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Technical Note

A testing procedure for predicting strength in artificially cemented soft soils

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ABSTRACT

It is globally recognized that soft soils will have low strength and high compressibility and that under reduced loads might collapse or suffer large displacements. In order to reduce settlements and increase bearing capacity of structures built on such soils, their stabilization using cementitious materials such as Portland cement and/or quicklime (increasing strength and stiffness) is an efficient technique used worldwide. The focus of this research is to present and check the accuracy of a new testing procedure to evaluate strength gain in very soft soils when using cementation as a means of improvement. This testing procedure was intended to fasten acquiring strength results in artificially cemented soft soils. In short, in the proposed procedure the force applied to embed a flat base rod into a soil mass is measured by using high resolution load rings. The proposed flat base rod embedding test was shown to be adequate for evaluating the gain in strength of cemented soils. Results of embedding flat base rod strength have unique linear relations with both unconfined compressive strength and splitting tensile strength, being independent of type and amount of cementitious material (Portland cement and/or quicklime), as well as of the curing time period. The wrap up of present studies is that the developed testing procedure can be used as a substitute of unconfined compression and splitting tensile tests as a dosage test, being easier to mold specimens (might be molded in the field) and faster in acquiring strength results (can be carried out in a bucket filled with soil and the cementitious material, in which will be attached to the load ring) in artificially cemented soft soils.

1. Introduction

Soft soils are materials that possess many unwanted properties for engineering projects, such as low strength and high compressibility. For engineering projects comprising weak soils, one of the most used methodologies to improve the soil is through the insertion of cementitious materials. Admixture stabilization is a technique of mixing chemical additives with soil to improve the consistency, strength, deformation characteristics, and permeability of the soil. This improvement becomes possible by the ion exchange at the surface of clayey minerals, bonding of soil particles and/or filling of void spaces by chemical reaction products. Although a variety of chemical additives has been developed and used, most frequently used additives nowadays are cement and lime due to its availability and cost. The mechanism of the lime and cement stabilization has been studied extensively in 1960s by the highway engineers in relation to the improvement of base and sub-base materials for road construction. The needs of rapid construction on difficult soil conditions enhanced the application of mass stabilization, a new soil improvement method where stabilizer is mixed into peat, mud or soft clay. In such technique the whole soft soil mass is strengthened to a homogeneous slab structure that behaves like dry crust (Andersson et al., 2001; Jelisic and Leppänen, 2003). Use of deep binder mixing, named deep mixing method, was developed in Sweden and Japan in 1970s. The deep mixing utilizes the mixing blades or augers to manufacture a treated soft soil column of predetermined size and shape in situ. The strength of treated soft soils is in the order of 100 to 1000 kPa in terms of unconfined compressive strength (Terashi and Juran, 2000). This practice has been widely used, as described by Lin and Wong (1999), Andromalos et al. (2001) and Hussin and Garbin (2012). The research group at Federal University of Rio Grande do Sul, Brazil (e.g., Thomé et al., 2005; Consoli et al., 2008, 2009a,b,c, 2010, 2011, 2012, 2013a,b, 2014a,b; Festugato et al., 2013; Faro et al., 2015) has been studying key parameters dictating strength and stiffness of lime/cement treated soils.

To evaluate the strength gain of a soft soil resulting from the addition of a cementitious agent, a laboratory study involving the molding of specimens is usually required. However, a number of obstacles have to be considered when molding soft soil–cementitious blends for strength evaluation. For instance, the bottom and the sides of the molds of soft soils usually having high moisture contents must be made completely sealed so as to prevent loss of materials (including water), which might result in difficulties in the unmolding process, and, consequently, in damage to the artificially cemented specimens.

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The wrap up of present studies is that the newly developed testing procedure can be used as a substitute of unconfined compression and splitting tensile tests as a dosage test, being easier to mold specimens (might be molded in the field) and faster in acquiring strength results (can be carried out in a bucket filled with soil and the cementitious material, in which will be attached the load ring) in artificially cemented soft soils. By carrying out a fast and simple procedure, it is possible to evaluate the gain in strength during different curing periods in the same soil sample, minimizing molding problems.

1.1. Novel testing apparatus and procedure

The testing apparatus consists of one or more load rings of various resolutions, one or more flat base rods, a recipient to accommodate the treated soil mass and a simple embedding tool. A detailed description of the apparatus is given below.

1.1.1. Load rings

As shown in Fig. 1, three load rings made of nylon, with external diameter of 220 mm and different wall thicknesses were built and used during the tests. The characteristics of each ring are detailed in Table 1. In order to define the embedding strength and resolution of the load rings, calibration curves with the utilization of know weights were constructed. Fig. 2 shows the calibration curve for the 10 mm wall thickness load ring and Table 2 shows the calibration equations obtained for the three rings. It should be noticed that the resolution of the rings may be changed by using different materials, such as PVC, and different wall thicknesses. All tests carried out in present research used the 10 mm wall thickness load ring.

1.1.2. Flat base rods

Differently from the conventional cone penetrometer, the flat base rod was designed to avoid interference from lateral friction during the embedding process, thus entirely transmitting the force to the soil through the base area of the rod. Four stainless steel flat base rods with distinct base areas were built and utilized, as shown in Fig. 3. The rods present groove marks every 5 mm to be used as a reference during pushing. Table 3 shows, for each rod, the area of the base, the maximum pressure transmitted into the soil, and the resolution for each combination of rod base area and load ring wall thickness. All tests carried out in present research used a unique flat base rod (with area of 0.5 cm^2).

Table 1
Nylon rings used in the experiments showing thickness of the walls, maximum applied forces, resolution and maximum and minimum stresses.

Ring	Wall thickness (mm)	Maximum force (N)	Resolution (n)	Maximum stress (kPa)	Minimum stress (kPa)
1	10	639	0.515	12,780	1.60
2	6	121	0.121	2420	0.30
3	3	35	0.035	700	0.09

1.1.3. Embedding system

The embedding system may be manual, since the verticality is guaranteed and there is no interference from any external element. For the experiment reported herein, a manually operated 100 kN reaction frame was utilized.

1.1.4. Soil recipient

The only requirements for the soil recipients are that they are large enough so that no edge effects occur and that the thickness of the soil layer is at least four times as deep as the final depth of the embedded rod. If more than one test is to be performed in the same specimen, it is recommended that a thin wall be vertically placed within the mass of highly cemented soil specimens to prevent fissures from propagating and making other readings unfeasible.

1.1.5. Modus operandi

The test involves the determination of the maximum stress applied to an artificially cemented soil mass, measured during the embedment of a flat base rod up to a depth of 10 mm. After the load ring and the flat base rod, selected based on the estimated strength of the material to be analyzed, are coupled to the embedding system, the flat base rod is pushed into the soil up to a depth of 10 mm, using the aforementioned

Fig. 1. Load rings.