Effect of physicochemical interaction on the compressibility of tropical gneiss residual soils

Effet de l'interaction physico-chimique sur la compressibilité des sols résiduels des gneiss tropicaux

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ABSTRACT: When soils are inundated with liquids other than water, a physicochemical interaction takes place and can alter the soil behavior. Depending on the type of soil and on the solution, the soil can become more compressible and lose strength (or the contrary). In this paper, tropical residual gneiss soils are used, namely lateritic and saprolitic soils. The solution used are a mixture of sodium hexametaphosphate and sodium carbonate. Solutions were prepared with different concentrations such that the pH value remained at 10.5. Sodium concentration was used to interpret the results. Oedometer tests were carried out with samples permeated with these solutions. The lateritic soil behavior was found to be quite distinct from the saprolitic one. While the lateritic soil becomes much more compressible upon the increase in the concentration of sodium, the saprolitic soil swells progressively

RÉSUMÉ: Lorsque les sols sont inondés de liquides autres que l'eau, une interaction physico-chimique a lieu et peut altérer le comportement du sol. Selon le type de sol et la solution, le sol peut devenir plus compressible et perdre de la force (ou au contraire). Dans cet article, on utilise des sols de gneiss résiduels tropicaux, à savoir les sols latéritiques et saprolitiques. La solution utilisée est un mélange d'hexamétaphosphate de sodium et de carbonate de sodium. Des solutions ont été préparées avec différentes concentrations telles que la valeur du pH reste à 10,5. La concentration de sodium a été utilisée pour interpréter les résultats. Des tests oedométriques ont été réalisés avec des échantillons imprégnés de ces solutions. Le comportement du sol latéritique s'est révélé très différent de celui saprolitique. Alors que le sol latéritique devient beaucoup plus compressible par l'augmentation de la concentration de sodium, le sol saprolitique se gonfle progressivement.

KEYWORDS: physicochemical, tropical soil, lateritic soil, saprolitic soil

1. INTRODUCTION

Physicochemical interaction can turn soils not previously presenting engineering problems into problematic soils. For example, non-expansive soils can swell or non-collapsible soils can be deformed through collapses caused by the infiltration of liquids that alter the soil structure. Tropical soils have quite a different chemical and mineralogical composition as compared to temperate soils, as they have a dominance of minerals with a variable charge as well as distinct electro-chemical behavior. Consequently, research is needed to expand the knowledge of the mechanisms and factors related to physical and chemical interaction processes and their impacts in terms of structural changes and geo-mechanical behavior.

2. MATERIAL AND METHOD

The specimens were collected in the municipality of Ouro Preto in the southeast of Brazil. The geotechnical profile is typical of a residual gneiss soil in a tropical environment. Futai et al (2004, 2005) summarize the conventional data of the physical index and the granulometric composition of this location (Fig. 1). The surface layer is a lateritic soil, while the lower layer is a saprolitic soil. The soil samples were collected at 1 m and 5 m depths to represent both types of soil. In this paper, results of geotechnical tests with chemical solutions will be presented and only conventional tests were performed by Futai et al (2004).

To simulate real situations in laboratory, in which the soil is percolated with different chemical substances, the interstitial fluid was replaced with a solution used on a daily basis in soil laboratories, with a simple stable chemical composition that can be dissolved in water capable of inducing structural changes without dissolving the clay minerals in the soil. Solutions containing sodium hexametaphosphate $(NaPO_3)n$ and sodium carbonate (Na_2CO_3), with predefined concentrations and pH=10.5, were selected.

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Conventional oedometer tests were carried out on inundated samples of lateritic and saprolitic soils, which were intact, remolded and permeated with solutions containing sodium at concentrations of 0.68g/l; 0.83g/l; 7.67g/l and 55.37g/l. The samples were inundated with distilled water or with solutions after the stabilization of the settlement corresponding to the 3.125 kPa stage (settlement load). The increases in load stages maintained the ratio $\Delta\sigma v/\sigma v=1$. In the tests with the solutions, after the stabilization of the deformations corresponding to the inundation with solution, the samples were percolated with a volume of the solution equal to twice their void ratio. The duration of each loading stage was sufficient to allow for the stabilization of deformations.

The soil parameters were obtained using conventional methods. The pre-consolidation stress was determined by the Casagrande method and was called vertical yield stress, σ_{vy}. The influence of physicalchemical interaction on the soil characterization can be found in Martins (2004).

3.RESULTS

The void ratio of the lateritic soil varies a lot due to its heterogeneity. Various tests were carried out with the same solutions, as shown in Figure 2. The vertical deformation could not normalize the compression curves. For the samples with the highest void ratio and in the same test conditions, the greater the void ratio, the lower the vertical yield stress was observed.

The alteration in structure and the dispersion of clay can also be seen in the compressibility of the lateritic soil. The greater the concentration, the more compressible the soil becomes.

The compression curve of the remolding soil depends on the initial water content (or void ratio) in which the sample was prepared. It was not possible to prepare remolded samples with e=1.0, since at this level there was too much water content below the liquid limit. Figure 2 allow verifying that the compression curve of the intact soil is positioned above the curve of the remolded soil, a behavior typical of structured soil. The presence of cementation due to iron oxides and hydroxides and aluminum allows the intact soil to maintain void ratios higher than the remolded soil. Figure 3 shows the results of the oedometer compression tests for the saprolitic soil, while the compressibility curves were also obtained.

Some tests were carried out in duplicate (Figures 3a, 3b and 3c) to investigate the heterogeneity of the soil and the repeatability of the tests. The compression curve of the intact soil is positioned below the curve for the remolded soil at the liquid limit, a characteristic that is typical of soils that are not structured by cementation. The 5 m-depth has this structure due to the interlocking arrangement of its constituent materials, and is similar to a highly over-consolidated soil. This aspect was visualized with SEM sweep tests (Futai et al, 2015), as reported above, in relation to the soil description. In Fig. 3d, compression tests were selected with initial vacuum levels between 0.9 and 1 in order to compare the results without the interference of heterogeneity. When the soil was tested with solutions, the results were in an intermediate position between those of intact soils and remolded soils.

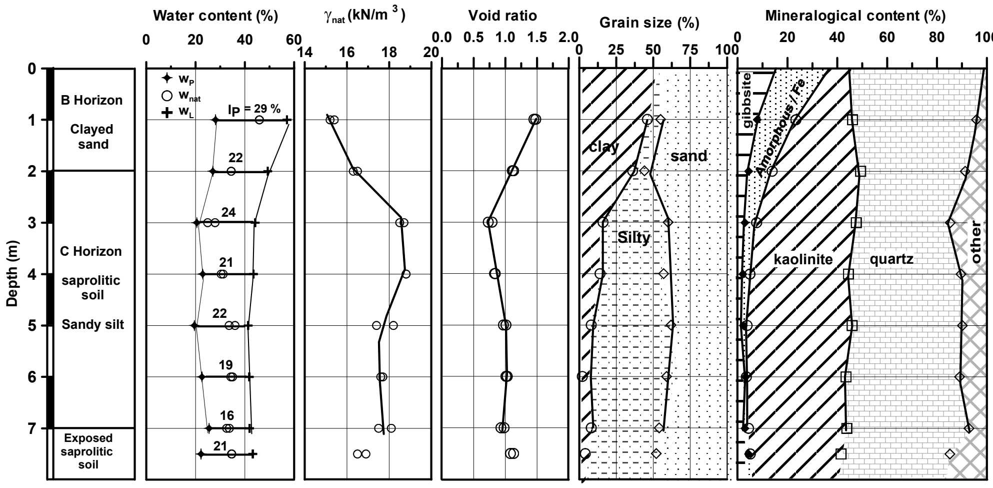

Figure 1 - Site characteristics (Futai et al, 2004).

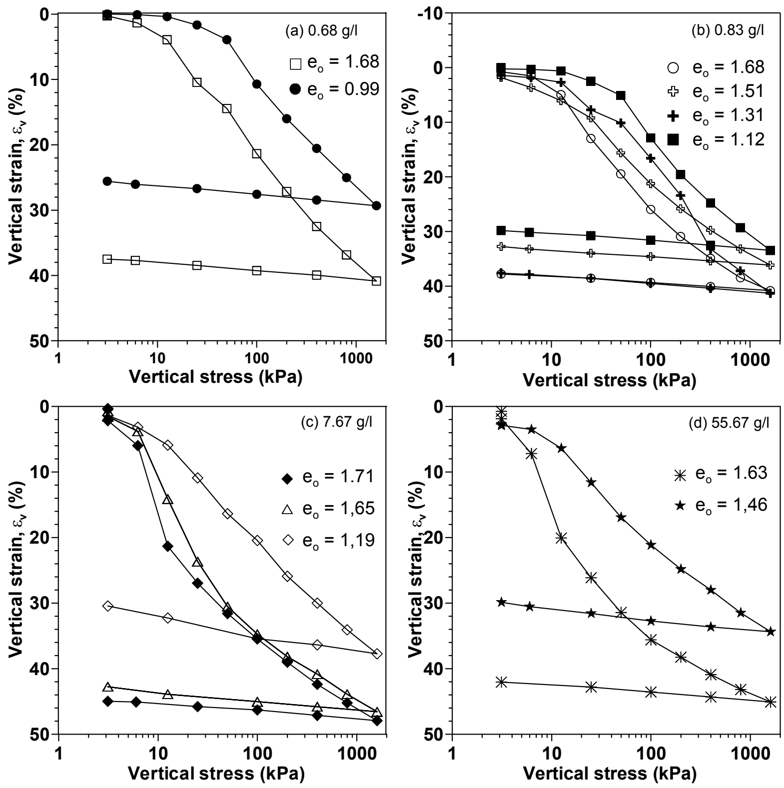

Figure 2. Compressions curves of lateritic soil (1 m depth): void ratio influence

The greater the concentration, the greater the initial swelling; for higher stresses, the curves are convergent (Fig. 3d). The parameter Cc for σ_v > 500 kPa is practically the same; i.e., concentration and remolding do not exert an influence, as shown in the detail of Figure 3. This was limited to a vertical stress equal to 30 kPa and included the volumetric strain due to swell. The intact soil did not swell when inundated with distilled water, while inundation with the solutions caused significant expansions of up to 5% (Fig. 4). The vertical yield stress σ_{vy} is reduced with the increased concentration of Na. This occurs due to the initial swelling which raises the initial part of the curve. The recompression index did not practically vary for the different conditions tested, while remolding caused the breaking of the mineral arrangement, resulting in destructured soil

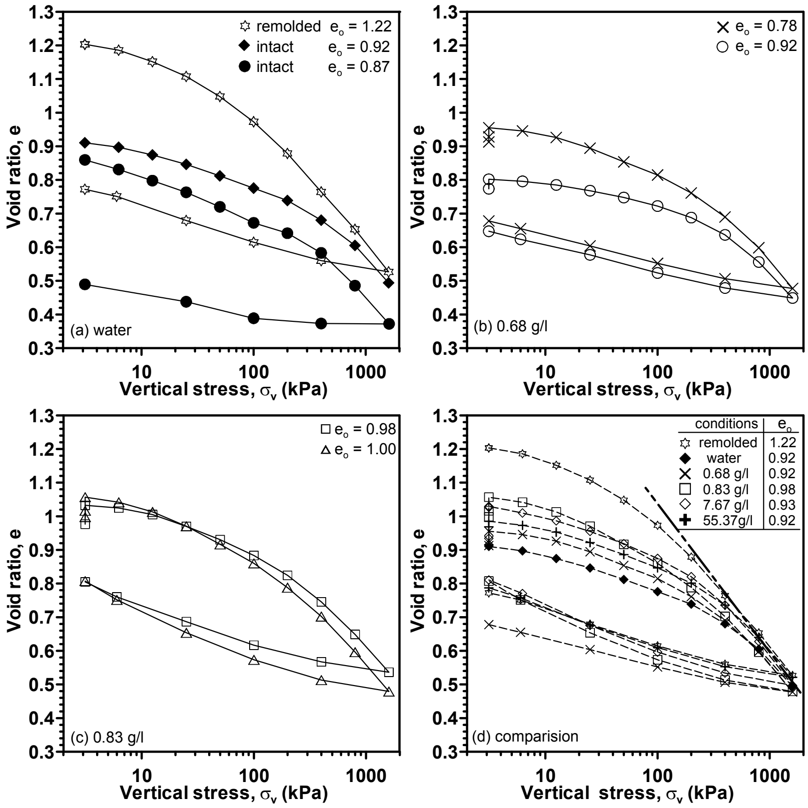

Figure 3 - Compressions curves of saprolitic soil (5 m depth)

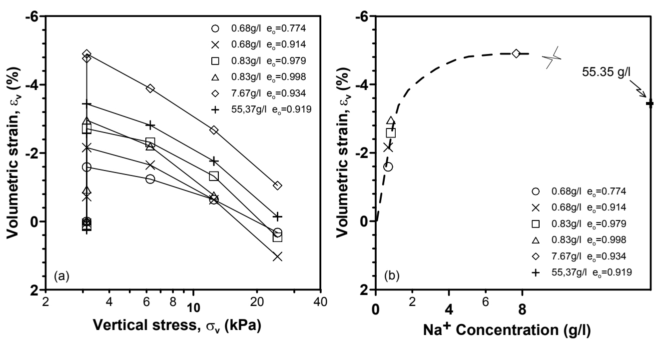

Figure 4. Initial swelling of saprolitic soil

The variation in the compressibility parameters with concentration can be seen in Figure 5. In this figure, the parameters referring to the tests presented in Figures 2 and 3 were used.

There is a rapid reduction in the vertical yield stress with the increase in the concentration of Na both for the lateritic and the saprolitic soil (Fig. 5a). This behavior is not repeated for the compression index. In the lateritic soil, Cc is reduced with the increase in the concentration of Na; however, it practically does not influence the values of Cc in the saprolitic soil (Fig. 5b). The recompression index, Cr, of the lateritic soil is significantly affected by the concentration of Na. In the highest concentrations (7.67 g/l and 55.37g/l of Na), the values of Cr were greater than Cc (Fig. 4c). This is the result of the occurrence of an abrupt change in the structure under a low load level. Figures 5b and 5c contain a schematic drawing that illustrates this behavior. On the other hand, the values of Cr for the saprolitic soil vary little with the concentration.

Figure 4 shows that the saprolitic soil is significantly influenced by the initial swelling and this is also confirmed in the swelling index, Cs (Fig. 5d). The tendency of Cs increases with the concentration of sodium in the case of the saprolitic soil, but there is practically no influence on the lateritic soil.

The difference in behavior can be explained by the granulometric composition (the lateritic soil is more clayey and the saprolitic soil is more silty), degree of weathering, mineralogy and by the structure seen in SEM (lateritic soil with weakly cemented aggregations of clay and a saprolitic soil organized by the piling of kaolinite particles).

Putting e:σ_{vy} into a graph (Fig. 6), some differences between the lateritic soil tested with distilled water and the soil tested with solutions with different concentrations can be verified. It can also be observed that there is a relationship between e and σ_{vy} in the lateritic soil tested with distilled water; the same cannot be said for the other tests carried out using solutions.

The void ratio for the saprolitic soil used in Fig. 6 contains values after the initial swelling. There is a direct relationship between the void ratio and the vertical stress yield. Therefore, the saprolitic yield stress depends on the initial swelling.

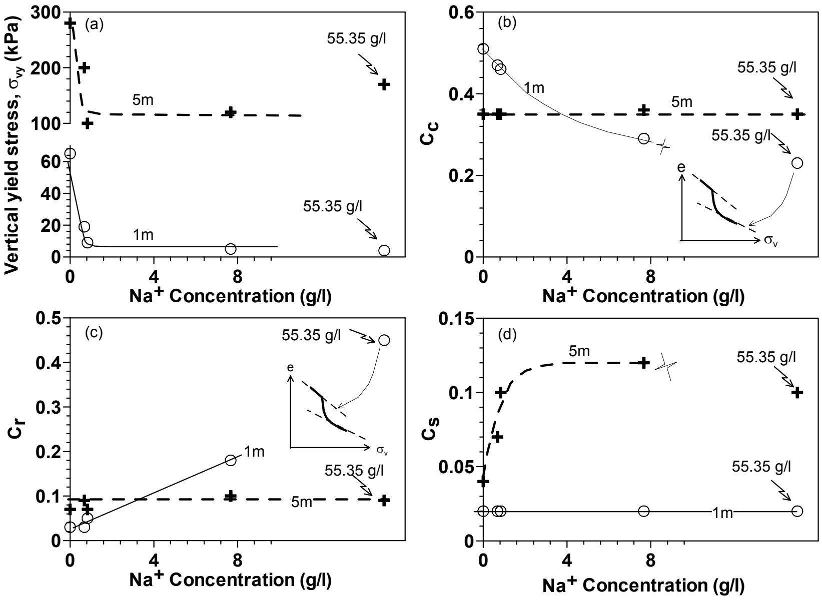

Figure 5. Compressibility parameters

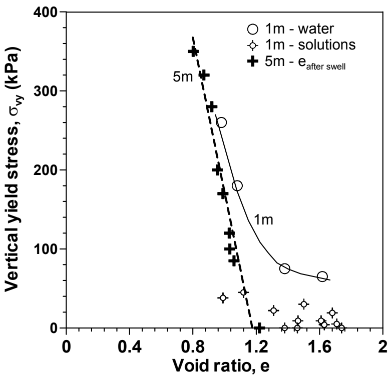

Figure 6. Vertical yield stress and void ratio relationship

Bolt (1956), Abdullah et al (1997), Alawaji (1999), Chen et al. (2000), Brancucci et al. (2003) and Sivapullaiah and Manju (2006) tested compacted soils. It is difficult define a general aspect of physicochemical influence on natural soil such as presented in this paper, because it will depend on the soil, on the solution and on their interaction.

3. CONCLUSIONS

Specimens formed intact at 1 m-depth (lateritic soil) and 5 m (saprolitic soil), despite the same weathering environment, presented different behavior in the oedometer compression tests due to their (chemical and mineralogical) composition and microstructure peculiarities, associated with the degree of alteration of each soil. The behavior of the 1-meter intact soil reflects the existence of the cementing of iron and aluminum sesquioxides, while the behavior of saprolitic soil reflects the influence of the arrangement of the constituent minerals. The cementing (lateritic soil) and the mineral arrangements (saprolitic soil) were gradually broken, while for the highest vertical stress, the behavior of the intact soil was closer to the behavior of the remolded soil. The intact saprolitic soil did not swell when being inundated with water (oedometric tests) although it expanded significantly when inundated with solutions containing sodium. These expansions were probably caused by structural changes and the rupture of connections that inhibit the expansion of the intact state when inundated with water. Electronic microscope sweep tests using soil treated with the solution allowed the visualization of these structural changes (Futai et al, 2015). The mechanical behavior of the saprolitic soil was verified to be associated with the initial expansion (unlike the lateritic soil). There is a direct relationship between the void ratio after swelling and the vertical yield stress. The interaction was found not to significantly influence Cc or Cr, even though Cs rose according to the increase in the concentration of Na, maintaining the pH constant and equal to 10.5. The compression curves for the saprolitic soil tend to converge in the 'normally condensed' band, which does not occur with the lateritic soils.

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