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Effect of Laboratory Repeatability of Direct Shear Test on Slope Stability

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Abstract. The present work quantified the laboratory geotechnical variability by repeatability direct shear test (DS) on alluvial fine-grained soils. The effect of laboratory variability of geotechnical parameters (cohesion c' and friction angle φ') on slope stability was investigated. A mixture of compacted fine sand (40%) and clayey silt (60%) taken from a quarry fines stockpile was used: these soils are commonly used to backfill exhausted quarries located in the River Paglia alluvial plain (Central Italy). As knew in the literature, the dry density achieved by a given degree of compaction controls the shear strength parameters affecting the performance of compacted soil. Four direct shear tests were conducted following the ASTM D 3080-72 procedure on samples having a dry density of about 16.5 kN/m^3, corresponding to 95 % of maximum dry density. Combining four DS tests yielded 256 pairs of shear strength parameters in terms of effective stresses, φ' and c' parameters show normal distribution with φ'= 27.0 ± 0.8° and c'= 19.22 ± 4.08 kPa, for the stress range 100÷250 kPa. In most of the 256 combinations, the friction angle decreased as the cohesion increased. It is generally accepted that the strength parameters (c' and φ') have a negative correlation, although it is appreciated this is not always the case and different cohesion values can be obtained for the same friction angle (i.e., for the same slope of Coulomb failure envelope). The effect of the uncontrolled experimental variability of shear strength parameters on the long-term stability of a single homogeneous slope whose geometry can vary was investigated. Analyzing the factor of safety obtained using all the 256 combinations of shear strength parameters, the probability of having safety factors lower than 1.30 for the different slope heights was calculated. Such analyses demonstrate not only that direct shear testing is reliable, but also that the stability of a slope can be assessed with greater accuracy.

Keywords. Repeatability test, direct shear testing, slope stability, reliability analysis, quarry backfill.

1. Introduction

In the last decades the problem of geotechnical uncertainty has been investigated by several authors, mainly dealing with inherent and spatial variability of soils (Ang and Tang, 1984; Haldar and Miller, 1984a,b; Soulié et al., 1990; DeGroot, 1996; Phoon and Kulhawy, 1999; Whitman, 2000; Baecher and Christian, 2003; Parker et al., 2008; Raspa et al., 2008).

In general, data for engineering projects and/or for slope stability characterization are collected from in situ investigations and/or from laboratory measurements. According to Phoon (2003) each measurement inevitably produces random errors which cause differences between the results of repeated tests.

In order to investigate the laboratory geotechnical uncertainty, repeatability has to be performed according to ASTM E177. Mechanical parameters (friction angle – φ', and cohesion –*c'*) are widely obtained by means the direct shear (DS) test which is simple to perform and less expensive and more quickly than triaxial shear test (i.e., Terzaghi et al., 1996; Pakbaz et al., 2008). Although DS testing is designed to obtain drained shear strength parameters for both natural and remoulded grained soils, it is used also for fine-grained soils characterization (Day, 1999; Shaqour et al., 2008). In this framework, the present work investigates the effect of laboratory geotechnical variability (repeatability test) on the stability of homogeneous slopes.

2. Materials and Procedures

In order to evaluate the laboratory uncertainty, a remoulded fine-grained soil used to backfill exhausted quarries located in the River Paglia alluvial plain (Central Italy) was used (Fig. 1). Soils - belonging to fluvial–lacustrine deposits of the River Paglia (Cencetti et al., 2004; Di Matteo, 2012) - are made by a mixture of sand

(40 %) and clayey silt (60 %).
Materials have been compacted following the standard Proctor test (ASTM D698). The maximum dry density and the optimum moisture content were 17.3 kN/m^3 and 15.8% respectively. The quantity of fine soils is equal to 68% (ASTM sieve size n. 200 - 0.075 mm).

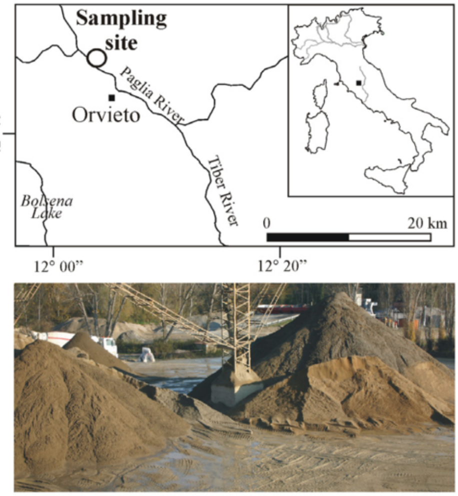

Figure 1. Quarry fines stockpile used to backfill exhausted quarries.

Consolidated drained direct shear tests were conducted at the *Istituto Sperimentale per l'Edilizia of Perugia* (ISTEDIL, Italy), following the ASTM D 3080-72 procedure to define the repeatability of the DS testing. In order to assure the drainage during the shearing, a slow strain rate of 0.005 mm/min was used. Soil samples were saturated before the shearing (degree of saturation higher than 96%).Tests were carried out with a TECNOTEST direct shear machine (Model T665/ 010) with a load cell periodically calibrated by the University of L'Aquila (Model AP 032/005, 5±0.0002 kN) and with two linear variable displacement transducers (Model MPE HS10/8717, 10±0.002 mm). In order to obtain representative samples with similar dry density and void ratio- as required for the repeatability test - a static compaction was carried out using a CBR moulds. This procedure, developed by Di Matteo et al. (2013), allows to reach a dry density of about 16.5 kN/m^3, corresponding to 95 % of maximum dry density. DS was repeated four times (named as T1, T2, T3, and T4) as shown in Figure 2. The shear strength values obtained for the four tests were combined obtaining 256 Coulomb envelopes, all having a regression coefficient (R^2) higher than 0.96 (256 pairs of φ' and c'). Figure 3 shows the frequency distribution for both shear strength parameters. Analyses of both φ' and c' data sets show normal distribution, as confirmed by applying the D'Agostino-Pearson omnibus (K2) normality test (D'Agostino, 1986).

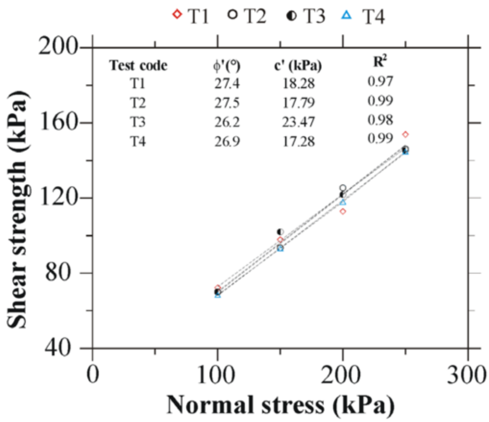

Figure 2. Relationship between normal stress and shear stress for the four tests (R^2 = regression coefficient). Modified from Di Matteo et al. (2013).

Similar distributions have been obtained for both geotechnical parameters by other authors in the literature such as Lumb (1966), Matsuo and Kuroda (1974), Tobutt (1982) and Mudler and Van Asch (1988). Applying sample standard deviations (SD) fromrepeat tests, an estimate of uncontrolled experimental variability was made, yielding a φ' of 27.0°±0.8° and a c' of 19.22±4.08 kPa.

As shown in Fig. 4 in most of the 256 combinations, the friction angle decreased as the cohesion increased. In some cases, different cohesion values can be obtained for the same friction angle (i.e., for the same slope of Coulomb failure envelope, Fig. 4).

3. Effect of Shear Strength Parameters Uncertainty on Slope Stability.

Safety factors for fully saturated slope having different slope angles and heights (Fig. 5) were computed taking into account all 256 pairs of shear strength parameters. The slope analysis was carried out by means the simplified Bishop method.

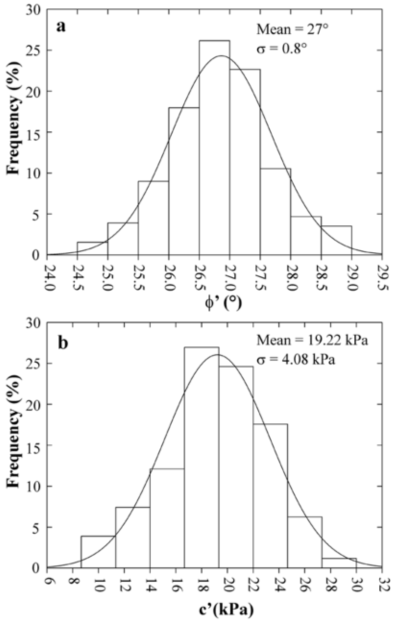

Figure 3. Frequency distribution of shear strength parameters: **a)** angle of internal friction ϕ'; **b)** cohesion c'.

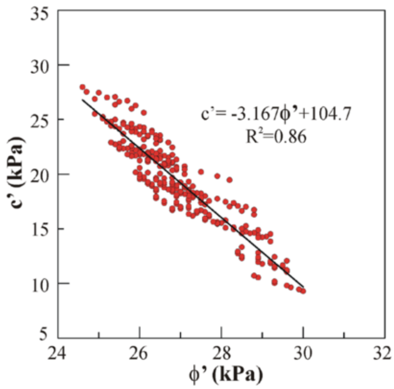

Figure 4. Relationship between friction angle and cohesion. Modified from Di Matteo et al. (2013).

Figure 6 shows the safety factor values as function of shear strength parameters ratio (φ'/c') for different slope heights and the same slope angle (Θ = 15°). For φ'/c' of about 1.4°/kPa, corresponding to the mean shear strength parameters, only the 15 m high slope has a factor of safety less than 1.3. Safety factors obtained with 256 pairs of c' and φ' and for each slope geometry (Fig. 5) show normal distribution as confirmed by the Person Chi-square test for normality. Figure 7 shows the probability curves of F<1.3 for the different slope heights. According to Selby (1982), slopes with factors of safety above 1.3 generally are considered relatively stable.

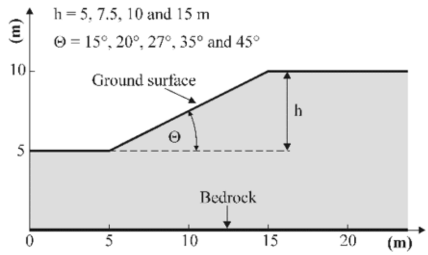

Figure 5. Sketched cross section of the homogeneous slope analysed. Water level is considered as coincident with the profile of the slope

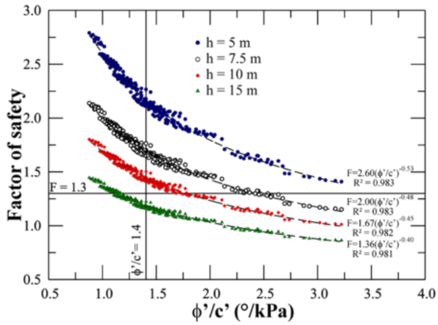

Figure 6. Safety factors as a function of ratio of shear strength parameters for a slope angle Θ = 15° (256 combinations). Modified from Di Matteo et al. (2013).

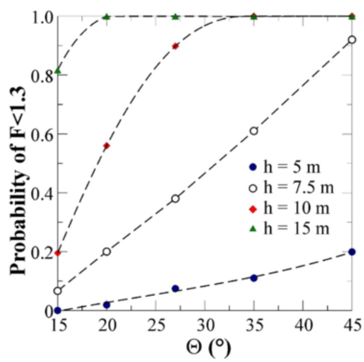

Figure 7. Probability curves of F<1.3 for different slopes outlined in Fig. 5. Modified from Di Matteo et al. (2013).

4. Discussion and Conclusions

The influence of the laboratory geotechnical variability on the long-term stability of saturated homogeneous slope having a wide range of slope angles and heights was investigated. Referring to F<1.3, the following consideration can be made analysing the results of the probabilistic approach:

1. For 5 m high slopes the probability of F<1.3 is very low, reaching the maximum value of about 0.20 only when the slope angle Θ = 45°;
2. For 7.5 m high slopes the probability of about 0.20 to have F<1.3 is reached for a Θ of just 20°. When Θ = 45° the probability became higher than 0.90.
3. For a 10 m high slope the probability of about 0.20 to have F<1.3 occurs only when Θ = 15°. For Θ higher than about 35° the probability approaches to 1.0.
4. For a 15 m high slope the probability of about 0.80 to have F<1.3 is observed for Θ = 15°: this is confirmed by observing data in Fig. 6.

The results of this study indicate that the laboratory uncertainty of shear strength parameters deeply affect the slope stability evaluation, indicating that similar study has to be pursued to evaluate more accurately the assessment of potential unstable slopes.

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