Characterization of Pavement Subgrade Soil Using Gyratory Compaction

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ABSTRACT

A parameter used to carry out the quality control of unbound compacted soil materials is the maximum dry unit weight obtained from a standard or modified Proctor test. However, these tests are far from simulating the field compaction mechanism produced by roller equipment. The gyratory compactor has been put forward as a new laboratory equipment to determine the compaction curves in the Highway Construction and Pavements Laboratory accommodated in the Polytechnic School of Democritus University in Xanthi Greece. Results of Proctor and modified compaction curves as well as those obtained from the gyratory compactor are presented in the current paper. The controlled variables in the gyratory compactor were the vertical pressure, the gyration angle, and of course the number of gyrations. The compaction curves are more or less similar disregarding the rate of gyration and gyration angle. The dynamic compaction yielded better results compared to those obtained by the gyratory compactor. The difference between the two compaction modes was greater at low moistures. Three different moistures were used. In any case, the dynamic method led to higher dry density values. California Bearing Ratio specimens prepared with dynamic or gyratory compaction have lower values with an increase in moisture contents and were generally greater in the case of dynamic compaction.

Keywords: soil compaction, modified Proctor, gyratory compactor, bearing capacity, unbound materials

INTRODUCTION

The process applied to densify a soil through mechanical means is called compaction and is one of the most critical features in the construction of transportation infrastructure like roads, embankments, airfields etc. Engineers have since long time desired to acquire a new laboratory process to compact soils. The aim is to represent more accurately the modern field compaction conditions [1]. Up to now, the compaction methods most commonly used are the Standard and Modified Proctor tests, which have remained relatively unchanged since the 1930s and 1950s, respectively. Technology progress has brought about advances in field compaction. On the other hand, the Proctor hammer is not necessarily representative of the usual field compaction motions and pressures (static, kneading or vibratory) [2].

The exclusive aim for the creation of Superpave Gyratory Compactor (SGC) in the decade of 1990 was to test hot mix asphalt. Many researchers have made the hypothesis that the new Superpave gyratory compactors may be used to compact soil materials in the laboratory [3, 4]. In 2006, Browne [5] studied the feasibility of using SGC for soil compaction suggesting that this device more closely represents in situ compaction. The procedure used by Browne was based on the guidance of the AASHTO T132 compaction method [6] for hot mix

asphalt. Depending on the soil type and the moisture content, the most important parameters controlled by the SGC were the number of gyrations as well as the confinement pressure.

In general, when the confinement pressure increases, the compaction dry unit weights for fine-grained soils also increase [7]. It has been shown that increasing the number of gyrations would lead to increased compaction dry unit weights for non-cohesive, granular soils [8].

Panko et al. (2011) [9] used the SGC trying to find an acceptable alternative to standard ASTM compacting methods for the moisture-density relation of pavement base and subbase materials. These authors concluded that increased number of gyrations yielded a high densification of unbound materials. When the modified Proctor test for the determination of the optimal moisture content (OMC) and maximum dry density (MDD) of soils is used, vertical work is exerted on the soil sample. On the contrary, when the SGC is being used to compact granular soils, shear work, due to the gyration angle, is applied to the soil complementing the vertical work.

Perez and colleagues in 2013 [10] have evaluated the method of soil compaction using gyratory compactor instead of Proctor compaction for three different soils (classified as sand SM, silt ML and clay CH according to Unified Classification System). At least for the three speeds and two angles of gyration tested, the resulting compaction curves were independent of these variables. Nevertheless, it had been found that a series of variables can be controlled in the gyratory compactor making it possible to obtain the standard compaction curve.

Many different reasons could underlay the favorable use of gyratory compactors for soil compaction in the laboratory. First of all, these instruments are generally more precise than impact hammers, have greater effectiveness against impact hammers, and its easier to repeat the testing conditions with gyratory compactors [11, 12, 13]. Flexible pavements systems experience moving traffic loads. The action of moving wheels which is transferred to the pavement structure can be simulated by the gyratory compactors which simultaneously apply vertical loads and kneading action [14]. Furthermore, the internal structure of specimens prepared with a gyratory compactor closer resembles that of actual soil material in road projects.

MATERIALS AND METHODS

The method of gyratory compaction using SGC achieves the assessment of the compactability of specimens by the application of a 600 kPa ± 18 kPa vertical stress via platens to a mass of asphaltic mixture inside a mold with a diameter of 100 mm or 150 mm (commonly used when testing asphalt). Whilst the machine keeps the platens horizontal and parallel to each other, the mold is gyrated along its longitudinal axis at a fixed angle $(1.25^{o}\pm0.2^{o})$ relative to the vertical axis. During the test, the height of the specimen is measured automatically and the mixture density and void content are calculated. Compaction data is displayed in real time. The compaction options are either to proceed for a prescribed number of gyrations or until a given mixture density or void content is achieved.

Five sampling sites in Xanthi, Northern Greece, have been chosen in order to take soil quantities for laboratory testing. The sites are scattered within an area of a radius of about 20 kilometers so as to be representative of different prevailing conditions. Soil samples were assigned the names S1 to S5.

A series of tests have been performed on the soil samples. These included the Atterberg limits determination, the methylene blue test, the sand equivalent test, as well as free swell tests and tests for the relationship between density and moisture (modified Proctor). For the optimum moisture content and three moisture contents under and over this value and for the corresponding maximum dry densities cylindrical specimens have been formed using both the

dynamic hammer compaction method and the gyratory compaction process. The California Bearing Ratio (CBR) tests on the samples determined the bearing capacity of these materials to be used as subgrades in highway construction works.

The grain size distribution of the soils tested is given in Figure 1. All soil samples have been characterized as A-2-6 according to the AASHTO classification of soils.
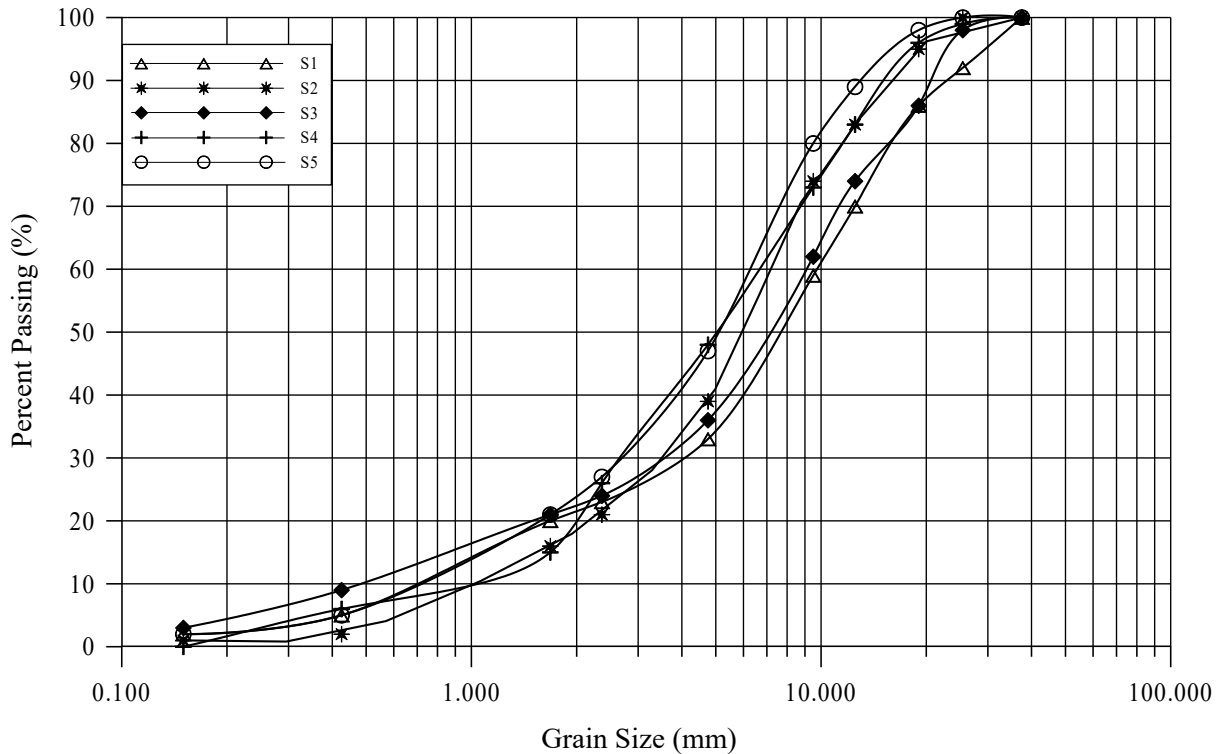

Figure 1 Grain size distribution of the soil samples tested.

LABORATORY TESTING RESULTS

In Table 1, the results of the different tests performed in the laboratory are listed for the five soils under investigation. It must be noted that all soils were sampled at the same time period. So, their natural moisture is indicative of the season of the year (spring). Due to the distance between the sampling sites moistures ranged between 6.40% and 20.08% for samples S5 and S2 respectively.

The greater value for the Linear Shrinkage (LS) measured has been found for the soil sample S2 as 13.57% along with the maximum Liquid Limit (LL) (38) which is consistent with the nature of the soil. On the other hand, the lower LS and LL values were obtained for the S1 sample (8.57% and 31, respectively).

The S3 sample presented the maximum and the S2 sample the minimum plastic limit (23 and 10 respectively).

Referring to the free swell of the soils, it is observed that it ranged between 35 (soil sample 1) and 57 (soil sample S5). The methylene blue test is based on the import in successive increasing portions of methylene blue solution on a suspension of the material to be examined until saturation is achieved. The methylene blue supplements the sand equivalent (SE) and Atterberg limits tests in determining the existence of particle with clay dimensions. The values of methylene blue determined in the laboratory are quite similar in magnitude with the higher one corresponding to S2 sample. The SE values for S1 sample and S5 sample are the highest and the lower of the five (24 and 8, respectively)

Table 1 Properties of the five soil specimens subjected to laboratory tests

	S1	S2	S3	S4	S5
Natural Moisture	11.96	20.08	9.53	10.21	6.40
Liquid Limit	31	38	35	35	37
Plastic Limit	14	10	23	17	14
Plasticity Index	17	28	12	18	23
Linear Shrinkage	8.57	13.57	9.35	10	12.19
Methylene Blue	15.59	17.42	13.98	9.14	15.59
Free Swell	35	51	43	37	57
Sand Equivalent	24	10	17	11	8
AASHTO Classification	A-2-6	A-2-6	A-2-6	A-2-6	A-2-6

The curves shown in Figure 2 refer to the relation of moisture content and the dry density values for the file soils taking part in the laboratory testing program. The water content which corresponds to the maximum dry density (MDD) is called optimum moisture content (OMC). The part of the soil materials retained on the 19 mm sieve has been compacted in moulds 152.4 mm in diameter in 5 layers.

In Table 2 the values of OMC and MDD along with those of CRB tests are shown. The OMC values ranged from 10.39% (S1) to 19.1% (S5), while MDD found in the region of 1741.79 (S4) to 1987.50 (S1). The values of CBR have been received using the optimum moisture content found through the modified Proctor procedure (ASTM D1557-12).
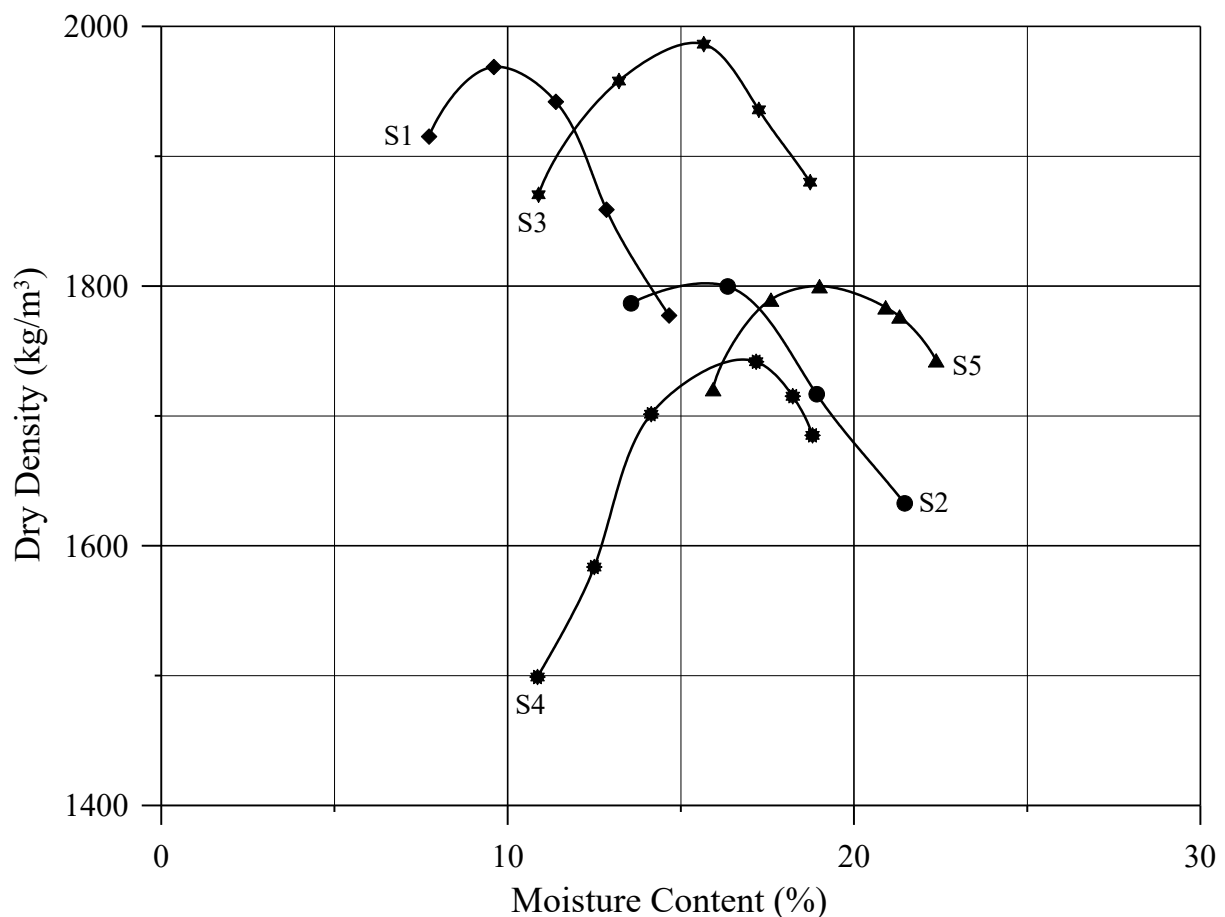

Figure 2 Moisture content vs. Dry density of soil specimens using the modified Proctor procedure.

Table 2 Moisture, Density (modified Proctor) and CBR values of soil specimens

Soil Sample	Optimum Moisture Content	Maximum Dry Density	CBR
S1	10.39	1987.50	18
S2	15.81	1801.13	7
S3	15.66	1986.36	8
S4	17.20	1741.79	13
S5	19.10	1840.00	10

Soil samples have been compacted both dynamically and with the gyratory compactor. Dynamic compaction is a well known technique for the improvement of soils since it densifies them using a drop weight. Each gyroscopic specimen has been compacted using a specified speed of 30 rounds per minute (rpm) and an angle of 20.00 milliradians (mrad) or equivalently 1.15 degrees.

In order to get comparable results with the CBR method, a limitation had been posed to the height of gyratory specimens (117.6 mm); in such a way the exactly same height and weight was determined for the specimens of the two methods. The height of the specimens was reduced initially with a higher rate after each rotation cycle.

The S1 specimen was compacted dynamically at 10.03% moisture content has yielded the maximum dry laboratory density (2024.95 kg/cm^3). The S3 specimen compacted dynamically at 21.55% moisture content yielded the lower dry laboratory density (1629.22 kg/cm^3). In the case of gyroscopically compacted specimens, the heist and lowest densities were furnished by the S4 and S3 specimens, respectively when they were compacted using 13.96% and 21.22% moisture contents. The dry density values in these cases were 1889.54 kg/cm^3 and 861.33 kg/cm^3, respectively.

As the moisture at which the specimen has been compacted increases, the shear is reduced. The higher shear (443 KN/m^2) was observed in the S2 specimen was compacted gyroscopically at 14% moisture. On the contrary, the smaller shear (35 KN/m^2) was observed in S3 specimen compacted gyroscopically at 20% moisture. Finally, the density of the sample specimens increases at the end of the rotation cycles. More specifically, the higher density (2211 kg/m^3) has been observed in the S3 specimen compacted gyroscopically at 14% moisture, while the lower density (1989 kg/m^3) has been observed in the S5 specimen compacted gyroscopically at 14% moisture.

It is obvious that when the dynamic compaction was used the result obtained was sensibly better compared to those yielded by the gyratory compactor. More specifically, at the low moistures, the difference is greater between the two compaction modes. Also, the dynamic method leads to higher dry density values for all specimens tested in all three different moistures used.

Figure 3 depicts the relationship developed between the moisture in the specimens and the recorded CBR values. In each graph of Figure 3, two different curves are shown referring to the way the specimen has been compacted (dynamically or with the use of gyratory compactor). All curves have a concave form with the exception of the one corresponding to the dynamically compacted sample S2 which is almost linear or convex shaped.

It can be seen from Figure 3 that the highest CBR value has been recorded for the specimen S5 compacted dynamically using 14% moisture content and is equal to 57. On the other end of the range of values, the S3 specimen yielded a CBR value equal to 1 when it was compacted dynamically at 20% moisture content.

The highest CBR value under the gyratory compaction conditions was 30 for the S5 specimen, compacted using 14% moisture content. The lower CBR value (2) has been recorded by the S3 specimen compacted gyroscopically at 20% moisture content.
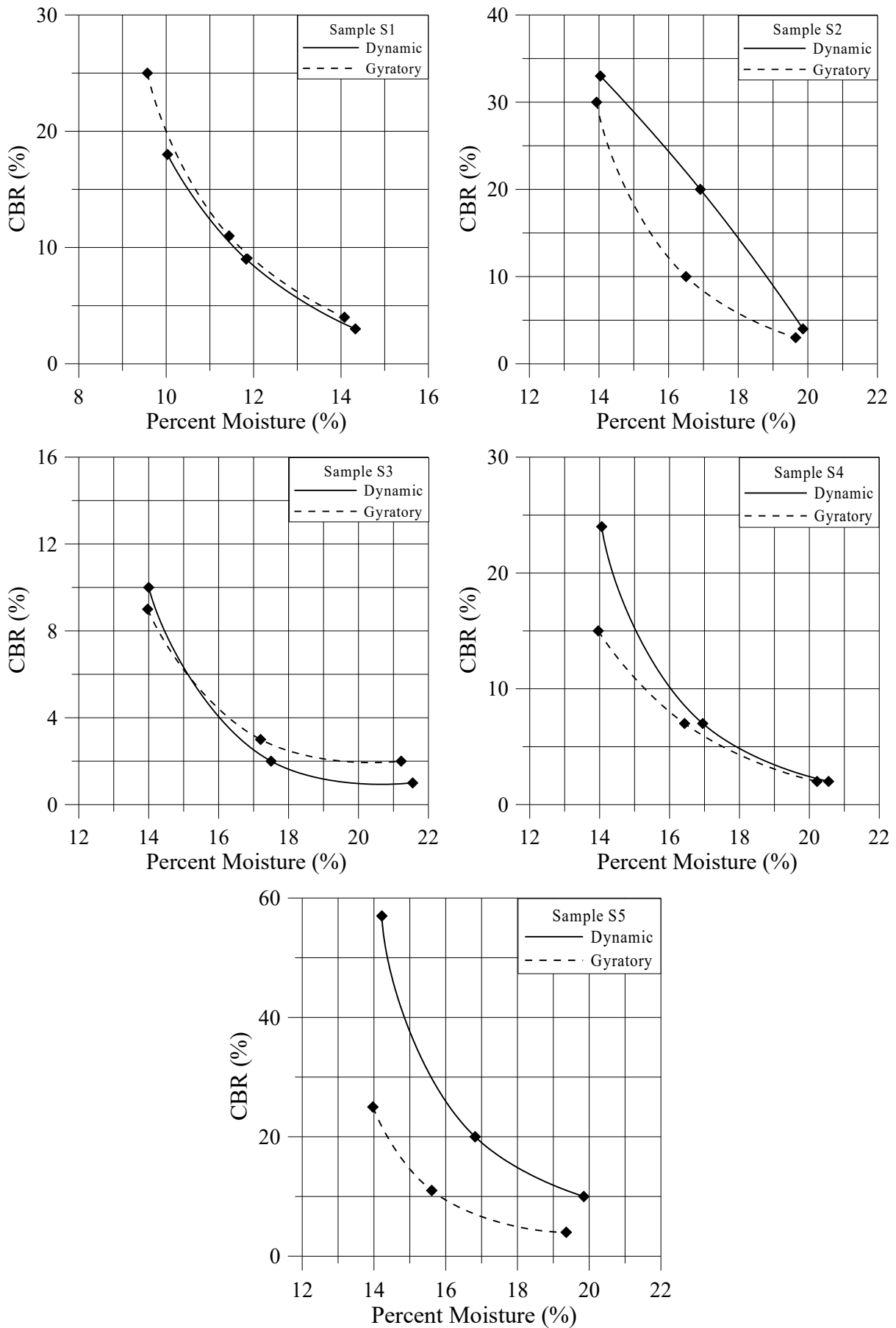
Figure 3 Variation of California bearing ratio as a function of moisture content.

CONCLUSION

It is important to study the behavior of compacted soils since they are involved in many civil engineering construction projects. The laboratory density can control the quality of this behavior. Proctor tests have served this determination for many years.

Soil dry unit weights can be a practical method for the analysis and further comparison of gyratory results to traditional compaction test results. In all five soils tested in this study the modified Proctor dry densities surpassed those from the gyratory compaction. Despite this observation, gyratory compaction could be considered as a feasible means of laboratory compaction.

More evidence is needed based on different soil types, and other variables involved in the procedure like the number of gyrations, the confinement pressure the angle of rotation etc. It is suggested the highest number of gyrations to be used to allow the maximum of soil densification to be achieved.

The CBR values proved to be a valuable assistance for the judgment of the compaction method to be used bearing in mind the drawbacks of both the Proctor and gyratory compaction methods. California Bearing Ratio specimens prepared with dynamic or gyratory compaction have lower values with an increase in moisture contents and were generally greater in the case of dynamic compaction. The difference was greater at moistures lower than the optimum one.

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