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Identification and classification of an expansive soil of Paulista in Pernambuco, Brazil

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ABSTRACT: Cycles of drying and wetting influence the swelling behaviour, the structure and texture of clays as well as lead to the transformation of smectite to illite and thus induce significant structural and textural reorganization of the material. Expansive clays, in both their remoulded and natural state, can present a certain building damage when it is not analysed in an adequate way in the construction and project phases. In Brazil, and specifically in Pernambuco, there is a large occurrence of expansive soils. Soils that experience swell/shrink problems are typically found in the arid, semi-arid soils corresponding to the drier parts of the state and in tropical climate typical of the east coast. Physical, chemical and mineralogical characterization tests (by thermogravimetry (TG) and X-ray diffractometry), suction (filter paper method) free expansion and expansion stress were carried out. The results indicate that the soil has medium to high expansiveness and may cause damage to buildings leading to demolition, especially the smaller ones.

1 INTRODUCTION

The soil volumetric variation (swelling or shrinkage) is due to water gain or loss. This transformation can cause undesirable stresses in the structures of the constructions. The volume change depends on the type of argillic mineral in the clay fraction, because not all filossilicates present volumetric changes when submitted to humidity change. This type of instability is relevant in vermiculites and montmorillonites. Also, it occurs in the interstratified of montmorillonite, mica and vermiculite. The phenomenon of soil swelling is very complex, involving a set of factors, such as the mineralogical composition of the clays, texture and environmental factors, for example: region climate, fluid composition, saturation degree of the soil.

In Brazil, swelling soils can be found in many regions of the country. Among the main known geological formations are the sedimentary basins: Recôncavo Baiano, Paraná and Rio Grande do Sul (Simões 1987). In Pernambuco, Ferreira (2008) identified and studied expansive soils in the following municipalities: Afrânio, Petrolina, Cedro, Cabrobó, Salgueiro, Floresta, Serra Talhada, Petrolândia, Inajá, Ibimirim, Carnaíba, Nova Cruz, Pesqueira, Paulista, Olinda, Recife and Cabo.

The Geographic Information System of the Expansive and Collapsible Soils of the State of Pernambuco (SIGSEC-PE) indicated a high and medium susceptibility of occurrence of expansive soils high in 51.3% of the State area (Amorim 2004; Ferreira et al. 2008).

The objective of this article is to present the methodology frequently used to identify, evaluate and classify the expansive soils of Pernambuco. The swelling soil of Paulista-PE, Brazil, will be used as an example, for exposure of these various methods.

2 MATERIALS AND METHODS

This methodology follows an execution order: regional characterization (climatology and geology), collection of deformed and undisturbed block type samples (ABNT 2016a) and then characterization tests are performed in the laboratory.

The characterization tests in the laboratory used the following methodologies: Preparation for characterization tests, performed under the requirements of ABNT (2016b); granulometry tests (ABNT 2016c); determination of the Liquidity Limit (ABNT 2016d); determination of the Plasticity Limit (ABNT 2016e); Determination of the Specific Mass (ABNT 2016f). The suction of the natural soil was evaluated by the filter paper method, according to Ferreira (1995).

The soil chemical characterization was performed according to the Manual of Methods of Soil Analysis of Embrapa (Donagema et al. 2011). The soil chemical analysis results were calculated according to the new Embrapa soil classification system (Santos et al. 2013): Sum of bases (S); The Cation Exchange Capacity (CTC or T); The Degree Saturation by Bases (V); Saturation per Aluminum (m); Saturation by Sodium and Oxides.

X-ray fluorescence spectrometry (FRX) was used for the quantitative evaluation of the chemical composition of the soil. The ten most abundant oxides contents were determined: SiO_2, Al_2O_3, Fe_2O_3, CaO, MnO, MgO, Na_2O, K_2O, TiO_2 and P_2O_5. Soil samples were placed in an oven to dry at 110°C and then taken to a muffle, at 1000°C, for two hours, for the determination of fire-exposed loss. The soil was analysed in the X-ray fluorescence spectrometer, Rigaku model RIX 3000, equipped with Rh, by the calibration curves method, which were constructed using international reference materials.

The mineralogy was determined by Thermogravimetry (TG), Derived Thermogravimetry (DTG) and X – ray Diffraction. the equipment model NETZSCH STA 409PC was used for this analysis. It has a Nitrogen 5.0 analytical atmosphere and heating rate of 10°C/min, up to a maximum temperature of 1000°C.

In addition, the microstructural characterization of the soil is also performed by Scanning Electron Microscopy. The metallization is performed with gold by evaporation using a vacuum hood of the Fine Coat type, Ion Sputter JfC-1100 of brand JEOL. The equipment was used JSM T200 Scanning Microscope of brand JOEL, with camera attached, and resolving power that allowed zooming of 40000 times.

Finally, conventional edometric cells are used to perform the free expansion and expansion tension tests, following the ABNT (1990g). The samples were carved in stainless steel rings of height 20.00 mm and diameter of 71.3 mm.

The expansion tension was determined by three different methods: 1) Load after expansion with different vertical consolidation stresses; 2) Expansion and collapse under tension: 3) Constant volume in undeformed samples, as described by Ferreira and Ferreira (2009). The values of the expansion potentials (SP), obtained by means of the simple edometric tests, were calculated by Equation 1:

$$SP = \Delta h \text{ x}100 / hi \quad (1)$$

where, *SP* is the expansion potential; *Δh* is the variation of the height of the specimen due to the flood; *hi* is the height of the specimen before the flood.

3 RESULTS AND ANALISYS

Data on the climatic conditions and the results of the climatological and geological characterization of the region, physical, chemical, mineralogical, microstructural and soil expansivity characterizations are presented.

3.1 *Climatological and Geological Characterization*

The region of Paulista-PE is geologically inserted in the Paraíba Basin. In this basin are found the sub-basins of Beberibe, Itamaracá, Gramame, Maria Farinha and Barreiras. According to Barbosa et al. (2003), the Beberibe Formation is composed by medium to thick continental sandstones varying to conglomeratic sandstones of lake fluvial environments. Above the Beberibe Formation is the Itamaracá formation composed of coastal deposits of estuaries and lagoons, containing fossils of saline marine environment, as well as carbonate sandstones, shales and carbonates with rich fossiliferous siliciclasts.

The Gramame Formation is represented by limestones and marls deposited in a carbonate platform of 100 to 150 meters thick. The expansive soil of Paulista-PE is a result of the physical and chemical weathering of claystones and limestone of the Maria Farinha Formation. It is situated in the Janga Sewage Treatment Station (ETE-Janga).

The climate of the region is classified, according to Köppen, as As', hot and humid tropical with a rainy autumn-winter season, with distinct periods of rainfall and drought. The rains are concentrated between the months of April and July, with a high incidence of thunderstorms in the months of May and June.

3.2 *Physical Characterization*

The expansive soil of Paulista has a granulometry with 16% to 31% sand, 17% to 37% of silt and 41% to 51% of clay and the silt / clay ratio decreased with depth, as shown in Figure 1. It has high plasticity (IP ranged from 24% to 34%) and normal activity (ranged from 55% to 73%), according to Table 2. The specific weight was 26.14 KN/m^3. The soil has high compressibility clay (CH) in accordance with the Unified Soil classification.

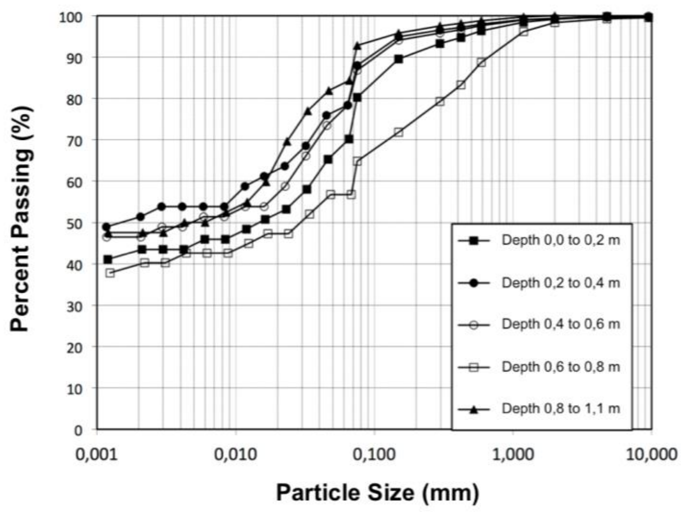

Figure 1. Gravulometric curves.

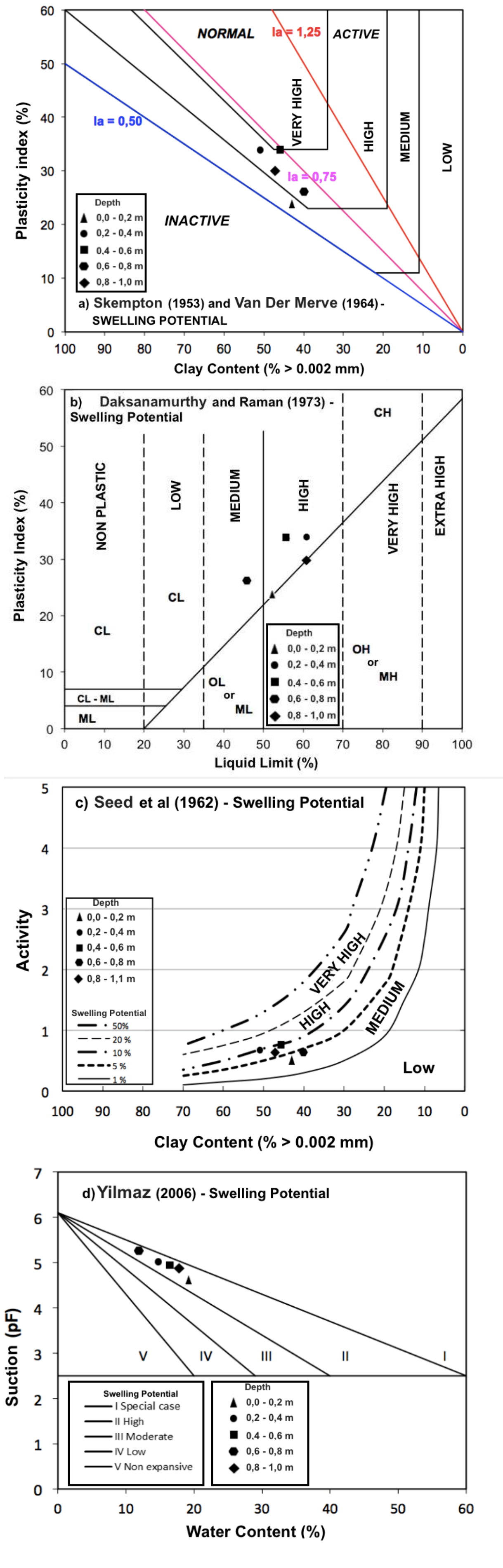

Figure 2. Criteria commonly used in the world to determine the potential for swelling: a) Skempton (1953) and Van Der Merve (1967); b) Daksanamurthy and Raman (1973); c) Seed et al. (1962); d) Yilmaz (2006).

Figure 2 shows several criteria commonly used in the world to determine the swelling potential. The soil physical characterization data were used, and the suction results were obtained considering the soil moisture and the characteristic curve obtained by Justino da Silva (2007). The potential of Paulista clay expansion is medium to high by the criteria of Van der Merve (1964) and Seed et al. (1962) and high by the criteria of Daksanamurthy and Raman (1973) and Yilmaz (2006).

3.3 *Chemical Characterization*

The results of the chemical analysis are shown in Table 1. In the natural soil, the pH is acid (< 7) and the cation exchange capacity is high (CEC > 27 cmol/kg). Base saturation is high for all depths (V > 50%). The percentage of sodium is low to the depth of 0.80 m and has a sodium character (100 Na / T) greater than 15. The cation exchange capacity of a soil can indicate how much soil is evolved, the type of argillic minerals and swelling degree. Buol et al. (1997) consider that soils with CEC higher than 20 $cmol_c/kg$ may present high montmorillonite contents. Silicon oxide prevailed over aluminum oxide and iron oxide (Table 2).

Table 1. Chemical characterization of soil.

Parameters /Unit.		Depth (m) 0,0-0,2	0,2-0,4	0,4-0,6	0,8-1,1
pH		4,91	4,94	4,77	4,93
Na^+	$cmol_c/kg$	1,34	0,22	4,22	14,6
K^+	$cmol_c/kg$	27,73	30,17	19,23	5,01
Ca^{2+}	$cmol_c/kg$	2,10	2,40	1,00	2,30
Mg^{+2}	$cmol_c/kg$	3,40	26,00	23,80	4,40
Al^{3+}	$cmol_c/kg$	7,40	12,00	12,50	10,10
H^+	$cmol_c/kg$	8,90	9,80	9,30	9,80
S	$cmol_c/kg$	34,57	58,79	48,25	26,30
CEC	$cmol_c/kg$	50,87	80,59	70,05	46,30
V	%	67,98	72,95	68,88	56,80
$100Na^+/T$	%	2,63	0,27	6,02	31,50

Subtitle: $S = Na^+ + K^+ + Ca^{2+} + Mg^{2+}$; $CTC = Na^+ + K^+ + Ca^{2+} + Mg^{2+} + Al^{3+} + H^+$; $V = 100\frac{S}{T}$;

Table 2. Values of percentages of oxides and loss when submitted to fire.

	Oxides (%)					
	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO
Paulista Soil	65,54	15,27	5,05	0,68	0,00	0,14
	Na_2O	K_2O	TiO_2	P2O5	PF	Total
	0,00	1,77	0,87	0,02	11,88	97,48

3.4 *Mineralogical Characterization*

In the TG / DTG analysis (Fig. 3a) between 100°C and 250°C there is an intense endothermic peak of water loss; at 400°C, the dehydroxylation reaction of the smectite hydroxide is started, which is completed at 700°C. Figure 4b, with the X-ray diffractograms for the soil, indicate that there is an irregular interstratification involving 2:1 minerals such as expansive micas and minerals (smectites and vermiculites), as well as the presence of kaolinite.

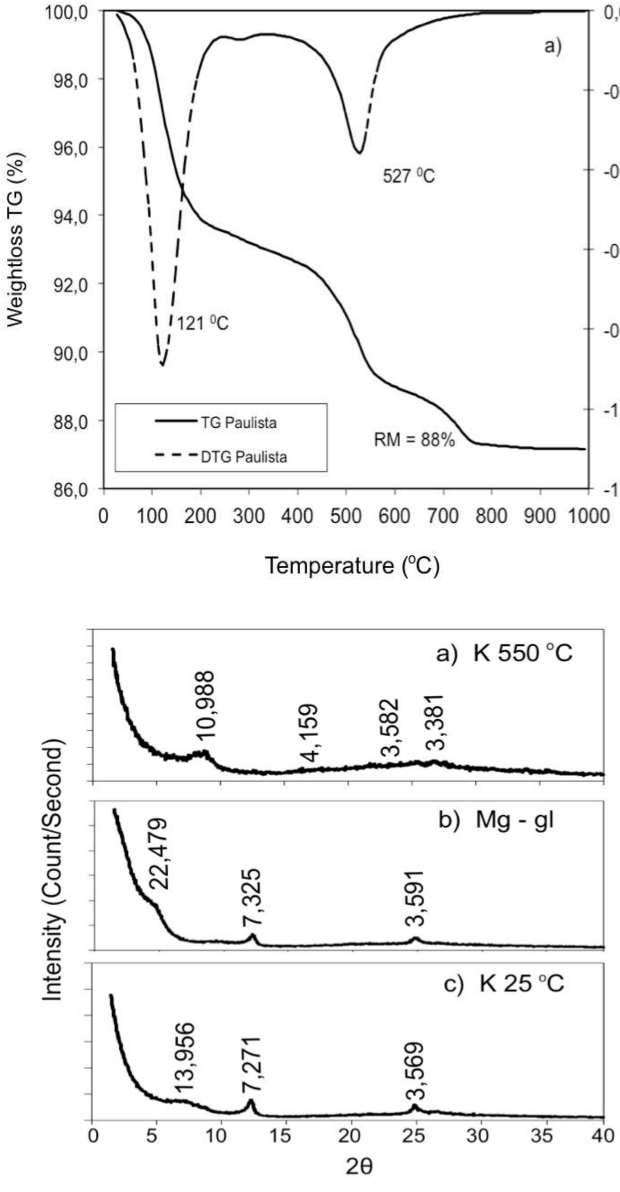

Figure 3. Results: 1st) TD/DTG e 2nd) X-ray diffraction.

3.5 *Microstructural Characterization*

The electron-micrographs of the Paulista soil were obtained from undisturbed samples. The microstructure is characterized by the union of the microaggregates, composed of a clayey plasma (Fig. 4). The soil texture is fine with predominance of silica clays pressed by calcite crystals that make up a large part of the silt fraction and fine sand.

Minor concentrations of particles are sometimes found to be lamellated, probably from the filling of channels, and flattened pores. There are a large amount of flattened pores, resulting from the typical expansion and contraction of high activity clays; small cavities also occur, predominating those of the interconnected type.

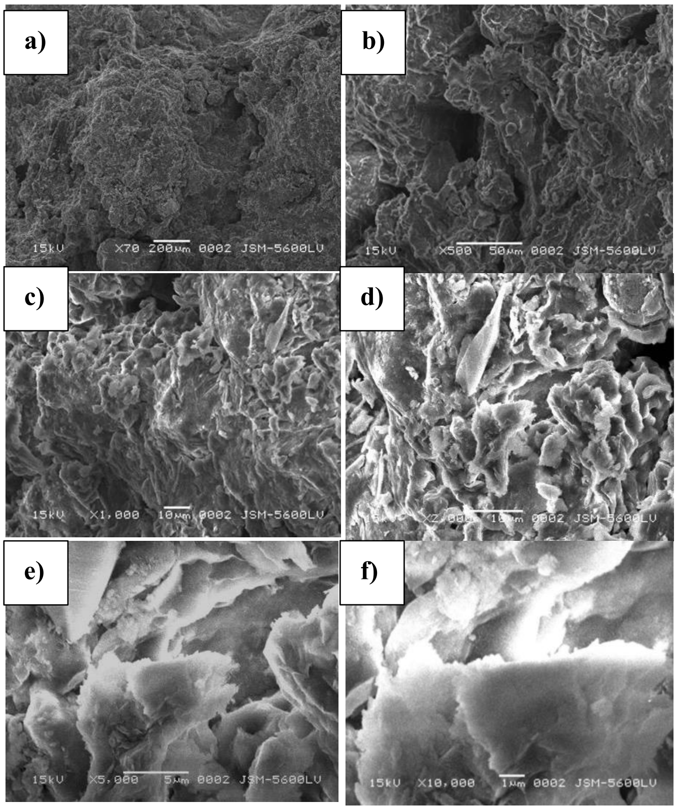

Figure 4. Electron-micrographs with use of zooms: a) 70 times; b) 500 times; c) 1,000 times; d) 2,000 times; e) 5,000 times and f) 10,000 times.

3.6 *Swelling Characterization*

The pressure application and the flood. In Method-1, the sample is first flooded and then loaded; in Method-2, the sample is first carried and then flooded; In Method-3, flooding and loading occur simultaneously. The different stress trajectories applied to the soil used in the methods lead to different values of the swelling pressure. Ferreira and Ferreira (2009) and Paiva (2016) obtained similar behaviour in clay from Petrolândia-PE and Ipojuca-PE.

Figure 5 shows the swelling pressure determined by different methods and Table 3 shows the values obtained. The mean value obtained by the three methods was 252 kPa.

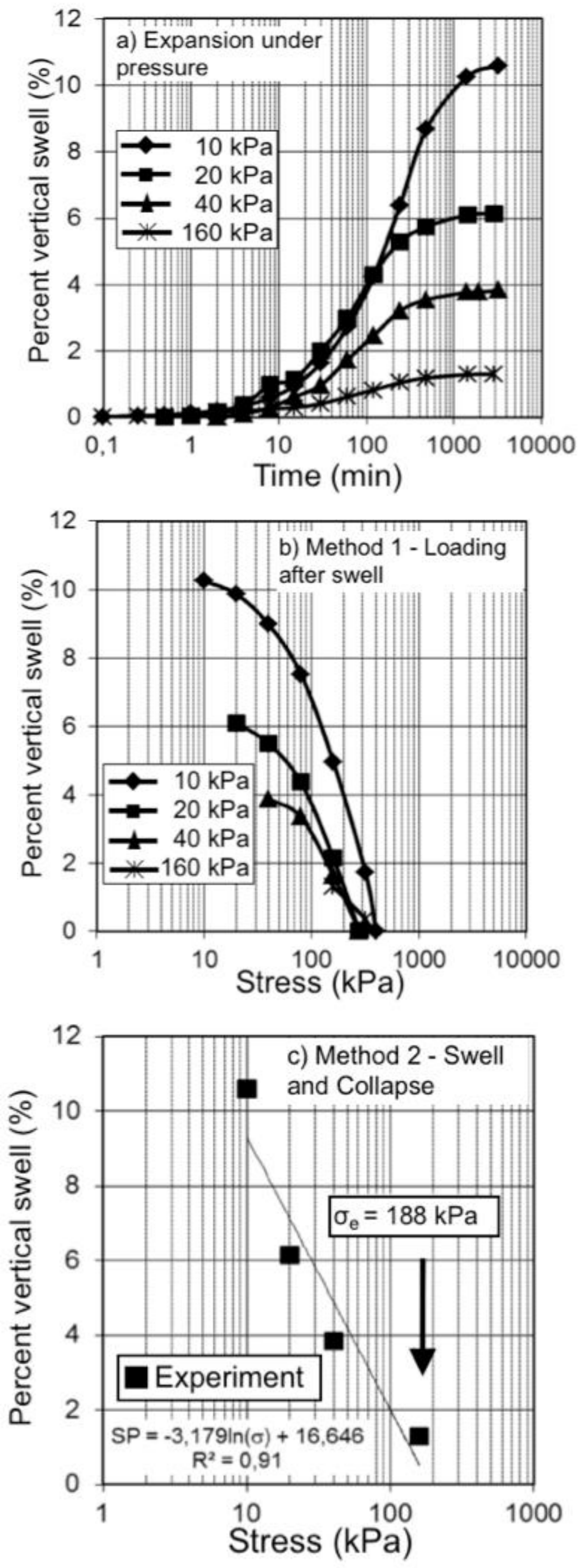

Figure 5. Swelling pressure methods: a) Expansion under pressure; b) Method 1 - Load after expansion with different vertical consolidation stresses; c) Method 2 – Swelling and Shrinking.

Table 3. Swelling Pressures.

Swelling Pressure Method	Swelling Pressure (kPa)		
	Paulista	Petrolândia Ferreira e Ferreira (2009)	Ipojuca Paiva (2016)
Charging after expansion	300	333	190
Swelling and shrinkng under tension	188	239	220
Constant volume	275	242	245
Average value	**252**	**271**	**218**

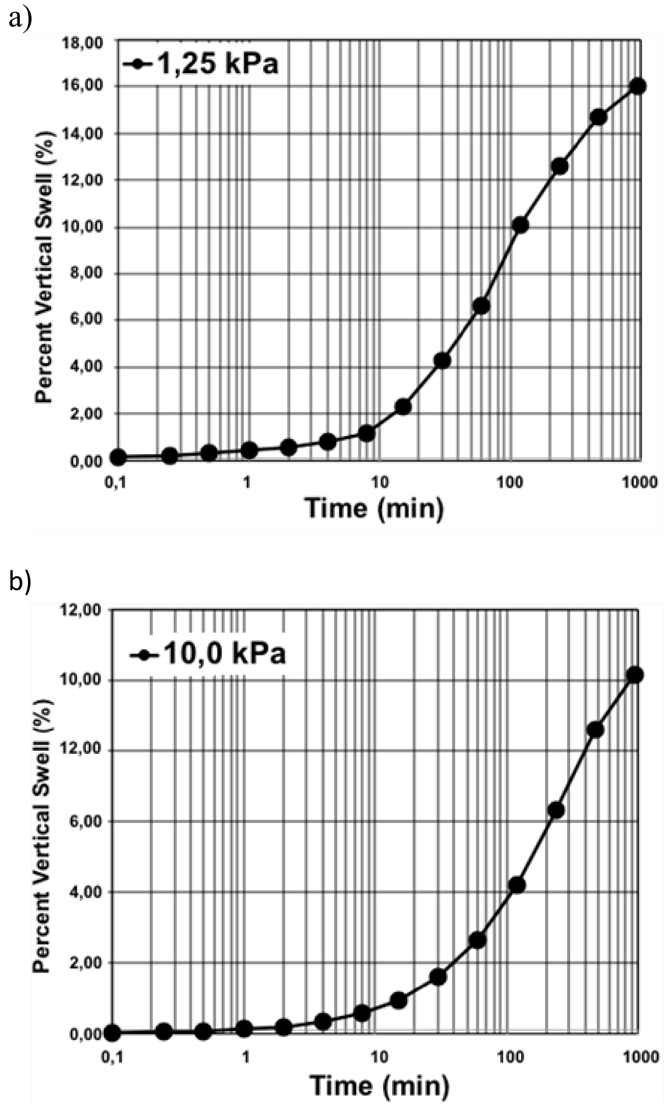

Figure 6. Results of free swelling tests with overloard: a) 1,25 kPa and b) 10,00 kPa.

The "free" swelling calculated by Equation 1 and obtained from conventional edometric tests is 10,16%, an overload of 10 kPa was used. The sample began the test with a height of 19,79 mm and ended with 21,80 mm. While carried out with a minimum overload of 50g or initial stress of 1,25 kPa, the free swelling results in 16,02%. The sample began the second test with a height of 20,00 mm and ended with 23,20 mm. By the criterion of Vijayvergiya and

Ghazzaly (1973), the degree of expansivity is high. These tests can be visualized through the graphic representation in Figure 6.

4 CONCLUSION

The natural soil of Paulista has a high expansivity by the Vijayvergiya Ghazzaly (1973) criterion. There is an irregular interstratification involving minerals of the type 2:1 like micas and expansive minerals (smectites and vermiculites), and the presence of kaolinite. The suction ranges from 5 MPa to 10 MPa and the medium value of the swelling pressure obtained by the three methods is 232 kPa. The swelling pressure is high, according to Jimenez Salas (1980), and may cause the demolition of buildings.

5 ACKNOWLEDGEMENTS

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