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Technical Note

A prompt procedure for prediction of strength in artificially cemented soft soils

Daniel Winter[a], Andry Soares Rilho[a], Bernardo Scapini Consoli[b] and Nilo Cesar Consoli[b,*]
[a]*Graduate Program in Civil Engineering, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil*
[b]*Department of Civil Engineering, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil*

Abstract. The focus of this paper is to present a new evaluation method for strength gain in very soft soils when using cementation as a means of improvement. This test procedure was created due to great difficulty encountered in molding specimens for compression and tensile tests in very soft clays and silts. The test consists in the measurement of the maximum force applied to embed a flat base rod into a soil mass using high sensibility dynamometric rings. The maximum pressure (maximum force divided by the flat base rod area) recorded up to 30 mm embedding of the rod into the soil mass is adopted as reference and has been shown to have direct linear correlation to Brazilian tensile tests. A correlation was set to a range of different materials encouraging its use in engineering practice. The main advantages of the proposed test are the easiness to mold specimens, the option of carrying out multiple tests in a single specimen and the possibility of carrying out tests outside the laboratory environment.

Keywords: Soil stabilization, strength gain evaluation, tensile strength, artificially cemented soft soils

Notation

N	Newton
kPa	Kilopascal
cm^2	square centimeter
kg	kilogram
m	meter
m^3	cubic meter
mm	millimeter
PVC	polyvinylchloride
q_t	splitting tensile strength

*Corresponding author: Nilo Cesar Consoli, Professor, Department of Civil Engineering, Federal University of Rio Grande do Sul, Av. Osvaldo Aranha 99 – 3 andar, Porto Alegre, RS 90035-190, Brazil. Tel.: +55 51 81239266; Fax: +55 51 33083999; E-mails: consoli@ufrgs.br; danielwinterpoa@gmail.com (D. Winter); andrysr@gmail.com (A.S. Rilho); beconsoli@hotmail.br (B.S. Consoli).

1. Introduction

Soft soils are materials that possess many unwanted properties for engineering projects, such as low strength and high compressibility. For engineering projects that comprise soft materials, one of the used methodologies is soil improvement through the insertion of cementitious materials. This practice is widely used, as described by Jelisic and Leppänen [9] and Hussin and Garbin [10], as well as on research developed at Federal University of Rio Grande do Sul - Brazil [2–8].

To evaluate the strength gain of a soft soil by addition of a cementitious agent, a laboratory study by means of specimens molding is required. A number of obstacles has to be considered when molding soil-cementitious blends for strength evaluation. The bottom and sides of the molds must be made completely airtight so as to prevent loss of materials and other forms of failure in the preparation of the specimen, which might result in difficulties in the unmolding, and, consequently, damage of cemented specimens beyond use.

The objective of this new test apparatus is the attainment of an expeditious procedure for evaluating the gains in strength in soft soil - cementitious mixtures, which may even be used in the field. In carrying out a fast and simple procedure it is possible to evaluate the gain of strength during different curing periods in the same soil sample, minimizing the problems of molding. The test may be used as a project quality control procedure, in order to evaluate whether the gain of strength of the material is within the specifications expected for the project.

2. Equipment

This prompt test was created with ease of execution as its main objective. The equipment consists of one or more dynamometric rings of various sensitivities, one or more flat base rods, a recipient to accommodate the treated soil mass and a simple embedding tool. A detailed description of the equipment is given below.

2.1. Dynamometric rings

As shown in Fig. 1, three dynamometric rings made of nylon, with external diameter of 220 mm and various thicknesses were built and used during the tests. This, in turn, generated a distinction in the sensitivities, allowing the strength of the soil to be measured accurately according to specifications of each ring. The characteristics of each of the rings are detailed in Table 1. Figure 2 shows the calibration curve for the 10 mm wall thickness dynamometric ring and Table 2 shows the equations obtained for the three rings. The sensibility of the rings may also be altered by making the rings out of different materials such as PVC.

Fig. 1. Dynamometric measuring rings.

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

Ring	Wall thickness (mm)	Maximum force (N)	Sensibility (N)	Maximum stress (kPa)	Minimum stress (kPa)
1	10	639	0.515	12780	1.60
2	6	121	0.121	2420	0.30
3	3	35	0.035	700	0.09

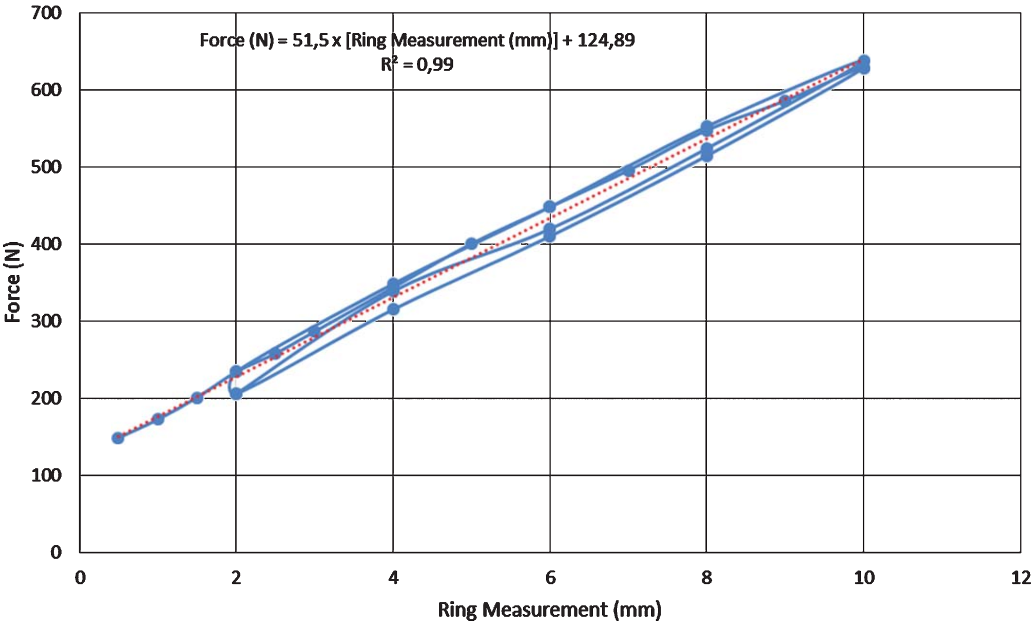

Fig. 2. Calibration of dynamometric rings with wall thickness of 10 mm.

Table 2
Calibration equations of the rings

Pushing force	
Ring	Strength (N)
1	51.5 × [ring measurements (mm)] + 124.89
2	12.11 × [ring measurements (mm)]
3	3.52 × [ring measurements (mm)]

2.2. Flat base rods

The rod to be used in the embedding was designed to have a flat base in order to avoid interference from lateral friction during the embedding of the element, thus transmitting all of the force applied to the rod into the soil through the area of the base. Four stainless steel flat base rods with distinct tip areas were used, as shown in Fig. 3. The rods possess grooves spaced 10 mm from each other, so as to allow the investigator to observe the embedding into the soil with the necessary accuracy. Table 3 describes the recommended area of each rod, the maximum stress transmitted into the soil and the sensibility of the equipment for each base and ring.

2.3. Embedding system

The embedding system may be manual, so long as the verticality is guaranteed and there is no interference from any external element. For the execution of this experiment, a reaction frame with a 100 kN capacity is recommended.

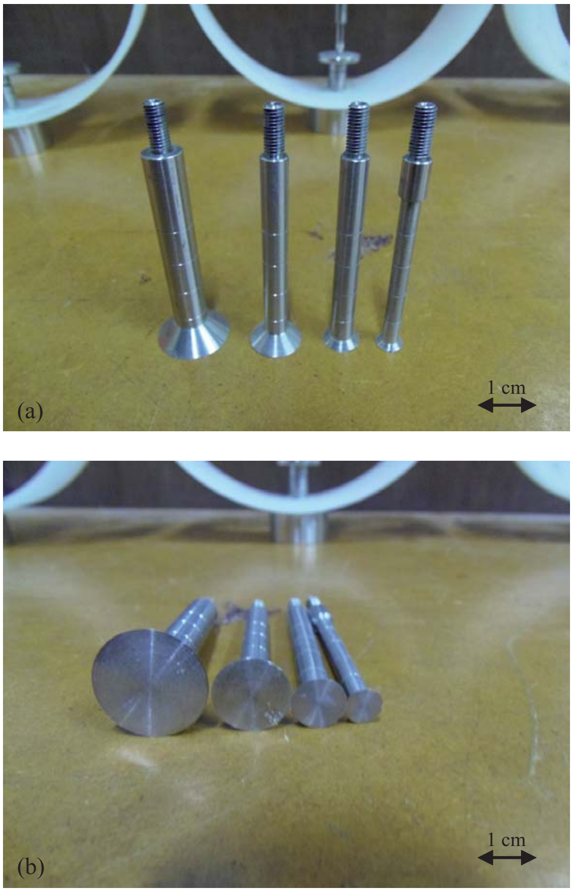

Fig. 3. Flat base rods with different tip areas used in the experiment: (a) lateral view and (b) underside view for 4 cm^2/22.568 mm, 2 cm^2/15.958 mm, 1 cm^2/11.284 mm and 0.5 cm^2/7.979 mm area/diameter.

Table 3
Area of the flat base rod steel tips showing maximum and minimum stresses for each base

Tip area (cm^2)	Wall of 10 mm		Wall of 6 mm		Wall of 3 mm	
	Minimum stress (kPa)	Maximum stress (kPa)	Minimum stress (kPa)	Maximum stress (kPa)	Minimum stress (kPa)	Maximum stress (kPa)
0.5	12.78	12780	2.42	2420	0.70	700
1.0	6.39	6390	1.21	1210	0.35	350
2.0	3.20	3195	0.61	605	0.18	175
4.0	1.60	1598	0.30	302.5	0.09	87.5

2.4. *Soil recipient*

The only requirement for the recipient is it should be large enough to avoid edge effects. The thickness of the soil layer must be at least twice as deep as the final depth of the embedded rod. It is recommended to place a plastic partition within the highly cemented soil sample so as to prevent fissures from propagating and making successive readings unfeasible.

3. Methods

The test consists on the acquisition of the maximum applied stress in a cemented soil through the 30 mm deep embedding of a flat base rod into the soil mass. After the dynamometric ring and the flat base rod tip were selected, based on the strength of the material to be analyzed, they are mounted on the embedding system. The 30 mm deep embedding of the flat base rod tip into the soil is carried out using the aforementioned grooves as reference. With the maximum longitudinal displacement obtained from the ring during the test and the calibration equation of the ring, the maximum force applied in the soil by the steel end tip during the procedure is determined. Dividing this force by the area of the tip of the rod will result in the maximum applied stress.

Different rings and different flat base rod tips, as mentioned previously, allow for the evaluation of the gain of strength for cemented soil in different states, from very soft soils to very hard soils.

4. Case study

In order to evaluate the validity of the method, Bravo [1] carried out a series of splitting tensile tests in soft clay containing 11% organic matter and very high moisture content (varying from 125% to 175%). The soil was treated with quicklime, silica fume and rice husk ash. Quicklime was used in dosages of 100 kg/m^3 and 200 kg/m^3; mixtures of quicklime and silica fume were used in dosages of 50 kg/m^3 of quicklime plus 50 kg/m^3 of silica fume and 100 kg/m^3 of quicklime plus 100 kg/m^3 of silica fume; mixtures of quicklime and rice husk ash were used in dosages of 50 kg/m^3 of quicklime plus 50 kg/m^3 of rice husk ash and 100 kg/m^3 of quicklime plus 100 kg/m^3 of rice husk ash. A total of 54 tests were performed with curing times of 14, 28 and 56 days.

Flat base rod tip embedding tests were carried out for all conditions described for splitting tensile tests. The comparison between the results of splitting tensile tests and the maximum embedding stress is shown in Fig. 4. An unique linear relationship with a high correlation ($R^2 = 0.94$) was attained between splitting tensile strength and peak flat base stress for distinct cementitious agents, amounts of cementitious agents, curing time and moisture

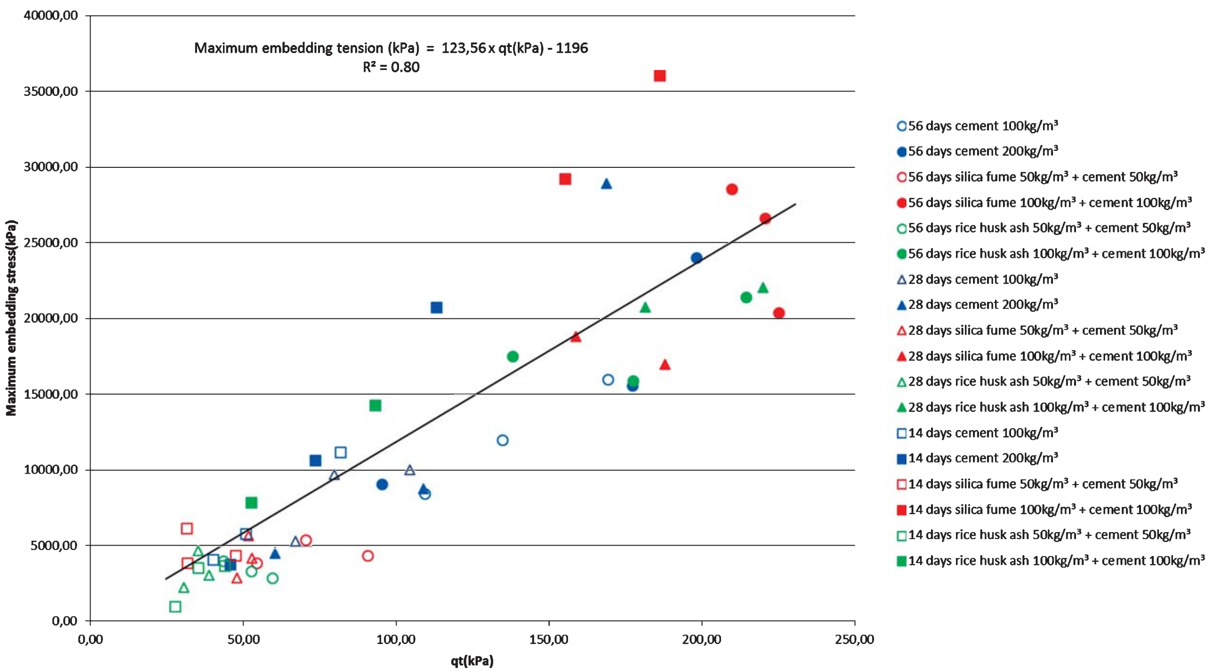

Fig. 4. Relation between splitting tensile strength (q_t) of soil – quicklime, soil – quicklime – silica fume and soil – quicklime – rice husk ash and maximum embedding stresses obtained during the experiment proposed herein.

contents. This set of results demonstrates the usefulness of the approach in providing a prompt procedure to evaluate strength gain of soft soils treated with cementitious materials.

5. Conclusions

The following conclusions were reached based in the studies carried out in present research:

- The proposed flat base embedding test was shown to be an adequate means of evaluating the gain of strength of cemented soils. A clear unique linear relation between splitting tensile test results and peak stress results from flat base embedding tests was obtained for distinct cementitious agents (quicklime, quicklime and silica fume, quicklime and rice husk ash), distinct amounts of cementitious agents, different curing time periods and moisture contents.
- The test consists on a prompt procedure to evaluate the strength gain in cemented materials. The specimens are easy to mold and may be used at various curing times, distinct cementitious agents, distinct amounts of cementitious agents and moisture contents. The tests may be performed in the field, needing only a simple reaction frame system to guarantee verticality and accuracy on stress measurements.
- The proposed test is faster than standardized splitting tensile strength test given the same qualitative information as demonstrated by the constant ratio of measured splitting and embedding strengths.

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