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Chemical clay soil improvement: from laboratory to field test

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Abstract

Soil deterioration can be an important cause of earthflow activity. Current studies try to provide a deeper understanding of the processes that influence soil deterioration and of the processes that, on the contrary, can improve soil mechanical properties. This paper points out the role of the composition of pore fluid. In the *Costa della Gaveta* slope, this is an aqueous ion solution, with concentration increasing with depth to values typical of seawater. Na^+ is the prevailing cation, a reduction of its concentration causes dramatic decrease in strength. On the other side, the laboratory results show that exposure of the soil to KCl solutions, inducing an increase in pore K^+ concentration, makes shear strength increase greatly and permanently. First results of chemical treatment by KCl columns at *Costa della Gaveta* show that ion transport is faster than hypothesized on the basis of *in situ* falling head permeability tests, probably because of preferential flow patterns along the slip surface and other discontinuities.

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1. Introduction

Shear strength of clay soils is strongly influenced by pore fluid composition [1,-6]. Many different processes can account for a decrease in pore solution concentration of marine origin soils which can cause soil deterioration and can thus trigger or reactivate different types of landslides [2,6,7,8,9,10]. On the other hand, stabilization techniques based on K^+ diffusion from KCl piles are used very effectively since the 60s in the Quick Clays formation [2,11,12,13].

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A systematic study of the effects of such a stabilizing method in a clay shale formation widespread in the Italian Apennines has been recently initiated with the aim of controlling both shear strength parameters and excess pore water pressure induced by ion concentration gradients. The study is based on both laboratory and field experimentation. The test site is *Costa della Gaveta* hill, east of Potenza, Southern Italy. The clay shale formation of Varicoloured Clays is there affected by various types of landslides which have been studied extensively by means of hydro-mechanical models [14-17]. In addition, a chemical characterization of the landslide is currently being carried out. The first results [18,19] show that the pore fluid of *Costa della Gaveta* is an aqueous solution with composition and concentration varying greatly with depth. It is very dilute in the most superficial soil layer but its concentration increases to values typical of seawater at depths depending on the location on the hill. Na^+ is the prevailing cation: its influence on soil behaviour has been found strong in the whole range of the field natural variation. Its concentration reduction can be hypothesized as one of the causes of the soil mechanical deterioration [8]. On the other side, laboratory test results show that exposure to concentrated KCl solutions makes shear strength parameters of the soil increase greatly and permanently [4,19]. In order to evaluate the field effects of exposure to KCl, an experimentation has been recently initiated in the head zone of the *Costa della Gaveta* earthflow. Some boreholes, deeper than the slip surface, have been filled with KCl grains, some others are used to monitor groundwater composition and to induce hydraulic gradients which should drive water flow and ion transport. Piezometers, tensiometers and inclinometers have been installed to monitor the intervention effects.

2. Soil properties and soil improvement by KCl treatment: laboratory results

Costa della Gaveta subsoil is characterized by values of *c.f.*>40%. The clay fraction is constituted by illite-muscovite, kaolinite and smectite in percentages variable from site to site [20]. Pore fluid composition has been shown to influence greatly the soil mechanical behavior [14,15,18,19]. Pore fluid composition was determined on a large number of samples. A given weight of dried material was powdered and then hydrated with a given weight of water to obtain homogeneous suspensions. After sedimentation, the supernatant solution was analyzed and, the water content being known, the natural pore solution concentration was calculated. Figure 1a shows water content against depth from the ground surface evaluated in some boreholes of the test field in the earthflow head zone and the main ion concentration profiles. Figure 1b shows the analogous parameters evaluated on samples extracted from three boreholes drilled in the channel. The figures show that in the head zone the soil is unsaturated in the first 2-3 m, and it is saturated below. The water contents of the saturated soil in the landslide body of the head, which is about 8 m thick, are noticeably higher than those of the underlying stable soil. In the channel, the soil is saturated from the ground and water content variation is more gradual. Na^+ is the prevailing cation in any vertical, its concentration increases with depth to values typical of sea water. In borehole I9b, this occurs at a depth of about 30 m. Ca^{2+} is characterized by noticeable concentration in the upper soil, probably as an effect of the presence of many fragments of the Corleto Perticara limestone formation. K^+ concentration is negligible everywhere. The observed concentration profiles indicate conditions far from chemical equilibrium. In the vicinity of the ground surface, water adsorption due to exposure to rain and other transport phenomena are likely to have caused a decrease in Na^+ concentration in the pore fluid, thus determining chemical potentials lower than those of the deeper soil. The chemical gradients, in turn, can induce ion diffusion towards the surface and/or water flow downwards. Both processes cause a reduction in pore solution concentration and therefore also a decrease in shear strength [18].

A companion paper presented at this conference [21] shows experimental data relative to the reconstituted and undisturbed soil which highlight the dependence of φ'_r on Na^+ concentration in the pore solution. The Authors hypothesized that, due to the ion concentration variations, φ'_r ranges between 7° and 14° along the slip surface!

Natural processes occurring at *Costa della Gaveta* - such as exposure to rain, contact with more permeable aquifers, unloading and fresh water adsorption - induce further Na^+ decrease and thus shear strength decrease. In order to evaluate how to invert the process and make the soil improvement procedure as efficient as possible, many laboratory and field tests are being carried out. In particular, many specimens have been exposed to concentrated KCl solutions in the course of shear tests. The tests were carried out by the Bishop and the Bromhead ring shear devices and the Casagrande direct shear box, at displacement rate v = 5 μm/min in the Casagrande and Bishop devices and v = 18 μm/min in the Bromhead apparatus. Figure 2a shows the results obtained for a specimen which,