Soils and Foundations 2016;56(6):1082–1088

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Soils and Foundations

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A unique relationship determining strength of silty/clayey soils – Portland cement mixes

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Received 20 December 2015; received in revised form 5 August 2016; accepted 30 September 2016

Abstract

This technical note advances the understanding of the key parameters controlling the unconfined compressive strength (q_u) of artificially cemented silty/clayey soils by considering distinct moisture contents, distinct specimen porosities (η), different Portland cement contents and various curing time periods. The q_u values of the specimens moulded for each curing period were normalized (i.e. divided) by the q_u attained by a specimen with a specific porosity/cement index. A unique relationship was found, establishing the relationship between strength for artificially cemented silty/clayey soils considering all porosities, Portland cement amounts, moisture contents and curing periods studied. From a practical viewpoint, this means that, at limit, carrying out only one unconfined compression test with a silty/clayey soil specimen, moulded with a specific Portland cement amount, a specific porosity and moisture content and cured for a given time period, allows the determination of a general relationship equation that controls the strength for an entire range of porosities and cement contents, reducing considerably the amount of moulded specimens and reducing projects development cost and time.

Keywords: Normalization; Porosity; Portland cement; Strength; Fine grained soils; Porosity/cement index

1. Introduction

In roads and other shallow constructions, Portland cement is often used to improve soils, for example to make them better suited as subgrades and foundation backfill (e.g. Ingles and Metcalf 1972; Mitchell 1981; Thomé et al. 2005; Consoli et al. 2013; Onyejekwe and Ghataora 2015). Previous studies of silty/clayey soils–cement (Consoli et al. 2007, 2011, 2012, Marques et al. 2014) have shown that their behaviour is complex, and affected by many factors, such as the size and shape of the sand, the amount of Portland cement, the porosity and the curing time period. Consoli et al. (2007) were the first to establish a unique dosage methodology based on rational criteria where the porosity/cement index plays a fundamental role in the assessment of a target unconfined compressive strength. In the present research, the possibility of taking advantage of normalizing the results was investigated using the

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Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2016.11.011
0038-0806/

Nomenclature

C	cement content (expressed in relation to mass of dry soil)
C_{iv}	volumetric cement content (expressed in relation to the total specimen volume)
D_{50}	mean effective diameter
q_u	unconfined compressive strength
R^2	coefficient of determination
η	porosity
η/C_{iv}	porosity/cement index
γ_d	dry unit weight
γs_c	unit weight of cement grains
γs_s	unit weight of soil grains
w	moisture content

porosity/cement index. This study shows the influence of the amount of Portland cement and the porosity on the unconfined compressive strength (q_u) of seven different silty/clayey soils: London clay, Paraguayan dispersive clay, Portugal silty sand, Botucatu clayey sand, Nova Santa Rita organic soft soil, Cachoeirinha red silty clay and Pantano Grande silt. Normalisation was investigated by dividing every single strength value (for each silty/clayey soil studied) by the q_u attained at a specific porosity/cement index and a unique power function was obtained allowing the influence of amounts of Portland cement, porosity and curing time to be quantified in the assessment of q_u of silty/clayey soil–cement mixtures. From a practical viewpoint, this means that carrying out only one unconfined compression test with a specimen of the studied silty/clayed soil, moulded with Portland cement and cured for any time period allows the determination of a unique relationship that controls the strength of an entire range of porosities and cement contents. Consequently, it was possible to generalize such relationship to fine grained materials (gold tailings and coal fly ash – grinded and not grinded) treated with Portland cement.

2. Experimental program

The experimental program was carried out in two parts. First, the properties of the several silty/clayey soils were characterized. Then a number of unconfined compression tests were carried out for silty/clayey soils: Portland cement blends considering different amounts of cement, up to four dry unit weights varying from low to high values, and up to three moisture contents and distinct curing time periods (from 3 to 28 days of curing).

2.1. Materials

Seven different silty/clayey soils were used in present research: London clay, Paraguayan dispersive clay, Portugal silty sand, Botucatu clayey sand, Nova Santa Rita organic soft soil, Cachoeirinha red silty clay and Pantano Grande silt. The characteristics of these soils are shown in Table 1. As can be seen in Table 1, silty/clayey soils with distinct characteristics were considered, including high plasticity and low plasticity soils, silty/clayey sands and even an organic soil.

Early strength Portland cement was used as the cementing agent. The standard curing time period adopted was 7 days (however eventually 3 and 28 days were also used). The specific gravity of the Portland cement grains was considered to be 3.15.

Tap water was used for the characterization tests, as well as for moulding specimens for the mechanical tests.

3. Methods

3.1. Moulding and curing of specimens

For the unconfined compression tests, cylindrical specimens 50 mm in diameter and 100 mm in height were used. A target dry unit weight for a given specimen was then established through the dry mass of silty-clayey soil-Portland cement divided by the total volume of the specimen. In order to keep the dry unit weight of the specimens constant with increasing Portland cement content, a small portion of the clay was replaced by Portland cement. Porosity (η) is defined as the ratio of voids (in volume) over the total volume of the specimen. As shown in Eq. (1), porosity (η) is a function of dry unit weight (γ_d) of the blend and Portland cement content (C). Each blend (soil and Portland cement) has a unit weight of grains (γs_s and γs_c), which also needs to be considered when calculating porosity.

$$\eta = 100 - 100\left\{\left[\frac{\gamma_d}{1+\left(\frac{C}{100}\right)}\right]\left[\frac{1}{\gamma s_s} + \frac{\left(\frac{C}{100}\right)}{\gamma s_c}\right]\right\} \quad (1)$$

After each silty/clayey soil, early strength Portland cement and water were weighed, every soil and cement were mixed until the mixture acquired a uniform consistency. Water was then added, and the mixing process was continued until a homogeneous paste was created. The amount of cement for each mixture was calculated based on the mass of dry soil. The specimen was then statically compacted in three layers inside a cylindrical split mould, which was lubricated, so that each layer reached the specified dry unit weight. The top of each layer was slightly scarified. After the moulding process, the specimen was immediately extracted from the split mould and its weight, diameter and height measured with accuracies within about 0.01 g and 0.1 mm, respectively. The samples were then placed inside plastic bags to avoid significant variations of moisture content. They were cured in a humid room at 23 ± 2 °C and a relative humidity above 95%. The samples were considered suitable for testing if they met the following tolerances: *Dry unit weight* (γ_d): degree of compaction between 99% and 101% (the degree of compaction being