro and macro porosity is presented to evaluate the void ratio after swelling. These results show a linear relationship between the void ratio after swelling and air void ratio.

Microvoids can be estimated as the origin ordinate and macrovoids is proportional to the initial macrovoids.

Acknowledgments

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