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# ESTABLISHING THE DIFFERENCES IN THE RESULTS OF TWO STANDARD PROCTOR TEST PROCEDURES

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RESUMEN

Compaction is a soil densification process in which its resistance and load capacity are increased. The degree compaction of soils is evaluated through two parameters: its maximum dry specific weight ($\gamma_{dmax}$) and its optimal humidit ($w_{opt}$), these parameters can be determined through many laboratory techniques. Globally, one of the most used is the Standard Proctor test. The standard process of this test established the definition of one compaction curve using values from a single soil sample after being compacted several times during the procedure. However, in the usual implementation of this test has emerged a variation of the process, to define the compaction curve using more than one sample soil. The goal of this investigation is to provide information about the discordance of the resulting values from the two different techniques of the Standard Proctor test. To accomplished this, over a fist group of samples, it was determined the optimal compaction parameter of two different soil types from the Mexican state of Tabasco after following the standardized process of the Standard Proctor test. These first results served as control values. Subsequently, the second group of samples of the same soil types from the first procedure was tested again with the Standard Proctor test, but now, over several soil samples instead of one (every soil sample was compacted once). All the tests were carried out in triplicate and the results were adjusted using a polynomial line. Comparing the results from the second group of samples against the control values, the second technique caused a 1% decrease in the maximum dry specific gravities, and optimal humidity increase close to 5%. These differences are caused by the process of preparing the soil samples in the Proctor test variant.

**Palabras clave**

*Standard Proctor, dry specific weight, moisture content, re-compaction.*

The main objective of compaction is to improve the performance characteristics of the soil. With this technique, it is possible to decrease the compressibility of soils and increase their volumetric stability to changes in water content, in addition to obtaining an increase in strength, rigidity, and decreased in permeability (Abeyrathne *et al*., 2019; Zhang *et al*., 2018; Hossain & Yin, 2010; Yin, 2009). The compaction state of a soil sample is defined by two state variables: the dry specific weight ($\gamma_d$) and the moisture content (w). When water is added to the soil during compaction, it acts as a lubricating agent on the particles, sliding one over the other, leaving them densely packed. When the moisture content is gradually increased and the same compaction effort is maintained, the dry specific weight of the soil progressively increases to a maximum known as the maximum dry specific weight ($\gamma_{dmax}$). Beyond this limit, any increase in water content tends to reduce the dry specific weight (Image 1). The moisture content at which the maximum dry specific weight is reached is called the optimum moisture content ($w_{opt}$) (Das: 2015)

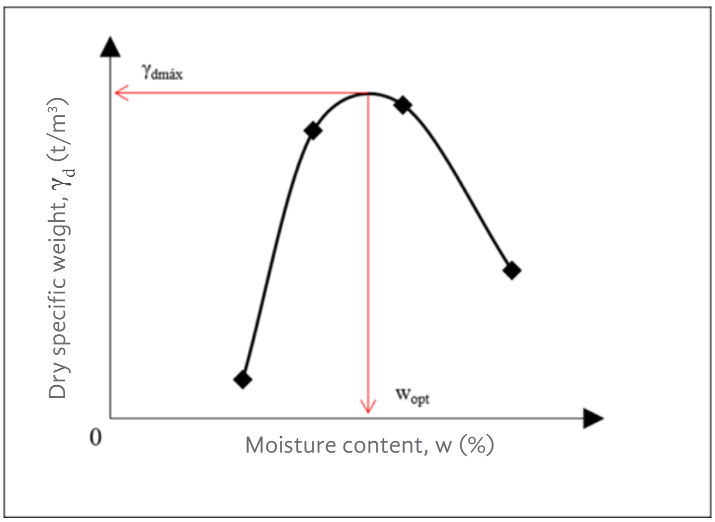



*Image 1*. Standard Proctor compaction curve. Source: Own elaboration

The classic methods for determining compaction parameters are those defined by Ralph R. Proctor (1933): Standard and Modified Proctor tests (also known as standard AASHTO and modified AASHTO, respectively) Regarding the first of these tests, the manual of Sampling and Materials Testing Methods of the Mexican Institute of Transportation, M-MMP-1-09 (2006), in its section 09 (compaction AASHTO), describes the procedure to determine using a compaction curve the maximum dry specific weight and the optimal humidity. The books published by Juárez-Badillo and Rico-Rodríguez (2005), as well as by Braja M. Das (2015) also describe the aforementioned procedure.

Overall, the procedure for performing the Standard Proctor Test can be summarized as follows: (*i*) a representative portion of approximately 4 kg of soil is separated by quartering; (*ii*) a quantity of water necessary to homogenize the soil is added to the selected portion of soil so that it has a water content 4 to 6% lower than the estimated optimum; (*iii*) this portion of soil is compacted within the test mold (Image 2) in three layers, applying 25 strokes to each one with a 2.5 kg rammer at a height of fall of 30.48 cm; and (*iv*) once the compaction of the layers is completed, the specific weight of the compacted material and its moisture content is determined. With this procedure, a point on the compaction curve is achieved. It is advisable to have at least four points to have a well-defined curve (Image 1).

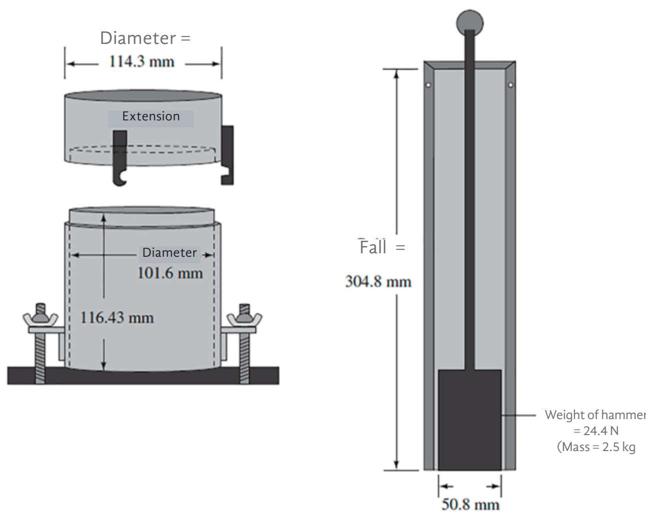



*Image 2*. Equipment for the Standard Proctor Compaction Test (Das: 2015). Source: Own elaboration

To achieve the next point, the manual M-MMP-1-09 (2006) states that the same portion of soil used on the first point is used and that approximately 2% of water be added to the initial mass of the test portion and steps (*iii*) and (*iv*) above be repeated. This procedure must be repeated for each point. That is, the same portion of soil is used several times. Optimal compaction conditions are determined by identifying the moisture content for which the maximum dry specific weight is achieved ($\gamma_{dmax}$ and $w_{opt}$) (Image 1).

Several factors influence the compaction process, for example, Sivakumar and Wheeler (2000) studied the influence of compaction pressure, water content, and type of compaction on the mechanical and hydraulic behavior of white kaolinite clay. Other researchers have studied the effect of soil type (Mora-Ortiz *et al*., 2014; Izquierdo *et al*., 2011; Rico-Rodríguez & del Castillo, 1992), water content (Jiang *et al*., 2015; Duong *et al*., 2013), room temperature during the test and the level of applied energy (Heitor *et al*., 2015; Mendoza: 1992). However, the possible effects of using the same portion of soil for the entire Standard Proctor Test are not mentioned in the literature.

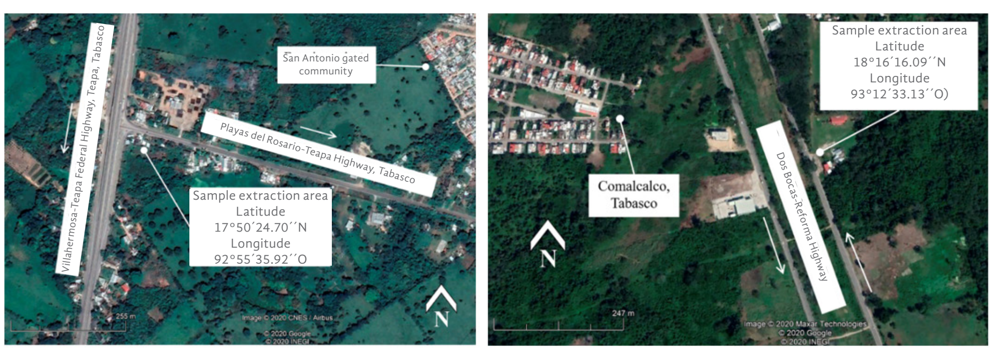
In the usual practice of this test in materials laboratories, it is common to use several portions of soil instead of just one, that is, for each point of the compaction curve a portion of soil is used. With this, it is possible to reduce considerably the time of execution of the test. With the use of this variant in the Proctor Test procedure, a question arises, will there be any change in the result of the Standard Proctor Test if instead of using a single portion of soil as indicated in the manual M-MMP-1-09 (2006) to determine the compaction parameters, independent portions are used for each point of the compaction curve? This research aims to provide information about the variation in results obtained between these two ways of performing the Standard Proctor Test.

## METHODOLOGY

To carry out this investigation, two different types of soils were used, which were obtained by the PCA method (open pit) at a depth of 1.5 m, below is their basic information:

**Soil 1**. This soil was obtained at the side of the Villahermosa-Teapa Federal Highway at the junction with the Playas del Rosario-Teapa State Highway, at km 020+285 (Image 3). The extracted material is color red and has no organic matter content. The basic characteristics of the soil are shown in Table 1.

**Soil 2.** This soil was extracted on one side of the Dos Bocas-Reforma Federal Highway, better known as the short road in the municipality of Comalcalco, Tabasco, close to the family restaurant Oasis (Image 3). The extracted material is color brown and has no organic matter content. Its basic characteristics are shown in Table 1




(a) Soil 1 (b) Soil 2

*Image 3.* Extraction areas of the soils understudy. Source: Google maps

**Table 1**
*Classification and basic characteristics of the soils understudy*

| Property | Soil 1 | Soil 2 |
|---|---|---|
| Liquid limit (LL) | 83% | 34.9% |
| Plastic limit (PL) | 17.33% | 25.62% |
| Plasticity Index (PI) | 65.66% | 9.28% |
| Solid specific weight (Ss) | 2.69% | 2.58 |
| Fine content (%) | 97.44 | 96.52 |
| Sand content (%) | 2.56 | 3.48 |
| USCS Classification* | CH (High plasticity clay) | ML (Low plasticity slit) |

*Unified Soil Classification System

Source: Own elaboration

To determine if there is a variation in results between the two Standard Proctor Test procedures, the procedure described below was followed:

First, the optimal compaction parameters ($\gamma_{dmax}$ and $w_{opt}$) for both soils were obtained following the conventional procedure outlined in the Manual of the Mexican Institute of Transportation (M-MMP-1-09): 2006), that is, using a single portion of 4.5 kg of soil for the entire test (Image 4). These results had the function of reference values.

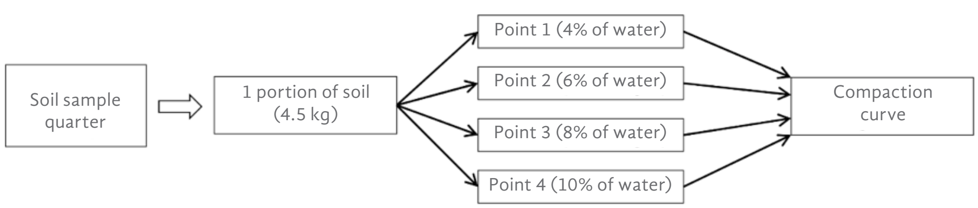



*Image 4*. Reference test (a portion of soil for the entire Standard Proctor Test). The % of water is relative to the initial mass of the test portion. Source: Own elaboration

All Standard Proctor Tests in this research were conducted three times and adjusted by a polynomial line. The tests were carried out in a temperature-controlled laboratory (24ºC) ensuring that every aspect of their execution (increments of water during the test, the position of the rammer, distribution of the blows, etc.) was the same for all and according to the indications of the manual M-MMP-1-09 (2006). The optimal compaction parameters were determined according to the traditional method proposed by Proctor (1933): identifying the moisture content for which the maximum dry specific weight is reached.

1. With the reference compaction parameters obtained, the next step was to repeat the Standard Proctor Tests in both soils, following

the procedure outlined in the Manual of the Mexican Institute of Transportation (m-mmp-1-09: 2006), but with the variant of using a portion of 4.5 kg of soil for each point of the compaction curve (Image 5), that is, each portion of the soil was only compacted once to obtain one point of the compaction curve. Each of these portions was obtained by quartering. A percentage of water was added to each portion, concerning the initial mass of the test portion, and it was left to rest in hermetically sealed containers for 24 hours before compacting.

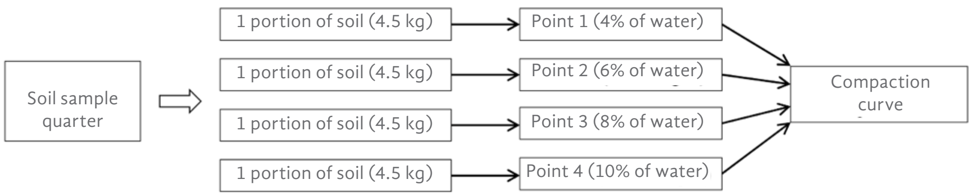


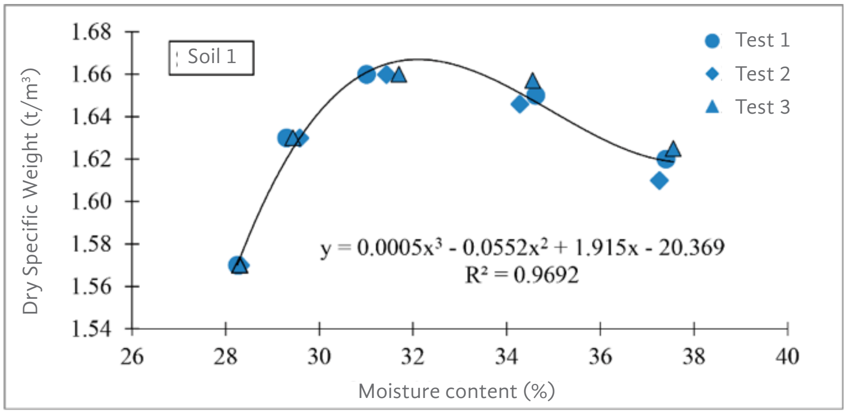

*Image 5.* Test with several soil portions (a variant of the Standard Proctor compaction procedure). The % of water is relative to the initial mass of the test portion. Source: Own elaboration

2. Finally, the results obtained with both procedures of the Standard Proctor Tests were compared and comments and conclusions were made.

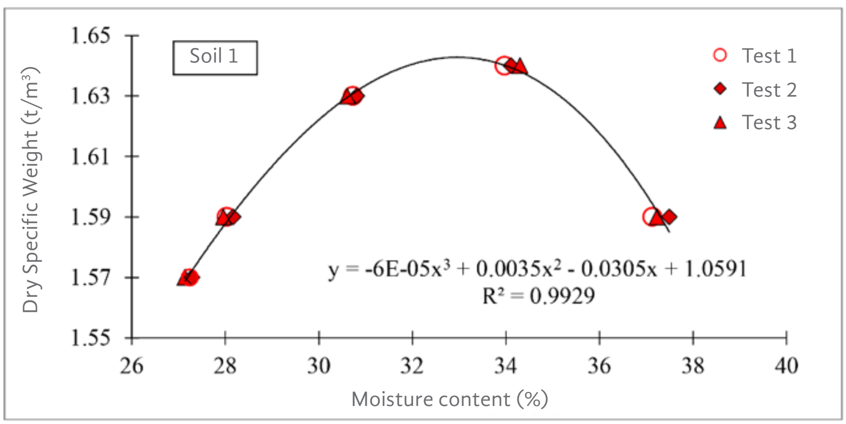
## RESULTS

Image 6 shows the results of the Standard Proctor Compaction Tests performed on soil 1: a) conventional test with a single portion of soil; b) Proctor test using several portions of soil, and c) comparison of the compaction curves obtained with both procedures.

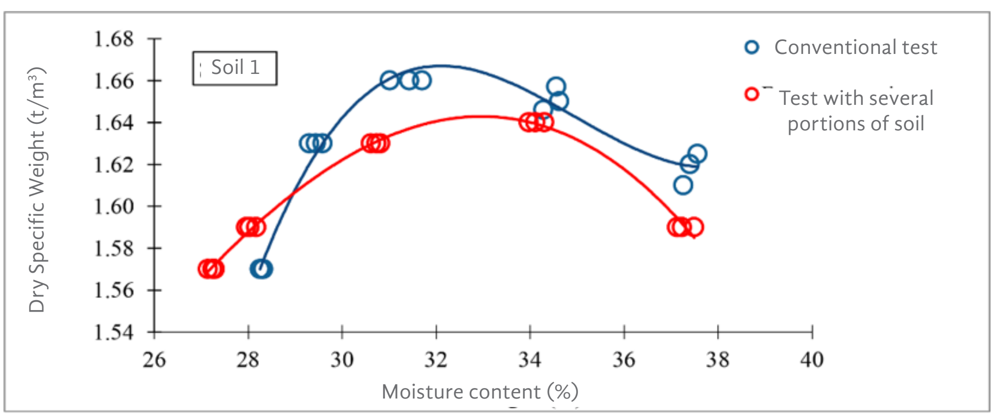
Image 6(a) shows the three repetitions of the Conventional Proctor Test performed on soil 1, each of the three tests were performed in the same manner. In each test, five points of the compaction curve were obtained. It is observed that point one in the three tests has approximately the same moisture content ($w \approx 28.3\%$) and the same dry specific weight ($\gamma_d = 1.57$ t/m$^3$). However, from point two there are slight variations between the same points of each test, for example, if point three of the three tests are compared with each other, a maximum difference of 1% in moisture content is observed. On the other hand, comparing point five in the three tests the maximum difference in dry specific weight between them is 2%. It is observed that the difference between the same points in each test is accentuated as the moisture content increases. These differences occurred despite running the Conventional Standard Proctor Test with the same procedure, under the same conditions, and with the same water increments for each point (M-MMP-1-09: 2006). The above is evidence that variations in moisture and specific weight between the same points in the three tests are linked to the distribution of water in the only portion of soil used for each test, and that after each increase of water there is no rest time for it to be distributed homogeneously in the soil mass. This lack of time affects the uniform distribution of water in the sample, producing the variations shown in Image 6(a).




(a) Conventional Standard Proctor (1 soil portion per test)




b) Standard Proctor with several soil portions per test




c) Compaction curves with both variants of the standard Proctor test

*Image 6*. Standard Proctor Test on Soil 1. Source: Own elaboration

Image 6(b) shows the three repetitions of the Proctor Test on soil 1 but using a portion of soil for each point of the compaction curve. It is possible to observe a greater correspondence between the values of *w* and $\gamma_d$ for the same points of the three repetitions. It is observed that all dry specific weights are equal to each other for the same points in the three tests. However, there were differences of less than 1% in moisture content between the same points in each test. This uniformity in the values of $\gamma_d$ for the same points of the three tests is due to the preparation process of each portion of the soil. As explained above, in this variant of the Standard Proctor Test, a portion of soil is used for each point of the compaction curve. Each portion receives a different moisture content and is allowed to rest for 24 hours in hermetically sealed containers (Image 5) before compacting. The resting period for each portion of the soil ensures that the moisture is homogenized throughout the sample.

Image 6(c) compares the compaction curves obtained with both procedures of the Standard Proctor Test on soil 1, while Table 2 shows the values of the maximum dry specific weight ($\gamma_{dmax}$) and the compaction optimum moisture ($w_{opt}$) determined with both procedures.

The results show that the conventional procedure generated higher dry specific weights at lower optimal humidity, compared to the variant that uses several soil portions. The difference between the $\gamma_{dmax}$ was 1.5%, while for the $w_{opt}$ it was 1%.

Image 7(a) shows the three replicates of the Conventional Proctor Test performed on soil 2, each of the three tests was performed in the same manner. In each test, four points of the compaction curve were obtained. As in the previous case, it is observed that point one in the three tests has the same dry specific weight ($\gamma_d$ = 1.73 t/m$^3$) with slight variations in moisture content (1.31% maximum difference between points).

**Table 2**

*Standard Proctor test results for both soils understudy*

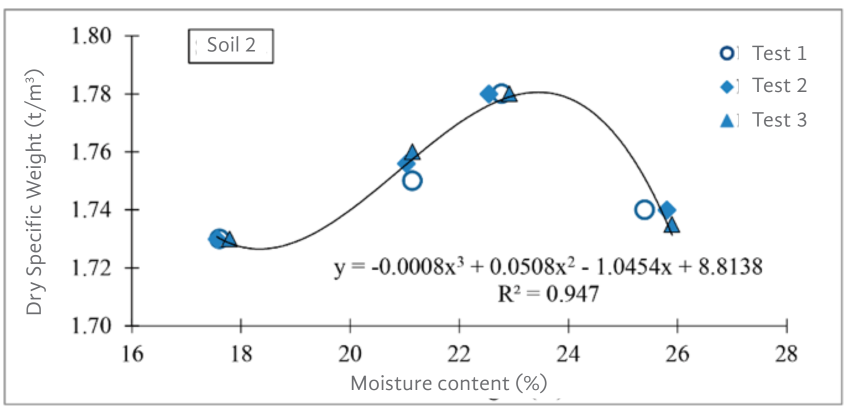
| Compaction parameters | Soil 1 High plasticity clay | | Soil 2 Low plasticity slit | |
|---|---|---|---|---|
| | Conventional test | Test with several portions of soil | Conventional test | Test with several portions of soil |
| Maximum dry specific weight (t/m$^3$) | 1.668 | 1.643 | 1.781 | 1.772 |
| Optimal Humidity (%) | 32 | 33 | 23.4 | 24.7 |

Source: Own elaboration

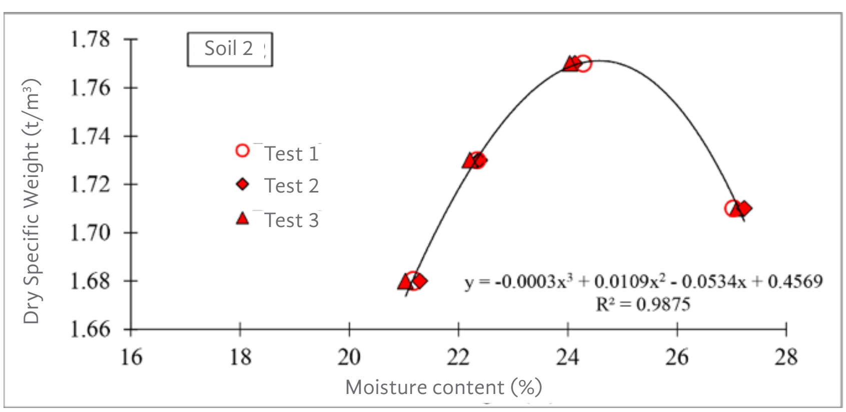
As in soil 1, it is noted that comparing the same points in the three tests, from point two there are variations in the values of dry specific weight and moisture content. These variations are accentuated by the increase in water content. The maximum differences are presented in points two and four, with maximum magnitudes of 2% in moisture content and 1% in dry specific weight.

Image 7(b) shows the three replicates with soil 2 of the Standard Proctor test variant using several soil portions. Again there is a greater correspondence between the values of w and $\gamma_d$ for the same points of the three repetitions. Note that all dry specific weights are the same for each point of the three tests. The moisture content between the same points in the three tests varies by less than 1%. As in the case of soil 1, it is observed that the variant of the Proctor Test shows more homogeneous results between the same points of the three tests. This is due to the sample preparation process, which, as explained above, allows homogenization of moisture within the soil portion.

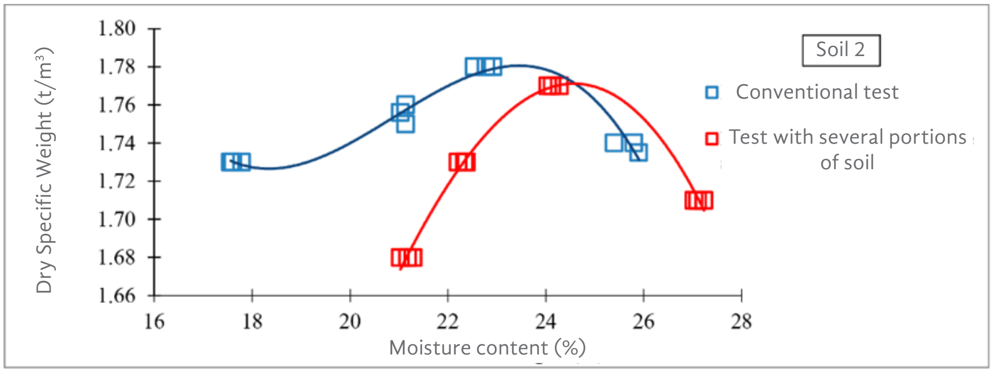
Image 7(c) compares the compaction curves obtained with both procedures from the Standard Proctor Test on soil 2. Table 2 shows the optimal compaction values ($\gamma_{dmax}$, $w_{opt}$) determined with both procedures.




a) Conventional Standard Proctor (1 soil portion per test)




b) Standard Proctor with several soil portions per test




c) Compaction curves with both variants of the standard Proctor test

*Image 7.* Standard Proctor Test on Soil 2. Source: Own elaboration

Comparing both compaction curves, it can be seen that the conventional procedure generated higher dry specific weights at lower optimal humidity, compared to the variant that uses several soil portions. The difference between the $\gamma_{dmax}$ was 0.51%, while for the $w_{opt}$ it was 1.3%.

## CONCLUSIONS

The experimental results showed that, at least for the soils under study, performing the Standard Proctor Test with the variant of using a portion of soil for each point of the compaction curve, generates slightly lower maximum dry specific weights with optimal moisture contents, slightly higher than those that would be obtained with the conventional Standard Proctor test. It is interesting to note that although the differences between the optimal compaction parameters obtained with both procedures (Table 2) are small, they also show a constant behavior. That is to say, the Proctor tests carried out with several portions of soil always generated a $\gamma_{dmax}$ lower than the one obtained with the conventional procedure.

During the execution of both procedures of the Proctor test, it was found that the variant that uses several portions of soil is performed faster than the conventional procedure, because it is not necessary to make water increments on the same portion of the soil, nor is it necessary to mix until homogenizing, since the portions of soil previously wetted are available and, with a 24-hour rest, the homogeneity of the humidity is guaranteed. The time saved in the execution of the test depends on the operator, but without a doubt, time-saving is a very important factor in the professional field. Besides, the difference between the magnitudes of the maximum dry specific weights obtained with both procedures could lose importance from the practical point of view, since this difference is less than 1.5% in magnitude.

More extensive studies on this topic are needed, a second phase of this research will be to test other types of soils with different sand contents, more repetitions of the tests, different compaction energies, and with other compaction methods, such as the miniature Harvard.

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