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Difficulties of using the Harvard Miniature Compaction Apparatus as a reference test in the study of soil compaction

Difficultés d'utilisation de l'appareil Harvard miniature comme test de référence dans l'étude du compactage de sols

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ABSTRACT: Harvard miniature compaction apparatus appears as an alternative procedure for simulating the compaction conditions of sheepsfoot rollers. However, despite its advantages, its application is not very common mainly due to the absence of effective standardized procedures. To verify the applicability of this apparatus, six different Portuguese natural soils were collected and prepared for compaction tests. After calibrating a standard procedure, assessing both the number of tamps and layers, triaxial UCS-type tests were conducted to evaluate the results quality. The analysis of both the unconfined compressive strength and the deformability modulus shows that some soils may experience failure by puncture while using the stiffer spring.

RÉSUMÉ: L'appareil de compactage miniature de Harvard apparaît comme une alternative pour simuler les conditions de compactage des rouleaux à pieds de mouton. Cependant, malgré ses avantages, son application n'est pas très courante principalement en raison de l'absence de procédures standardisées efficaces. Pour vérifier l'applicabilité de cet appareil, six sols naturels portugais différents ont été collectés et préparés pour des essais de compactage. Après avoir étalonné une procédure standard, en évaluant à la fois le nombre de poinçonnement et de couches, des essais triaxiaux du type UCS ont été effectués pour évaluer la qualité des résultats. L'analyse de la résistance à la compression non confinée et du module de déformabilité montre que certains sols peuvent subir une rupture par poinçonnement lors de l'utilisation du ressort plus rigide.

Keywords: Harvard miniature compaction apparatus; standard procedure; poncture failure.

1 INTRODUCTION

Soil compaction is probably the most widely used form of soil improvement technique in the world. It is well documented that shallow surface compaction technique depends on the type of soil. For fine-graded materials, it is suitable to use sheepsfoot rollers. Pneumatic rubber-tired rollers are suitable for clays and smooth-drum rollers and vibratory rollers are used primarily for granular materials. The compaction modes differ from equipment to equipment and the compaction energy may result from a static force, a dynamic/ramming action or a combination of vibration and a static force.

To achieve the best results, it is necessary to previously study the compaction properties of soils, namely the maximum dry unit weight and optimum moisture content. Also, it is suitable to simulate the in-situ compaction technique. However, in laboratory, the compaction study is based on one single apparatus, the Proctor compaction test, which only properly simulates the application of a ramming action. Among other laboratory testing apparatus to study soil compaction, the Harvard miniature compaction apparatus appears as an alternative for simulating the compaction conditions of sheepsfoot rollers (Wilson, 1950).

Despite the advantages of the latest equipment, its application is not very common mainly due to the absence of effective standardized procedures as well as the fact that it is highly dependent on the laboratory operator. In the present study, after calibrating a standard procedure based on sensibility analysis, Harvard compaction results of natural soils collected in different locations are compared with Proctor compaction results. In addition, triaxial UCS-type tests were performed with the aim of comparing the stress-strain behaviour of samples compacted by both types of equipment, comparing the compressive strength and the deformability modulus.

2 EXPERIMENTAL PROGRAM

The laboratory testing program may be divided into two stages. In the first one, six different soils were submitted to compaction tests using regular Proctor compaction equipment and Harvard miniature compaction apparatus. The main purpose of this stage is the proposal of a standardized procedure to run Harvard compaction tests, using modified Proctor compaction results as reference values. After the establishment of a procedure, which guarantees the quality and the repeatability of results, samples with optimum moisture content were prepared to be subsequently submitted to shear strength tests. These latter tests are part of the second stage of the laboratory testing program, in which triaxial-UCS type test were run in a static triaxial apparatus.

2.1 Soil properties

Six soils, collected from three different locations in the centre of Portugal, were used to perform the present study. Table 1 sums up the most relevant soil properties. The compaction tests were carried out on all the soils, but only the first five soils were used to calibrate a standardized procedure to carry out Harvard compaction tests. The shear strength tests were only performed on the first three soils plus *Remessa* soil.

Table 1. Soil properties

Soil designation	Location	Fines content (%)	IP (%)	G (-)	Unified Class.
Pediatric Hospital	Coimbra	38	7	2.5	SC-SM
Industrial Area	Ponte de Sor	61	9	2.65	SC
Ladeiras	Ponte de Sor	31	14	2.66	SC
Ribeirinha	Ponte de Sor	27	5	2.65	SC-SM
Soil B	Aveiro	91	15	2.71	CL
Remessa	Pombal	51	21	2.69	CL

2.2 Testing equipment and procedures

The different compaction and triaxial apparatus, as well as the testing procedures are described in the following sections.

2.2.1 Harvard miniature compaction apparatus

The Harvard miniature compaction apparatus consists of three parts: i) the mould; ii) the compaction tamper and iii) the collar remover/specimen ejector. The mould (Figure 1a) is 71.5 mm height and its inner diameter is 33.34 mm. The ratio of these two dimensions allows the direct use of Harvard samples in triaxial tests. The compaction tamper (Figure 1b) consists of a metallic cylinder with a spring inside, which is compressed during the compaction process. The Coimbra Engineering Academy Geotechnical Laboratory has three different springs: 20 lb, 37.5 lb and 40 lb. Finally, the collar remover/specimen ejector (Figure 1c) is used to remove and eject the collar and the sample, respectively. The compaction method results from a calibrating procedure based on sensibility analysis, which is presented later in this article.


a) b) c)

Figure 1. Harvard miniature compaction parts: a) mould; b) compaction tamper; c) collar remover/specimen ejector.

2.2.2 Proctor compaction apparatus

The proctor compaction apparatus is the most commonly used laboratory compaction device and its dimensions and procedures are properly normalised. In Portugal, this compaction test follows the E197-1996 specification from the Civil Engineering Nacional Laboratory (LNEC). According to this standard and the soil grain size distribution, the mould may be 117 mm height with a 102mm inner diameter or 114 mm height with a 152 mm inner diameter. Using two different drop heights and hammer weights, two different compaction energies may be applied.

In the present study, since the percentage of soils particles retained in sieve No. 4 (4.75 mm) for all the six soils is less than 20%, all the compaction tests were carried out with the smallest mould. Thus, each layer of soil is compacted twenty-five times. The number of layers depends on the compaction energy: three layers for the light compaction (regular Proctor test) and five for the heavy compaction (modified Proctor test) (LNEC, 1966).

2.2.3 Static triaxial apparatus

The undrained confined test (UCS test) is a very common shear strength test in geotechnics, due to its simplicity and execution speed. In this study, the tests were carried out in a Wykeham Farrance static triaxial apparatus, mark Tritech 50 kN, with the Triaxial Automated System from GDSinstruments. All the measurement instruments were previously calibrated, having reached 1,0 as coefficient of determinations (Silva, 2017).

The testing procedure comprises two stages: sample preparation and shear stage. All the samples tested were prepared with an optimum moisture content and, if they were compacted with the Proctor apparatus, the samples had to be cut to the desired dimensions, i. e., 76 mm height and 36 mm diameter. Note that the dimensions of Harvard samples are slightly smaller but their ratio is 2.0.

After setting up the sample on the triaxial pedestal and having achieved all the required adjustment, the sample were submitted to an UCS-type test. The tests were performed with a shear rate of 0.78 mm/min, within the limits suggested by Head (1994).

3 SENSIBILITY ANALYSIS-BASED PROCEDURE FOR THE HARVARD COMPACTION APPARATUS

The suggested procedure for running Harvard Compaction tests is based on a sensibility analysis, in which the number of tamps and the number of layers were defined. The analysis was performed, first, with the Pediatric Hospital soil. This soil was selected only for reasons of availability, since it comes from Coimbra. The procedure was subsequently applied to all soils except for the soil *Remessa*.

This analysis is due to the lack in information on how to correctly perform Harvard compaction tests. For example, it is proposed that the tamps must be applied at a rate of ten every fifteen seconds and how they have to be applied (Wilson, 1970), but the precise number of tamps is unknown. The exact number of layers to be compacted is also not widely accepted. There are authors that propose four layers (NDOT, 2009) and others that propose five layers (Wilson, 1970). Finally, since no references were found regarding the importance of the springs stiffness that control the applied tamps, it was decided to extend this analysis to all available springs.

For each spring (20 lb, 37.5 lb and 40 lb) and using five layers as a reference, samples were compacted with ten, twenty, thirty, forty and fifty tamps. The results of these tests are shown in Figure 2. It can be seen that the stiffer the spring, the less influence on the number of tamps. However, after thirty tamps, the influence of tamps tends to decrease and the efficiency of the compaction itself also decreases, namely with the 40 lb spring. According to these results, the thirty tamps in forty-five seconds are chosen as reference for performing Harvard compaction tests.

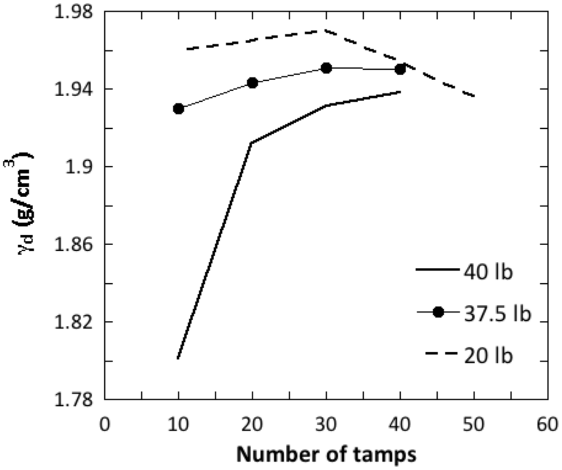

Figure 2. Influence of the number of tamps in the compaction results.

The definition of the number of layers was made by comparing the results of both Proctor and Harvard test for identical conditions. The aim was to check how many layers were necessary to reach identical dry unit weight in both light and heavy Proctor compaction tests. When using the 20 lb Harvard spring, samples were prepared with three, four and five layers, while using the 40 lb spring, samples were compacted with five and six layers. Some of the results are summed up in Table 2.

Table 2. Harvard compaction results for the definition of the number of layers.

				□,□□□ (g/cm^3)		
Spring	**Layer**	**Pediatric H.**	***Ladeiras***	***Ribeirinha***	**Soil B**	**Industrial A.**
20 lb	4	1.896	1.903	1.895	1.754	1.882
	5	1.926	1.928	1.924	1.756	1.909
40 lb	5	1.909	1.985	1.998	1.804	1.986
	6	1.928	1.986	1.995	1.807	1.946

Comparing the Proctor compaction tests results with the Harvard 20 lb spring results, one may conclude that Harvard results are always greater than Proctor results, regardless of the soil tested. Nevertheless, when testing with only three layers, the samples show high levels of heterogeneity and the layer interfaces are easy to spot. Thus, it is suitable to carry out Harvard compaction tests using four layers with the 20 lb spring. When using the 40 lb spring, the results are not so obvious. For some soils, the increase in the number of layers induces a reduction in dry unit weight. Since this result is not consistent with the effect of compaction energy in soils, it is concluded that soil failure occurs during compaction. Therefore, it is recommended to use five layers of soil, when compacting with the Harvard 40 lb spring.

4 STRESS-STRAIN BEHAVIOUR OF COMPARED SAMPLES

In order to evaluate the effectiveness of the compaction process described in section 3, samples of four different soils, which were prepared via Harvard and Proctor compaction apparatus, have been submitted to triaxial UCS-type tests. As referred to before, while Harvard samples can be tested right after the compaction process, Proctor samples must be trimmed until the required dimensions are reached. The principal results of these triaxial tests are summarized in Table 3.

Table 3. Triaxial UCS-type results

	Compaction energy	**$\square_{\square}$ (kPa)**	
		Proctor	Harvard
Pediatric Hospital	Light / 20 lb	161.30	163.60
	Heavy / 40 lb	843.80	141.40
Ladeiras	Light / 20 lb	80.60	125.00
	Heavy / 40 lb	570.30	203.30
Industrial Area	Light / 20 lb	54.90	75.90
	Heavy / 40 lb	113.30	100.50
Remessa	Light / 20 lb	262.90	106.30
	Heavy / 40 lb	1513.40	139.00

The effect of compaction energy is easily identified in Proctor prepared specimens. The increase of compaction energy translates into an improvement of soils unconfined compressive strength. However, analysing Harvard-related results, the use of the 40 lb spring the increase in shear resistance is not so evident. In fact, a decrease of unconfined compressive strength is observed for the Pediatric Hospital soil. This incongruity may only result from soil failure by puncture during the compaction process. To reinforce this assumption, the deformability modulus for 50% of the unconfined compressive strength was also determined. Table 4 summarizes the obtained values for Harvard prepared samples. As it can be seen, there is an abnormal decrease in soil stiffness for Industrial Area and *Remessa* soils. It should also be noted that, the fact that either of these two soils have been referenced during the unconfined compressive strength analysis leads to a worrying inconsistency of results.

Table 4. Deformability modulus and axial strain for 50% of the unconfined compressive strength.

	Spring	**$\square_{\square\square}$ (kPa)**	**$_{\square\square}$ (%)**
Pediatric Hospital	20 lb	66.30	4.98
	40 lb	151.40	1.51
Ladeiras	20 lb	26.00	7.72
	40 lb	156.20	2.05
Industrial Area	20 lb	32.70	4.70
	40 lb	31.10	3.21
Remessa	20 lb	17.90	12.89
	40 lb	17.01	14.45

5 CONCLUSIONS

The present study focuses on the complications associated with the use of the Harvard miniature compaction apparatus. In the absence of predominantly accepted test standards or test procedures, a sensibility analysis was carried out in order to access a technique which would assure both quality and repeatability of results. This analysis concludes that, depending on the spring used inside the tamper (20 lb or 40 lb), the compaction process requires thirty tamps in forty-five seconds applied in four or five layers, respectively. It should be emphasized that the results depend on both the number of tamps and layers. For certain combinations, soil failure by puncture may occur.

This last aspect is confirmed by the triaxial UCS-type test carried out. In opposition to the soil compaction theory, the increase of compaction energy does not always cause the increase of the dry unit weight and, consequently, a more resistant soil. This behaviour is clear evidence of soil failure during the compaction process. The same conclusion outcomes from the calculation of the deformability modulus for 50% of the unconfined compressive strength. Stiffer samples are not always obtained with increasing compaction energy. Also, these inconsistencies were observed, separately, in different soils.

In conclusion, despite the advantages of Harvard miniature compaction apparatus, the obtaining of consistent and reliable results is not trouble-free to warranty. In addition, the whole compaction procedure is highly dependent on the technician, from which issues may arise that are outside the scope of this study.

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