Impact of mining waste effluents on the shear strength of compacted lateritic soils used in waste containment dikes (DRC)

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Abstract

Hydraulic fracturing is the evoked main cause of dikes failure. Several authors analyzed the soils properties under mechanic and hydraulic solicitation. However, these analyses don't take into account the chemical influence of liquid percolating the matrix of soil. This article analyzes the impact of liquid effluents emanating from ore concentrators on compacted lateritic soils behavior in waste containment dikes. It emphasizes shear strength parameters of compacted laterite and percolated by liquid effluents with different chemical nature. The tests include the shear strength measurements when the specimens were imbibed with different fluids. The results show that acid and basic liquid effluents affect shear strength parameters and the strain modules are modified. The effect of the initial suctions and the density before the imbibition was also investigated, which reveals that structural changes caused by initial saturation and density of specimens seem to be more important for explaining strength behavior than chemical interaction.

Keywords: Waste, Effluent, Shear, Lateritic, Dikes.

1. INTRODUCTION

Chemical effects of percolating fluid on shear strength parameters and strain modulus of compacted lateritic soils, used in waste containment dikes in Katanga (DR Congo), are investigated in this paper. Consolidated drained and undrained shear strength were determined using distilled water, acid and basic effluents from ore concentrators. Strength behavior was investigated by studying triaxial shear tests after imbibition with demineralized water as reference and imbibition in acid or basic liquid effluents, which led to the full saturation of the samples. Initial suction before wetting revealed to have significant impact on the behavior observed.

The interaction of the clay soil with ions in the percolating fluid is an aspect related with osmotic suction (Cardo-so et al. 2012), difficult to be interpreted in conventional saturated soil testing. This interaction explains the change of shear behavior observed when replacing the distilled water by liquid effluents acid or basic.

2. EQUIPMENTS AND MATERIALS USED IN THIS STUDY

For the physical characterization, we conducted a sieve dry and wet analysis according to CME 01.01 standard. The water content was determined by the oven method according to the standards NF P94-050 and NBN 589-203 respectively for laterites of Kakanda, Kipushi and laterite quarries. The determination of particle density was done in accordance with the pycnometer procedure: N03-09. Atterberg limits were obtained according to stand-ard NF P94-051 and shrinkage limits following the procedure Peltier 108. The maximum dry weight density and the optimum water content was obtained by Standard Proctor test according to NF P 94-093. The materials used are conventional laboratory equipment that require no particular description. The studied soil is laterite used in the construction of road embankments and tailings dams of dikes from mining companies and civil engineering earthworks in Katanga, D. R. Congo. The average density of the solid particles is of Gs = 2.77. Samples were taken at Kakanda on the big dam of Kakanda, at Kipushi on the dike of Kipushi and in quarries where road fill materials are extracted from.

The weight proportions on the extracted soil (Fig. 1a) and the fraction less than 2 mm (Fig. 1b) give us about 31 and 19%; 71 and 41% respectively for the clay laterite of Kakanda and Kipushi. Mineralogical composition of the laterites samples is given in table 1.

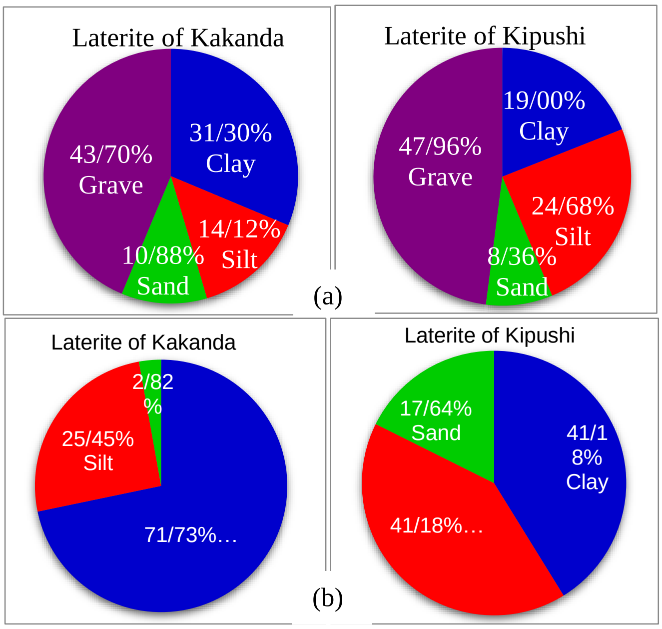


Figure 1. Grain size fractions of laterite on the raw sample (a) and on sieved to 2 mm (b)

Table 1- Mineral composition of the samples of laterite and oxides contained in the soil

Soil	Kda	Kshi	Oxydes	Kda	Kshi
minerals	[%]	[%]		[%]	[%]
Quartz	32,90	45,70	SiO_2	56,27	66,34
Kaolinite and Halloysite	34,87	19,77	TiO_2	1,10	1,06
Illite	11,64	16,24	Al_2O_3	16,31	15,62
Muscovite or feldspar	2,23	4,93	Fe_2O_3	15,29	8,78
Hematite	-	8,78	MgO	0,38	0,53
Gœthite	17,02	-	MnO	0,02	0,01
Corundum	-	3,02	CaO	0,08	0,06
Anatase	1,10	1,06	K_2O	1,15	1,82
Calcite	0,18	0,14	Na_2O	0,29	0,59
Pyrolusite	0,02	0,01	LI*	8,83	5,01
Total	99,96	99,65	Total	99,72	99,82

*** Loss on Ignition**

Liquid effluents used come from retention ponds of the dikes of Kakanda and Kipushi. They have a weakly basic pH being situated between 7.5 and 8.7 for Kakanda and weakly acid for Kipushi with values between 5.9 and 6.5 (Baize & Girard 2008). These liquid effluents were sampled in the various ponds of retention in the range of 3 years over various periods of the year. The values of the pH measures are averages of around thirty measurements made for the pH. The chemical composition of the liquid effluents used in this study is presented in the table 2 that shows the concentration in polluting elements, these elements which pollute the water of the ponds of dikes are not in weak quantity with regard to the legislation in force in DRC (Cabinet du Président de la RDC 2003)

Table 2: Chemical composition of the liquid effluents

	Chemical elements [ppm]						
Soil	Al	Ca	K	Mg	Mn	Na	P
Kakanda	3	11,9	68	58	0,313	274	2,4
Kipushi	200	328	22	1058	130	405	1,6
	Chemical elements [ppm]						
Soil	S	Iron	Co	Cu	Zn	Ni	
Kakanda	290	65,4	6,87	5,9	0,09	0,03	
Kipushi	2693	70	81	350	35	1	

The dosage of the chemical elements (total chemistry) was made by fusion at the metaborate and tetraborate of Lithium followed by putting in solution and an analysis of elements by spectrometry of atomic emission ICP AES (Inductively Coupled Plasma Absoption Emission Spectral), model ICAP on 2500. The values of the measures presented in the table 1 are averages of about ten measurements made for the chemical composition. These ions contained in the liquid effluents have an influence on the properties of the clayey fraction of the laterite.

A usual classification of pollutants is presented by Delage P. and Schrefler B. (Bouazza et al. 2005), it includes: soluble chemical pollutants; heavy metals; and the hydrocarbon compounds derived of some crude oil. The same source indicates three pollutant categories namely: metal (heavy metal), minerals (Ca, Mg, Na, K, Fe, Si, Sr, Ti, Al, N, Cl, F, P, S and cyanides) and organic (including, among other hydrocarbons, alcohols, phenols, esters, sulfides, pesticides ...).

3. IMPACT OF LIQUID WASTE ON THE SHEAR STRENGTH PARAMETERS OF COMPACTED LATERITIC SOIL

In order to analyze the strength behavior of the soil in a favorable ion exchange environment, the specimens were made with the same initial parameters and saturated with the polluted water of the retention basins or the distilled water. The triaxial apparatus used during our works consists of a triaxial cell of type Bishop and Wesley (Mukoko 2014). The whole is connected to a system of acquisition. The specimen of cylindrical shape is placed in a sealed chamber which is connected to the various systems of pressure application and measurement. The cell is filled with liquid (distilled water or liquid effluents), which allows to apply to the specimen a field of isotropic stress during consolidation and anisotropic during shearing. These triaxial tests have summers controlled in constant strain rate (0.2062 [mm/ min]), under confining pressures σ3 of 100, 150, 200 and 300 kPa.

When a sample is taken, it has an initial moisture and thus an initial suction that can be inferred from the retention curve. Similarly, when samples are reconstituted, we submit them to a certain suction and by shearing them directly, we can have an idea of the effect of the initial suction on soil strength characteristics. But a disadvantage is that the state of the sample is neither on the drying path nor on the moisturizing path of the retention curve.

• Effect of waste effluents of retention basins on the shear parameters.

The influence of the pollution on the response of lateritic soil at the undrained monotonous triaxial loading is de-scribed in the following figures (Figs 2-4, 5, 6) under the same initial state ($\gamma d = 17.31$ kN/m^3 et w = 14.95%), the figure 2 presents the failure envelopes of Mohr-Coulomb and the shearing parameters relative to that. It appears that the acid pollution decreases the cohesion, with a light increase of the internal friction. This observation is made on about fifteen tests of which the repeatability seems uniform.

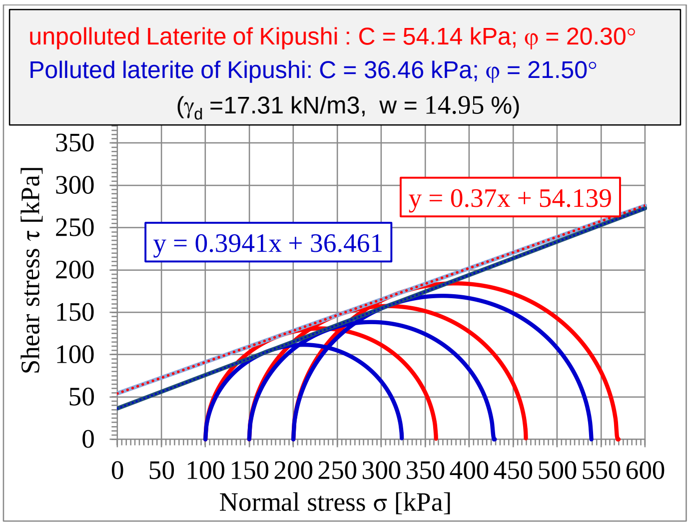
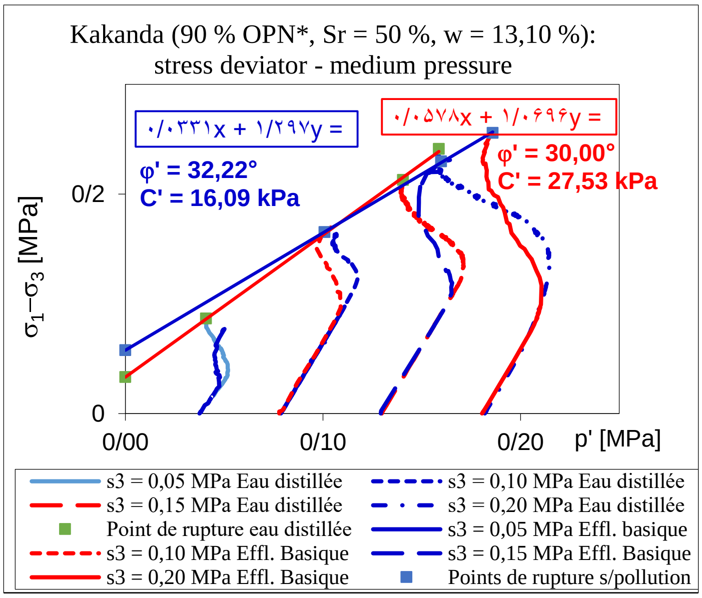


Figure 2. Circle of Mohr and intrinsic right for the soil of Kipushi

On the other hand, there is an increase of more or less 42 % of the effective cohesion and a decrease in the angle of friction as a result of the contamination by the basic liquid effluent for specimens tested at 90 % of the dry density for the soil of Kakanda (figure 3).



OPN* Optimum Proctor Normal

Figure 3. Effective stress path and critical state lines for the soil of Kakanda

This increase of the cohesion could be attributed to the contribution of the exchangeable cations by the basic liquid effluent in the ligands of the lateritic soil after interaction with the effluent.

On figures 5 and 6 we compare the variations of the deviator stress and the pore pressure in function of the axial deformation (in CU) respectively in the case of the soil of Kakanda (Fig. 5a) and of Kipushi (Fig. 5b) uncontaminated and polluted by the liquid effluents of retention basins.

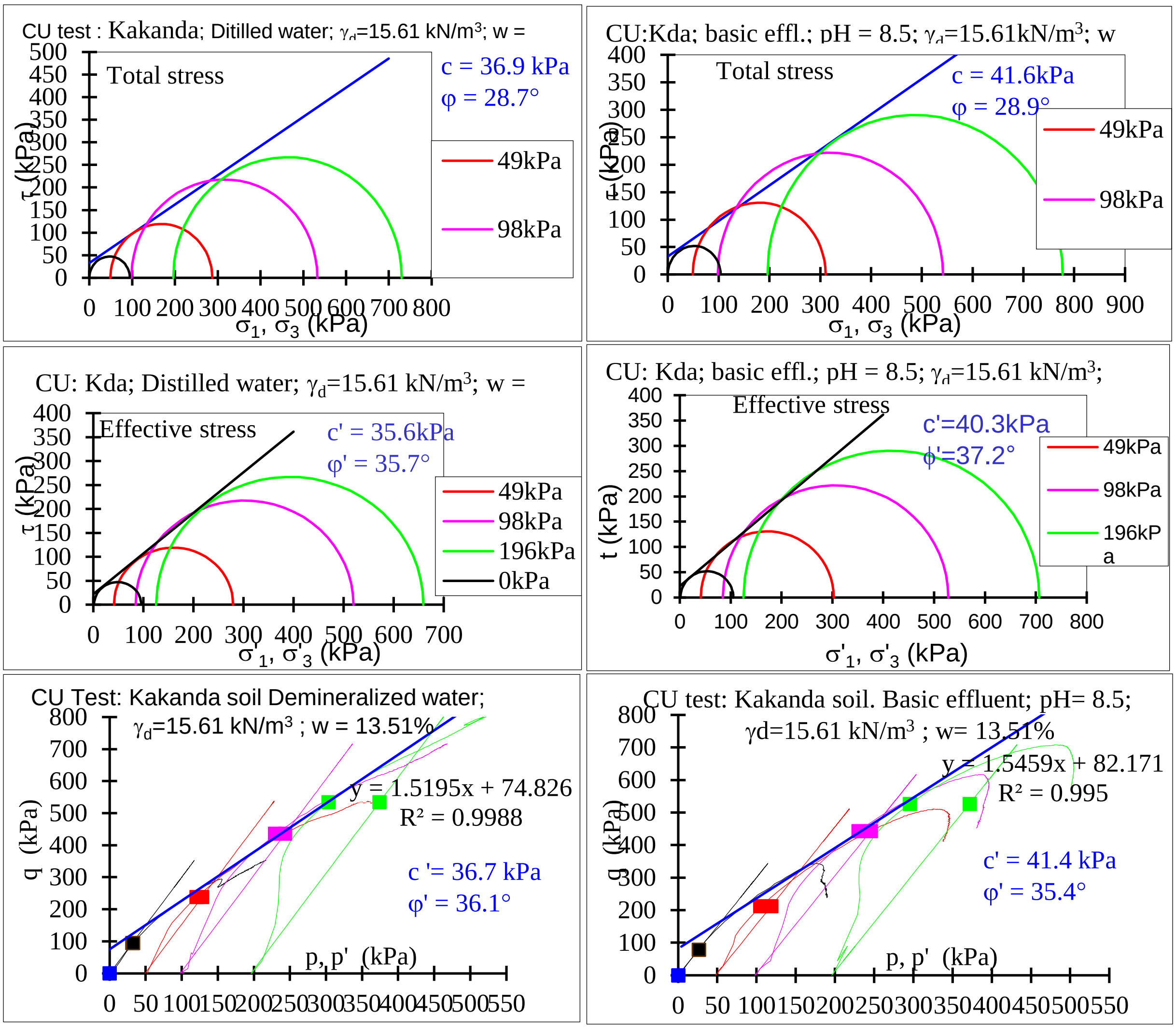


Figure 4. Circle of Mohr, intrinsic right, and critical state line for the soil of Kakanda.

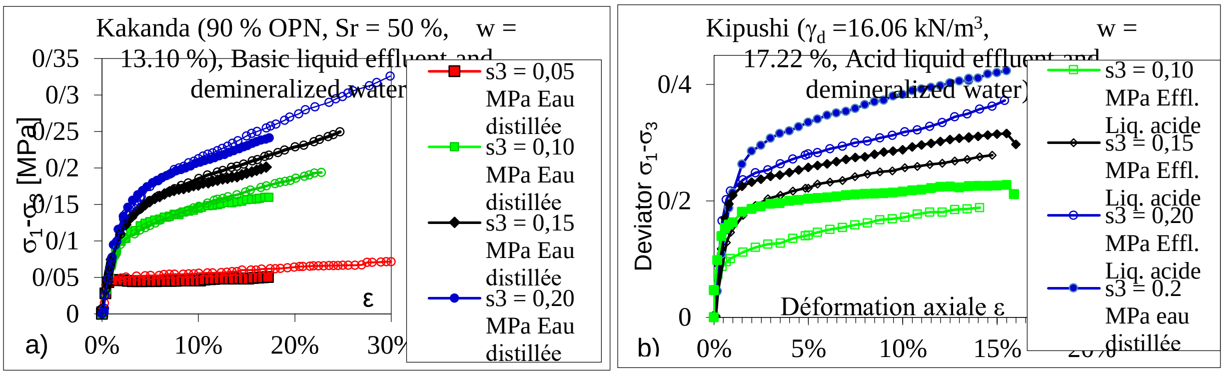


Figure 5. Diagram deviator - axial deformation in CU

We observe no influence of the soil pollution in the elastic domain where curves superpose (Figs 5a, 5b). On the other hand, in the plastic domain, the deviator stress for the soil saturated with the basic liquid effluent is slightly higher than its equivalent saturated with demineralized water, whereas it is widely lower for the soil saturated with acid liquid effluent compared to the soil saturated in distilled water.

As for the excess of pore pressure, the behavior is completely inverse, the strong increase of the pore pressure in the case of the saturated soil with acid liquid effluent (Fig. 7b) goes hand in hand with the hydraulic conductivity brought up under acid pollution (Mukoko et al. 2015). Available results in the literature (Spagnoli et al. 2010), (Spagnoli et al. 2011) attribute this behavior to the decrease of the pH in acid medium.

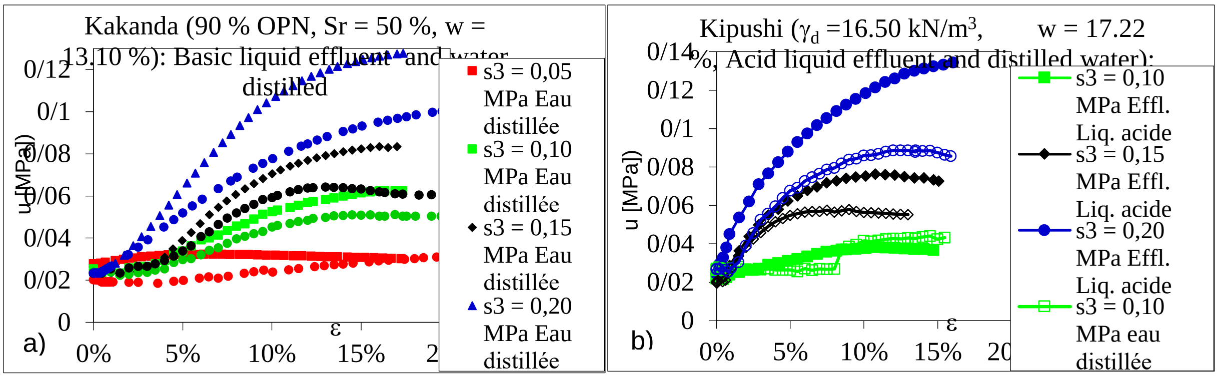


Figure 7. Diagram pore pressure – axial deformation in CU

Figures 7a and 7b present some UU testing results and show the impact of the initial suction of the specimens on the deviator stress at failure. In these figures we compare the results in unconsolidated and undrained compression. The behavior remains the same that is to say a reduction of deviator under acid contamination (Fig. 7a) and a slight increase in basic middle (Fig. 7b).

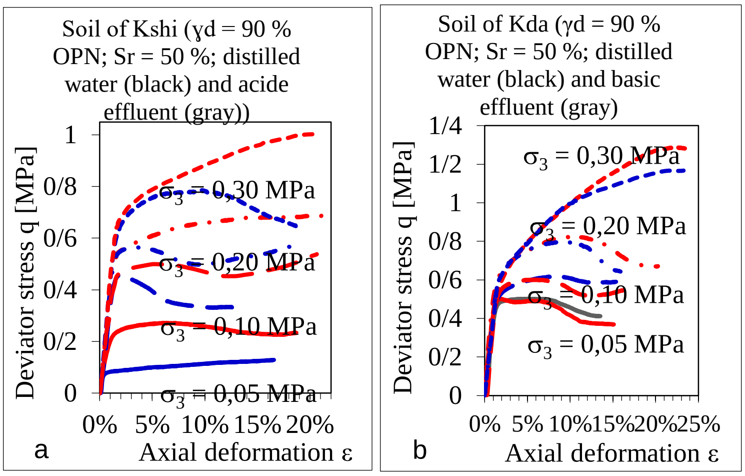


Figure 7. Diagram deviator stress - axial deformation (UU test)

• Effect of waste effluents of retention basins on the deformation modulus.

The experimental laboratory studies on different soils showed that the modulus of deformation depends on numerous factors, in particular on the size grading of soil, the density, the confining stress, the loading history, the specimens preparation method (Hardin & Richart 1963; Boelle 1983; Hicher 1985; Presti 1987) quoted by (Nguyen 2008).

These various factors are known and have been broadly studied. If we take into account the influence of the particle grading and the type of the soil, the void ratio (or compactness) and the confining stress, the deformation modulus can be written as:

- *Module = A(material) x B(compactness) x C (pressure)*

where: A (material): is a parameter that translates the influence of the nature of the material,
B (compactness): is a function that takes into account the compactness of the soil,
C (pressure): is a function related to the influence of the confinement.

For soil used in waste containment dikes, the influence of the pollution (by acid or basic liquid effluents) is not negligible, the module of deformation decreases for acid liquid effluent and increases for basic one, at least for the lateritic soil analyzed as showed in figure 8.

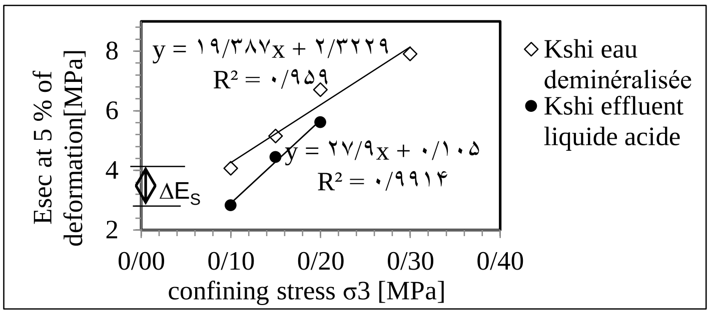


Figure 8. Variation of the secant modulus as a function of lateral stress

In this case, the modulus of deformation can be written:

- *Module = A(material) x B(compactness) x C (pressure) x D (chemistry of percolating fluid)*

With: D (percolating fluid): a parameter that reflects the influence of the pH of the liquid percolating the chemisorbed soil matrix.
Figure 8 shows the variation of deformation modulus as a function of the confining pressure and indicates the fall of the modulus in acid medium.

- Influence of the initial saturation of specimens on the deviator and the secant module of rigidity.

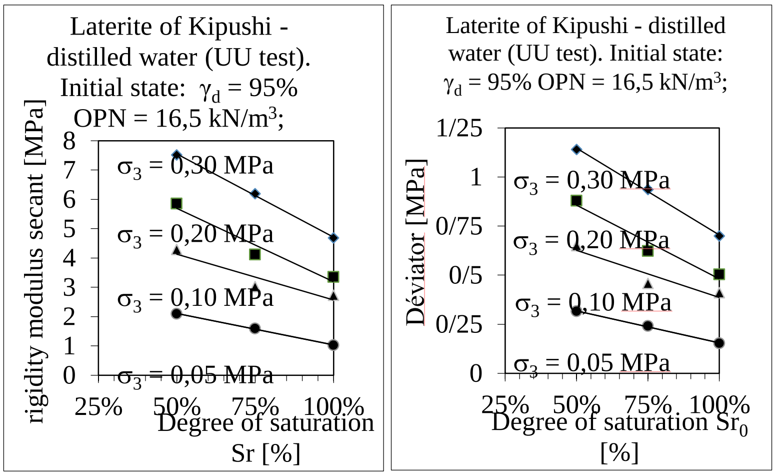


Figure 9. Influence of the initial saturation of the specimens on the deviator and the secant modulus of rigidity

The deviator stress at failure decreases significantly in the partially saturated soil with increasing saturation degree under the same level of compaction. As for the secant modulus at 15% of strain, shown in Figure 9 above, it increases with the confining pressure and decreases with saturation.

4. CONCLUSIONS

It appears that acid pollution decreases the shear strength parameters of laterite by increasing its deformability, while in basic pollution, that is to say by saturating specimens in basic liquid effluent, a tendency to oppose soil deformation is observed.

The deformation modulus not only depends on a parameter which translates the influence of the nature of the material such as its granularity, a parameter that takes into account the compactness of the soil such as its porosity and a parameter which translates the influence of the confinement, but also a parameter which reflects the influence of the pH of liquid percolating the chemisorbed soil matrix.

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