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Clay creep and displacements: influence of pore fluid composition

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Abstract

Time dependent shear displacements in clay soils under constant effective stresses can also be induced by changes in pore fluid composition. This paper presents the results of laboratory tests carried out on a sodium bentonite and on samples of the *Varicoloured Clays* formation outcropping east of Potenza, Southern Italian Apennines. The soils reconstituted with a 1M NaCl solution were submitted to shear tests under constant shear stresses in two different conditions: i) after shearing to the residual state, and ii) intact at various OCR. The applied shear stresses were lower than the residual strength of the materials reconstituted with the salt solution (residual friction angle, $\varphi'_r \approx 15°$) and higher than that obtained with distilled water ($\varphi'_r \approx 5°$). While exposed to 1M NaCl solution, the specimens didn't experiment creep; on the contrary, exposure to distilled water made the displacement rate increase greatly. The decrease in pore ion concentration obliterated the over-consolidation effects.

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1. Introduction

Creep is defined as the progressive, irrecoverable deformation of a soil element under a state of constant effective stresses [1]. An increase in the deviatoric stress level can result in a deformation response characterised by three successive phases which are named primary, secondary and tertiary creep, characterised by decreasing, constant and increasing strain rate respectively. The actual strain pattern is hypothesised to depend on the type of soil, stress level and stress history [2-5].

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Deformations at molecular, particle and aggregate levels can contribute to the creep phenomenon [6]. The different levels of deformation can be ascribed to two groups of micro-processes: rearrangement of matter and rearrangement of particles or aggregates [7]. Failure of cemented bonds or increase in the ratio of tangential to normal forces at the interparticle contacts are among the processes which can lead to creep rupture for loss of strength [1,7,8,9]. Loss of strength can be also caused by chemical variations of the pore fluid (among others: [10]). It was shown that such a type of deterioration can cause shear displacement with a typical creep pattern in soil specimens subjected to constant Terzaghi's effective stresses. Some results [11] refer to a sodium bentonite reconstituted with distilled water and with NaCl solutions at various concentrations. An analogous experimentation was also carried out on the *Costa della Gaveta* soil [10,12]. With the aim of analyzing the viscous behavior of the soils on pre-existing discontinuities such as slip surfaces, the specimens were first sheared under constant displacement rate until the residual conditions and then submitted to creep tests, under constant normal and shear stresses and in the absence of chemical gradients. At equilibrium, the specimens were exposed to water, inducing ion diffusion from the pores to the cell water. This caused shear displacement acceleration with a pattern very similar to that of tertiary creep [4]. In order to extend the experimentation to intact materials, this paper analyses the behavior of bentonite specimens reconstituted with 1 M NaCl solution, consolidated to different normal stresses, unloaded to different OCR values, and then submitted to shear tests under controlled shear forces, initially without chemical gradients and then with exposure to distilled water.

2. Materials

The tests were performed on the *Costa della Gaveta* soil and on a sodium bentonite. The first soil is characterised by high values of the clay fraction (*c.f.* > 40%) which is constituted by illite-muscovite, kaolinite and smectite [13]. The bentonite, provided by Laviosa Minerals SpA, Livorno, Italy, with *c.f.* ≈ 80%, is mainly composed of Na-montmorillonite. Some properties of the soil samples used for this experimentation are reported in Table 1.

Table 1. Physical characteristics, Atterberg limits and index properties of the tested soils.

Material	Borehole-Sample	Depth (m)	c.f. (%)	γ_s (g/cm^3)	w_L (%)	w_P (%)	I_P (%)	A	w_L(%)
					distilled water				*1 M NaCl*
Costa della Gaveta soil	S7-CD2	28.0 - 29.6	52	2.67	65.2	26.2	39.2	0.75	64
	I9c-CD18	4.00 - 4.35	33	2.67	77.8	28.6	49.2	1.49	
	S10-CD20	9.3 – 9.5	47	-	65.4	-	-	0.52	
	I15-CD6	18.3	60	2.65	123	46.9	76.1	1.27	68
Bentonite	-	-	82	2.75	324	44.8	279.2	3.4	116

3. Methods and results

The shear tests were carried out by means of different devices: the Casagrande and the reversal direct shear, the Bishop and the Bromhead ring shear. The devices were used both in the conventional mode, at constant displacement rate, and under controlled driving shear stresses thanks to an *ad hoc* modification. The constant rate tests were carried out at v = 0.018 mm/min in the Bromhead apparatus and at v = 0.005 mm/min in the other devices. The specimens were generally reconstituted with NaCl solutions at different concentrations and with distilled water at the corresponding liquid limit (Table 1). The residual strength is independent of initial conditions, thus, the specimens used only for the determination of it, were also prepared with solution content lower than the liquid limit.

3.1. Shear tests at constant displacement rate

A number of shear tests was carried out on a sodium bentonite and on the *Costa della Gaveta* soil reconstituted with NaCl solutions at several different concentrations and submerged in the same solution, i.e. in the absence of chemical gradients [10,11,12,14]. The results were interpreted in terms of residual friction angle φ'_r, the residual cohesion intercept c' being null for both materials. The strength parameter has been found to vary greatly with the