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Influence of degradation cycles on the mechanical characteristics of natural clays

Influence des cycles de dégradation sur le caractéristiques mécaniques d'argiles naturelles

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ABSTRACT
On low depths, soils are exposed seasonally to frequent wetting-drying and freezing-thawing cycles; the degradation effects of these cycles are more pronounced in clayey soils. The number of cycles is due to periods of rainfall and variations in air temperature. Such processes can trigger shallow instability essentially controlled by the physical weathering of soils. An experimental study was carried out to investigate how the physical weathering, reproduced by laboratory wetting-drying and freezing-thawing cycles, affects the mechanical behaviour of natural clays in the superficial layers. For this purpose block samples of Pliocene clays were taken from a slope in Southern Calabria (Italy). They are overconsolidated stiff clays which can be classified as to high plasticity clays (CH). Different specimens were trimmed from the block samples and they were subjected to different numbers of wetting-drying-freezing-thawing cycles and then tested in oedometer and direct shear tests. Results of oedometer and direct shear tests seem to show that the physical weathering has caused a degradation of the bonding due to an insufficient ability to resist this cyclic process. The variations of peak shear strength are pronounced in the first month then they may be regarded as essentially constant. The wetting-drying-freezing-thawing cycles also cause a decrease in compression index and an increase of swelling index.

RÉSUMÉ
Aux basses profondeurs, les terrains sont exposés à des cycles fréquents de mouillage-séchage et de congélation-décongélation; les effets de dégradation produits par ces cycles sont plus marqués sur les terrains argileux. Le nombre des cycles est dû aux périodes de pluie et aux variations de la température de l'air. Ces procédés peuvent prédisposer à des instabilités superficielles essentiellement contrôlées par l'altération physique du terrain. Un travail expérimental a été effectué pour observer la façon où l'altération physique, réproudite au laboratoire par des cycles de mouillage-séchage et congélation-décongélation, peut influencer le comportement mecanique des argiles naturelles des couches superficielles. Dans ce but, des échantillons en bloc d'argiles du Pliocéne ont été prélévés d'une pente localisée dans la Calabre du sud (Italie). Les terrains sont des argiles raides surconsolidées qui peuvent être classifiées comme des argiles à plasticité élevée (CH). Plusieurs échantillons ont été préparés avec ces blocs et ils ont été soumis à un nombre différent de cycles de mouillage-séchage-congélation-décongélation; ensuite ils ont été testés par oedomètre et ciseau direct. Les résultats des examens oedométriques et de ciseau direct semblent indiquer que l'altération physique a provoqué une dégradation des liaisons diagénétiques, pas suffisamment fortes au point de supporter les cycles utilisés. Les variations de la résistance au cisaillement de pic sont plus marquèes au cours du premier mois; ensuite, elles deviennent fondamentalement constantes. Les cycles de mouillage-séchage-congélation-décongélation produisent aussi une baisse de l'index de compressibilitè et une hausse de l'index de regonflement.

1 INTRODUCTION

The rainfall-induced slideflows affect many countries and are widespread all over the world. The slideflows are generally numerous and shallow and involved volumes are small. They occur in various types of soils with a wide range of sorting (Gullà et al., 2004).

Slope failures caused by heavy rainfalls are influenced by a complex interactions of topographical, geological, environmental and precipitation factors.

Unusual torrential rainstorm of September 2000 triggered many surficial slideflows clustered in relatively limited areas in the coastal zone of Ionian Southern Calabria (Italy) (Antronico et al., 2002). More than 1000 surficial failures were identified. The movement often started in slightly concave slopes (zero order basins), frequently in correspondence with natural or artificial breaks in slope. The involved slopes show heterogeneous stratigraphic conditions characterized from weathered soils.

The effects of weathering on soil properties and environmental conditions played a relevant role in spatial distribution of triggered events. Weathering is a destructive process due to both physical and chemical phenomena in which air and water play a major role. The weathering phenomena generally produce a decrease in particle size, changes in mineralogy and a decrease of interparticle bond strength (Leroueil, 2001). In particular, weathering contributes to destructuration of geomaterials when it is associated with climatic phenomena (wetting-drying cycles and freezing-thawing cycles) or chemical actions (Leroueil and Hight, 2003). From the mechanical point of view, it produces a degradation of the bonds between particles or aggregates and thus a destructuration of the material resulting in a lowering of the peak shear strength envelope of the geomaterial (Taylor and Cripps, 1987; Chandler and Apted, 1988).

The purpose of this paper is to examine the weathering and its effects on the mechanical behaviour of a natural fine-grained soil, involved in the slideflows of September 2000. It is an overconsolidated clay, which outcrops extensively in the southern Calabria (Italy). The influence of degradation is investigated with respect to compressibility and shear strength characteristics.

In the context of this paper weathering processes are considered as those processes which occur at a shallow depth, which involve the reaction of the deposit with the constituents of air and water, and which lead to an increase in water content (Chandler, 1972). Bjerrum (1967) postulated that weathering processes were responsible for the destruction of diagenetic bonds developed during the geological history of the deposit. Consequently the progressive breakdown of these bonds would result in the deposit having a range of water contents under the same effective overburden pressure, the elements with the higher water contents being those that are more weathered.

2 EXPERIMENTAL RESEARCH

Experimental tests were carried out on specimens trimmed from block samples (intact), reconstituted specimens and weathered specimens.

According to (Burland et al., 1996; Calabresi, 2004) in the context of this paper the term "intact" means soil that has not been altered due to the laboratory weathering process and that is not fissured. While the term "weathered" means soil that has been subjected to laboratory wetting-drying-freezing-thawing cycles described in the paragraph 2.2.

In particular, the experimental study was performed to investigate how the weathering, reproduced by laboratory wetting-drying-freezing-thawing cycles, affects the mechanical characteristics of natural clay in the superficial layers. Mineralogical analysis and SEM observations have been carried out too.

The laboratory experimentation has been conducted simulating, in shorter times than those in nature, by more intense cycles of degradation, the weathering process in site.

2.1 *Natural soil*

The soil used in the test program was a pliocenic overconsolidated stiff marly clay, of grey-white colour. Weathering at the site has produced a crust about 0.3 m deep which contains many fissures. To examine the effects of weathering, most tests were done on initially intact specimens from below this depth. In particular, block samples were extracted from a slope near Roccella village, from depths of 0.3-1.0 m, after removing the surface crust due to recent drying-wetting cycles.

Plasticity and liquidity limits vary between 28% and 31% and between 52% and 61% respectively. The clay fraction varies between 51% and 58%. The clays can be classified, according to USCS, as to high plasticity clays (CH). The clay minerals are mostly kaolinites and chlorites. The carbonate content varies between 47% and 56%. The overconsolidation ratio (OCR) is 3.5 and initial void ratio is 1.155. Results of classification tests are illustrated in figures 1-2. The average values of properties and main characteristics are reported in table 1.

Table 1: Characteristics and properties of test material

w_L (%)	w_P (%)	PI (%)	Ic	Gs	γ_d (kN/m^3)	γ (kN/m^3)
56.5	29.5	27	1.58	2.73	12.44	16.80

2.2 *Experimental program and test procedures*

Oedometer tests, as well as direct shear tests, were carried out on both the intact and weathered clays and on the corresponding reconstituted soils. In the following an asterisk (*) will be used to identify reconstituted soil properties (Burland, 1990). On these materials ring shear tests were carried too.

Compressibility (oedometer) and shear tests (direct shear) were performed using standard equipment.

Intact specimens were tested to assess the mechanical characteristics due to natural structure of clay. Other specimens were then subjected to wetting-drying-freezing-thawing cycles of different duration and their new mechanical characteristics evaluated. Finally reconstituted specimens were tested and the mechanical characteristics was determined.

The weathering process was simulated in a laboratory by wetting-drying-freezing-thawing cycles of different duration carried out in testing equipment. The cycles lasted: 1 day (D1), 7 days (D7), 30 days (D30), 60 days (D60) and 90 days (D90). Every whole degradation cycle has consisted of various phases repeated in a day: wetting in distilled water at 20°C, drying in heater at 100° C, wetting in distilled water at 20°C, freezing at 0° C, thawing in distilled water at 20° C. In the following the letter (D) will be used to identify weathered soil and the number the duration of process.

The specimens were reconstituted to form a slurry of initial water content 1.5 times the liquid limit (according to Burland, 1990). The tests were performed at very low stresses, because the studied landslides were superficial.

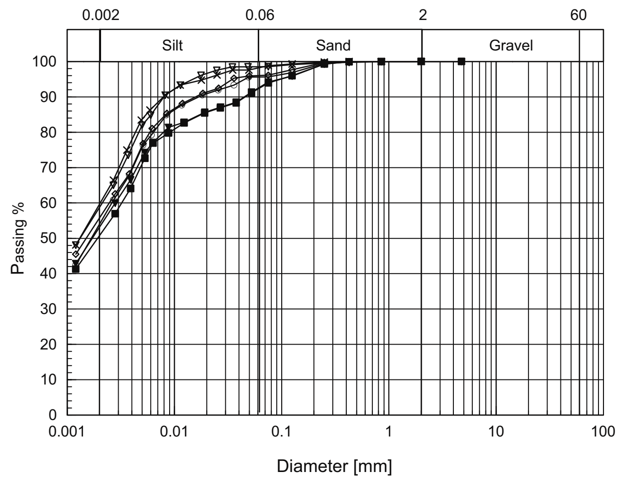

Figure 1. Grain size distributions

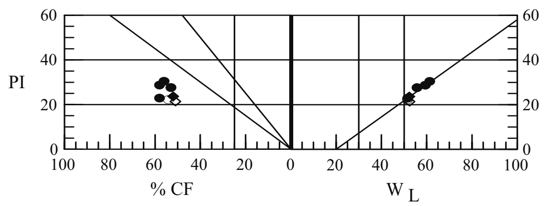

Figure 2. Plasticity and activity charts

3 ANALYSIS OF TEST RESULTS

The influence of the microstructure has been assessed on the compressibility and on the peak shear strength of natural clays. The term "structure" is used to account for both the particle associations and arrangements (fabric) and interparticle forces (bonding) (Mitchell, 1993).

3.1 *Compressibility and swelling*

The figure 3 shows the one-dimensional compression curve of the saturated intact clay, the intrinsic compression line (ICL) and the sedimentation compression line (SCL) in the I_v-logσ'_v plane. Where $I_v = (e-e^*_{100})/(e^*_{100}-e^*_{1000})$ is the void index, e^*_{100} and e^*_{1000} are the void ratios of the reconstituted clay at σ'_v=100 kPa and 1000 kPa respectively (Burland, 1990).

The yield stress σ'_{vy} of the intact clay is to the right of the ICL. It is due to the most great stability conferred to the microstructure by the natural deposition. The ratio $\sigma'_{vy}/\sigma^*_{ve}$, where σ^*_{ve} is the equivalent pressure on the intrinsic compression curve corresponding to the void ratio of the natural soil at yield, is a measure of the enhanced resistance to compression caused by the natural microstructure (Burland et al., 1996). This ratio is $\cong$ 2 for the studied material.

The ratio C_c/C_c^* is indicative of sensitive and brittle bonded microstructure. C_c is the compression index of the natural clay and C_c^* is that of the reconstituted clay. The value of C_c measured for the natural clay is 0.430. The ratio $C_c/C_c^* \cong 1.13$.

A parameter quantifying the effect of bonding is the swell sensitivity C_s^*/C_s (Schmertmann, 1969), where C_s^* is the swelling index of reconstituted clay and C_s is that of the natural clay. The corresponding value is 1.25 for the intact clay.

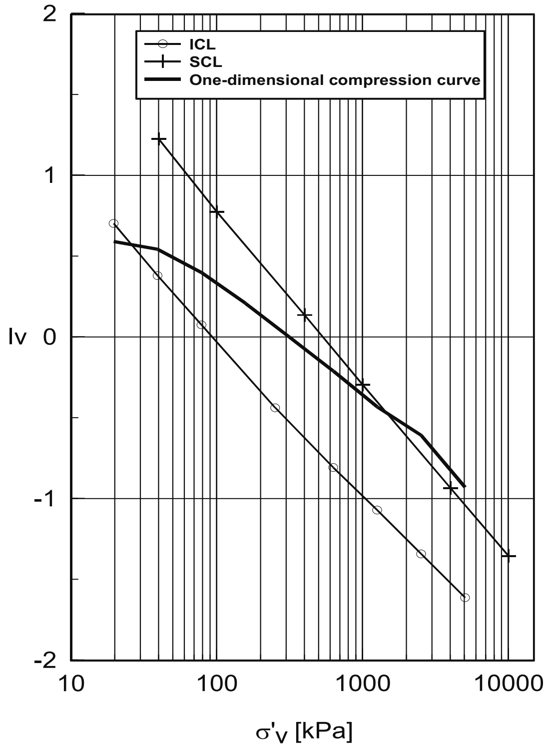

Figure 3. One-dimensional compression curve, ICL and SCL

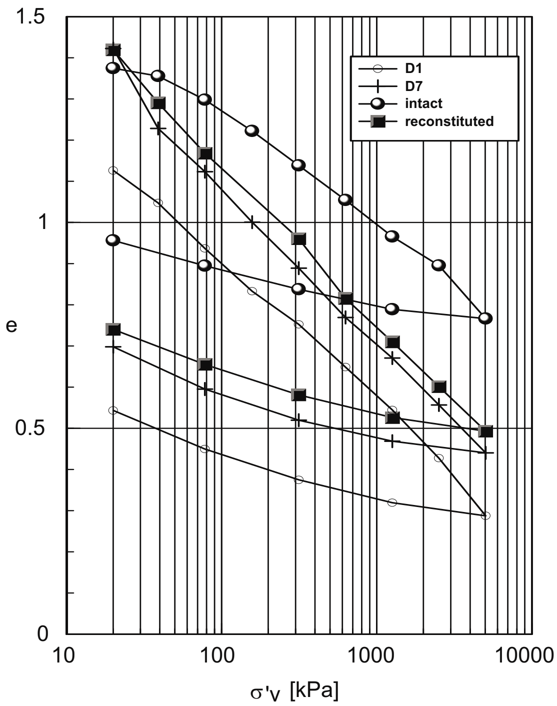

Figure 4. Oedometer curves of intact, weathered and reconstituted clay

These values show that the micro fabric of the studied material, referred to specimens sampled in superficial layers, is unstable and the bonding is not strong.

The figure 4 shows the one-dimensional compression curves of the intact, weathered and reconstituted clay.

Two main aspects can be noticed from the comparison of the curves. The first one, curves of weathered specimens go towards that of the reconstituted one. The second aspect, the void ratios increase with the duration of the cycles of degradation.

3.2 *Shear strength*

Results of the direct and ring shear tests are shown in figure 5. Considerable differences between the shear strength envelopes emerge. With the increase of degradation cycles the strength envelopes of weathered specimens bring near those of reconstituted. Moreover, the stress-displacement curves of intact clays exhibit a shear strength much greater than the shear strength of those weathered. The intact clay is strongest and it shows peak shear strength well defined that decreases with the displacement; on the contrary the weathered clays don't show such decay and the peak shear strength goes to asymptotic value with increase of displacement (Fig. 6).

The peak shear strength reductions are pronounced in the first month of degradation then they may be regarded as essentially constant. The peak shear strengths of specimens subjected to 30 days, 60 days and 90 days cycles of degradation are similar to each other.

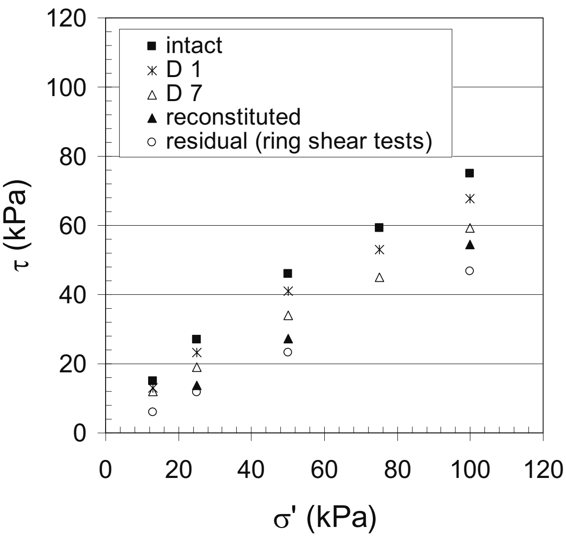

Figure 5. Strength envelopes of intact and weathered clay compared with reconstituted and residual envelopes

The observed differences of peak shear strength can be due to two factors: void ratio at failure and soil structure (Rampello, 1991). In order to quantify the shear strength reduction owing to structure, strength envelopes have been normalized by the σ^*_{ve} figure 7. The remaining differences in the normalized envelopes would be attributed to structure changes.

In fact, it can be observed that there aren't great differences between normalized strength envelopes of intact and D1 clays. The effect of natural structure maintains after first degradation cycle. First stage of destructuration occurs after a degradation cycle for 7 days and it continues for D30, D60 and D90 clays and they lie above envelope of the corresponding reconstituted clay.

In order to check mineralogical changes produced by degradation cycles in laboratory, index properties of the weathered specimens have been evaluated and compared to those of the intact specimens. It can be observed that the index properties do not change with degradation cycles. They are reported in table 2.

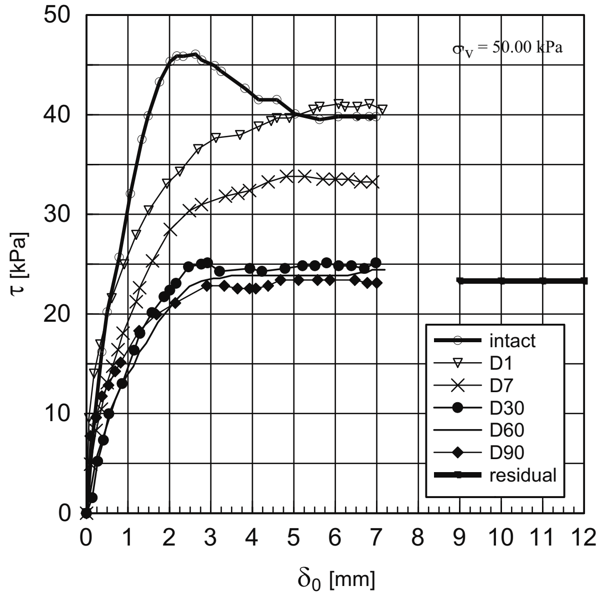

Figure 6. Stress-displacement relationships of intact and weathered specimens compared with residual shear strength

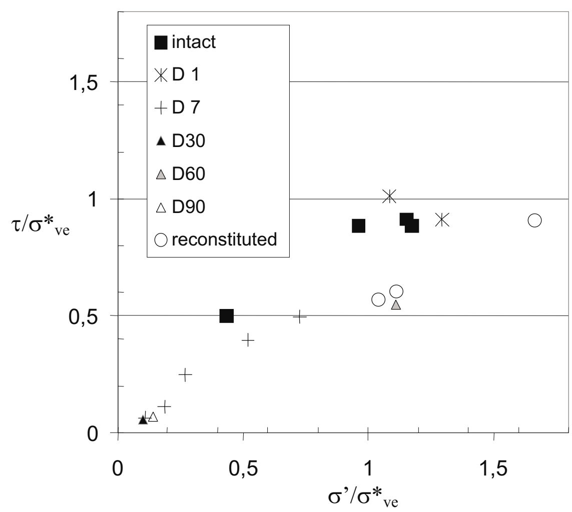

Figure 7. Normalized strength envelopes of intact, weathered and reconstituted clay

Table 2: Comparison index properties of intact and weathered test materials

State	w_L (%)	w_P (%)	IP (%)	CF (%)
Intact	51.47	29.33	22.14	55
D1	52.39	31.05	21.34	55
D7	51.47	29.33	22.14	55
D30	51.59	28.79	22.80	58
D60	51.60	28.80	22.85	57
D90	51.65	28.82	22.83	58

4 CONCLUSIONS

The analysis of the weathering processes reproduced in the laboratory by degradation cycles on Roccella clay allowed some conclusions.

Cycles of wetting-drying-freezing-thawing have disturbed its structure producing changes in fabric and bonding.

Oedometer tests on intact specimens show the microfabric is unstable and the bonding of the studied clay is not strong.

From the comparison of the oedometer tests of intact, weathered and reconstituted specimens it can be observed that with the increase of degradation cycles duration, the curves go towards that of reconstituted one.

The stress-displacement curves of intact clays show well defined peak strength on the contrary of those weathered.

The peak shear strength has been shown to reduce after degradation. The reductions are more pronounced in the first month of degradation.

The analysis of the strength envelopes normalized to respect to the effective equivalent pressure shows the strength decreases for degradation cycles of duration longer than a day and it can be due to changes in structure at failure.

The degradation cycles simulated in the laboratory do not produce mineralogical changes in tested clay.

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