Significance of using a Superpave Gyratory Compactor to Simulate Field Compaction of Fine Grained Soil

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Abstract

Field compaction equipment used for fine grained soil usually applies a kneading action or vibration that produces shear forces which also reshape soil particles arrangement. A state that might not be completely simulated by laboratory Proctor tests. This study aims at investigating the significance of using the newer modified Texas superpave gyratory compactor (SGC) to simulate field compaction of fine grained soil due to its ability to apply loads in different angles generating shear forces on the compacted soil specimens. Two types of soil (A-4) and (A-7-6) were compacted using standard Proctor, modified Proctor and (SGC). The results were compared to dry field densities of the same soil in order to evaluate the most representative test. It was found that maximum dry densities of soil type (A-4) obtained using (SGC) under (200 kPa) and (600 kPa) were lower by (2.07%) and higher by (1.35%) than the maximum dry densities obtained using standard and modified Proctor tests respectively. It was also found that maximum dry densities of soil type (A-7-6) obtained using (SGC) under (300 kPa) and (600 kPa) were lower by (1.02%) and higher by (1.23%) than the maximum dry densities obtained using standard and modified Proctor tests respectively. The aforementioned confinement pressure values were applied in order to achieve dry densities similar to that obtained by Proctor tests. When comparing laboratory results to dry filed densities, it was found that (SGC) test results were slightly closer to them than Proctor tests results. Nevertheless, the difference between (SGC) and Proctor tests results seems to be insignificant for these types of soil compared to the higher effort needed to perform (SGC) tests.

Keywords: Field soil compaction, Laboratory soil compaction, Superpave gyratory compactor, Standard and Modified Proctor tests.

1. Introduction

In this study an extensive effort using standard and modified Proctor tests and superpave gyratory compactor (SGC) was performed to determine the maximum dry density and the optimum moisture content of two types of fine grained soils brought from the site of “Khan Beni Saad Water Treatment Project”. Standard and modified Proctor tests were considered as impact laboratory soil compaction methods [1], whereas the (SGC) was initially designed to simulate degradation and particle orientation which occur in HMA during mix production, field compaction, and traffic degradation [2]. Maximum densities obtained using (SGC) and standard and modified Proctor tests were compared to field densities obtained from the soil investigation test report issued by the “National Center for Construction Laboratories and Research” (NCCLR). The comparison was made in order to explore whether gyratory or impact laboratory compaction was more significant to simulate field compaction. Effects of soil type, water content, and gyratory device parameters including confining pressure and number of gyrations were also studied.

1.1 Research Objectives

This study aims at investigating the significance of using a newer modified Texas gyratory compactor instead of standard and modified Proctor tests to compact specimens of fine grained soil type (A-4) and (A-7-6).

1.2 Research Justification

Soil field densities obtained using suitable field compaction equipment in the right way, are higher than those attainable using impact laboratory compaction methods. It is worthwhile to investigate whether using a newer modified Texas gyratory compactor is significant to simulate field compaction of fine grained soils.

1.3 Research Methodology

Two types of fine grained soil (A-4) and (A-7-6) were compacted using superpave gyratory compactor and standard and modified Proctor tests to determine the maximum dry densities and optimum moisture contents. Results were compared to each other and the maximum dry densities were also compared to field dry densities obtained from the (NCCLR) soil investigation report because the construction works at that part of the site was already completed and there was no chance to carry out new field tests [3]. Laboratory tests were carried out at the laboratory of soil mechanics in Al-Nahrian University.

2. Literature Review

Ping et al. in (2003) carried out a study to check which prevailing laboratory soil compaction technique was more representative to field compaction of coarse sandy soil depending on relative density. It was concluded that gyratory compaction was the most representative one [4]. Sebesta et al. in (2004) used the (SGC) to compact soils. It was found that it can also be used for studying swell characteristics and shear resistance [5]. Browne in (2006) investigated the possibility of using (SGC) to compact soil specimens of the types (A-1) and (A-3). It was found that gyratory compaction was suitable to compact granular soil at high number of gyrations [6]. Panko et al. in (2011) studied the compaction of granular soil using (SGC) at higher confining pressures. It was found that the materials were able to be compacted using (SGC) above the modified Proctor densities at similar moisture contents [7]. Perez et.al in (2013) evaluated the gyratory compaction for three types of soil (CH, ML and SM). The results showed that the optimum moisture content is reduced as the vertical pressure increases and the dry unit weight increases. In addition, it was observed that the Proctor compaction curve is obtained with a vertical pressure of (200 kPa) and around (200) gyrations regardless the type of soil [8].

3. Properties of the Soil Used

Both types of soil used in this study were brought from “Khan Beni Saad Water Treatment Project” in Deyala Governorate. Samples were taken from a depth of (1.5 - 2.0 m) beneath natural ground surface. The specific gravity of soil was determined according to AASHTO T100. The Atterberg limits were determined according to AASHTO T89 & AASHTO T90. The grain size analysis was determined using sieve analysis and hydrometer according to AASHTO T88. The physical characteristics are presented in Table (1). According to the unified soil classification system (USCS) soil type (A-4) is classified as (CL-ML) and soil type (A-7-6) is classified as (CL). The grain size analysis is shown in Table (2) and the particle size distribution curve is shown in Fig. (1).

Table 1: Atterberg limits and specific gravity of tested soil

Index Properties	Type of Soil	
	A-4	A-7-6
Liquid limit L.L. (%)	30	45.6
Plastic limit P.L. (%)	21.9	24.4
Plasticity index P.I. (%)	8.1	21.2
Specific gravity	2.65	2.65

Table 2: Grain size analysis of tested soil

Soil Classification	Percent Soil Finer Than		
	Sieve #10	Sieve #40	Sieve #200
A-4	99.5%	80.6%	56.4%
A-7-6	100%	99.8%	66.8%

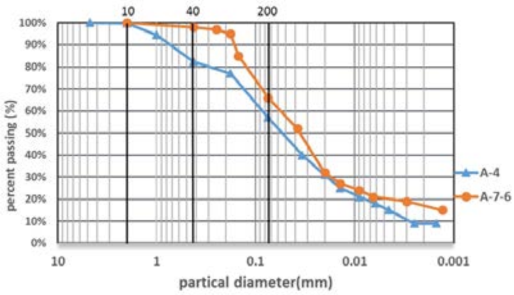

Figure 1: Grading of tested Soil

4. Field Compaction Characteristics

Field soil investigation of the site of “Khan Beni Saad Water Treatment Project” has been carried out by the Department of Soil Investigation at The National Center for Construction Laboratories and Research (NCCLR) [7]. Field compaction of the subgrade was carried out using sheep's' foot rollers with vibration. The results are summarized in Table (3).

Table 3: Field characteristics of tested soil[7]

Soil sample	Depth m.	q_u kN/m^3	γ_{wet} kN/m^3	γ_{dry} kN/m^3
A-4	2.0-2.5	537	19.5	16.5
A-7-6	2.0-2.5	114	19.3	15

5. Proctor Compaction Tests

All specimens were sieved by sieve No. 4 and the larger particles were discarded. Passing particles were dried at laboratory atmosphere. The maximum dry density and the optimum moisture content for both types of soil used were determined according to AASHTO T99 for standard Proctor and AASHTO T180 for modified Proctor. The water content of the tested soil was determined according to AASHTO T265. Results are shown in Table (4) and Fig. (2).

Table 4: Standard and modified Proctor tests results

Type of soil	Standard Proctor		Modified Proctor	
	Max dry density kN/m^3	OMC	Max dry density kN/m^3	OMC
A-4	16.85	16.25	18.45	14
A-7-6	14.85	19.25	16.25	16.35

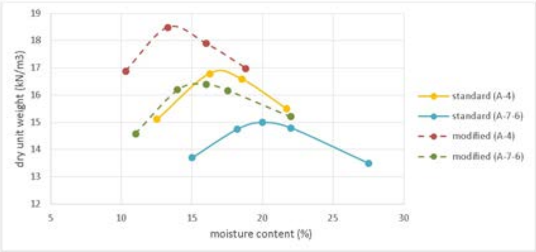

Figure 2: Standard and modified Proctor tests curves

6. Gyratory Compaction Tests

In this method, the compaction was achieved by the application of vertical pressure to a known mass of soil filled into a mold of internal diameter of (150 mm). The longitudinal axis of the mold was gyrated (rotated) at a fixed angle from the vertical axis while the top and bottom plates were kept parallel and horizontal as shown in Fig. (3). Height of the sample was automatically measured during compaction and the soil density was also determined. Knowing the operator can choose whether to compact until achieving a certain number of gyrations, a certain height of sample or a targeted density [9]. It is worthwhile to mention that even this equipment was initially designed to compact samples of asphaltic mixture, lately it was utilized to compact fine-grained granular soil [8]. The test procedure in this method of compaction involves a trial and error process starting with a combination of settings according to AASHTO T312 and the recommendations of previous research work mentioned earlier. The superpave gyratory compactor (SGC) can control some influencing variables.

The controlled variables in this research were the following:

- Vertical pressure = 200, 300, 400, 500 and 600 kPa.
- Angle of gyration = 1.25 degree.
- Number of gyrations = 350.
- Rate of gyration = 30 gyration/minute.
- Mass of compacted soil = 5000 g.

Figure 3: Superpave gyratory compactor, mold and container

6.1 Dry Soil Compaction

Dry soil with no moisture content was used first in order to eliminate the effect of moisture content when studying the effect of confinement pressure and number of gyrations. Dry soil samples of each type were prepared and placed in the mold where its interior face was already oiled. Two pieces of circular paper each was placed on the bottom and the top of the soil sample. Then the mold was placed inside the machine, which was programmed according to the aforementioned controlled variables. These steps were repeated for all samples of both types of soil. After each sample was compacted, it was gently extracted by hand jacking as shown in Fig. (4), then the dimensions and weight of each sample were recorded.

Figure 4: Samples extraction

6.2 Moist Soil Compaction

Dry soil samples of each type were weighted and different amounts of water were added to each sample so that the range of moisture content needed to accomplish standard and modified Proctor tests were fulfilled. Moist soil samples were kept sealed in plastic bags for (24) hours before being compacted in order to ensure a homogenous distribution of moisture. A mass of (5000 g) of wet soil was compacted each time according to the controlled variables taking into account the vertical pressure limitations. After each sample was compacted and extracted, the dimensions and weight were recorded. Then the water content and dry unit weight were calculated.

7. Analysis of Results

Unit Weight Compaction Curves (UWCC) were created to show the relationship between the dry unit weights against the number of gyrations and to evaluate the maximum dry densities obtained.

7.1 Results of Dry Compaction

The UWCC of soil types (A-4) and (A-7-6) using (SGC) under (200, 300, 400, 500 and 600 kPa) are shown in Figures (5) and (6) respectively. The effect of pressure on the maximum dry density of each type of soil is quite clear in both figures. The maximum dry density of silty soil type (A-4) under (600 kPa) is found to be less than field dry density by (3.73%) and less than the maximum dry density obtained using standard proctor test by (7.74%) as shown in Fig. (5). On the other hand, clayey soil type (A-7-6) shows a different behavior under the same conditions as shown in Fig. (6). It is found that the maximum dry density obtained using (SGC) under (300 kPa) is higher than field dry density by (2.75%) and the maximum dry density obtained using (SGC) under (400 kPa) is higher than the maximum dry density obtained using standard proctor test by (1.97%) for this type of soil.

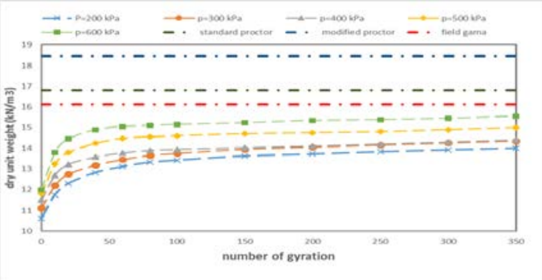

Figure 5: UWCC for dry soil type (A-4)

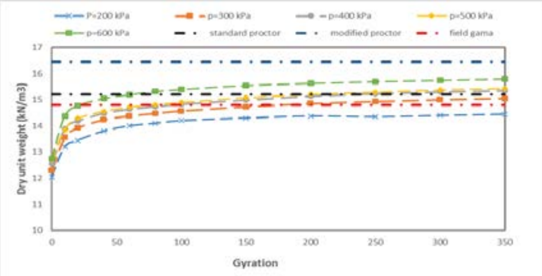

Figure 6: UWCC for dry soil type (A-7-6)

7.2 Results of Gyratory Compaction for Soil type (A-4)

The gyratory compaction of soil type (A-4) with different moisture contents was carried out under (200 kPa) and (600 kPa) which represent the minimum and maximum pressures suitable for the test. Results under (200 kPa) are shown in Fig. (7). It was found that the maximum dry density was lower by (2.07%) than the maximum dry density obtained using standard Proctor test.

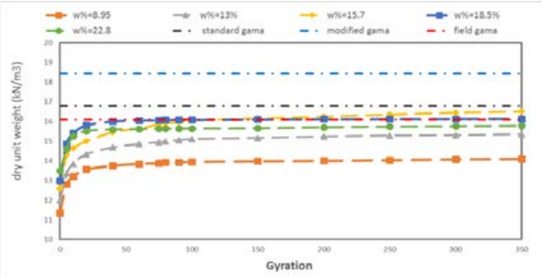

Figure 7: UWCC for (A-4) soil under 200 kPa and different moisture

When using (SGC) under (600kPa) it was found that the maximum dry density which was equal to (16.5 kN/m^3) was higher by (1.35%) than the maximum dry density obtained using modified Proctor test at (OMC) of (13.8%) as shown in Fig. (8).

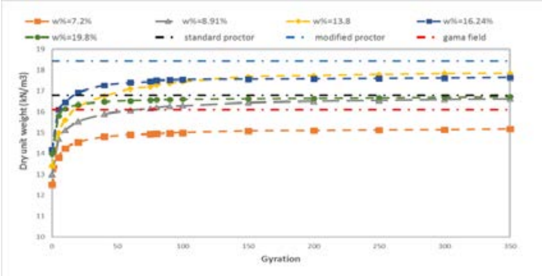

Figure 8: UWCC for (A-4) soil under 600 kPa and different moisture

The effect of the number of gyrations at each pressure value is illustrated by the compaction curves shown in Figures (9) and (10) using (0, 70, 90 and 500) gyrations under (200 and 600 kPa) pressure respectively.

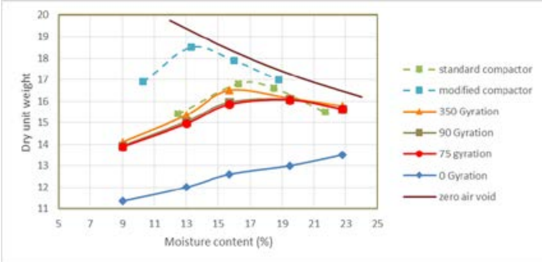

Figure 9: Compaction curves for (A-4) soil under 200 kPa

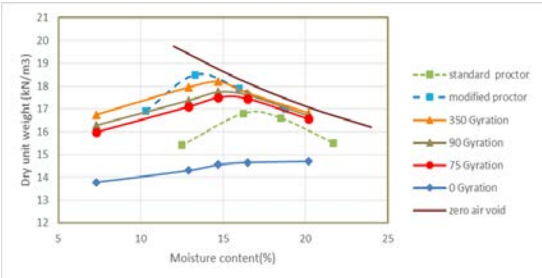

Figure 10: Compaction curves for (A-4) soil under 600 kPa

It was found that the maximum dry density and optimum moisture content of soil type (A-4) at higher number of gyrations was easy to be estimated as shown in Fig. (11). It was also clear that soil compaction results obtained using (SGC) at (350) gyrations under (600 kPa) were closer to modified Proctor test, also, the result obtained shows that loading pressure under (200 kPa) was closer to standard Proctor test.

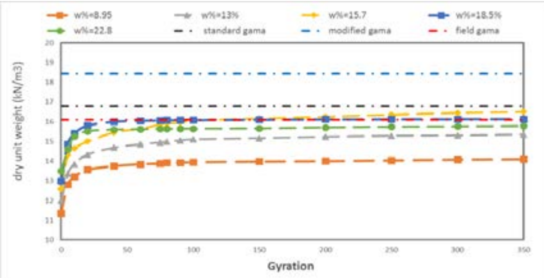

Figure 11: Compaction curves for (A-4) soil at 350 gyrations

7.3 Results of Gyratory Compaction for Soil type (A-7-6)

The effect of the number of gyrations on dry densities at different moisture contents for soil type (A-7-6) are shown in Figures (12) and (13). It was found that the maximum dry density of soil type (A-7-6) having a moisture content of (17.2%), obtained using (SGC) under (300 kPa) which was equal to (15.5 kN/m^3) was less by (1.0%) than the maximum dry density obtained by standard Proctor test as shown in Fig. (12).

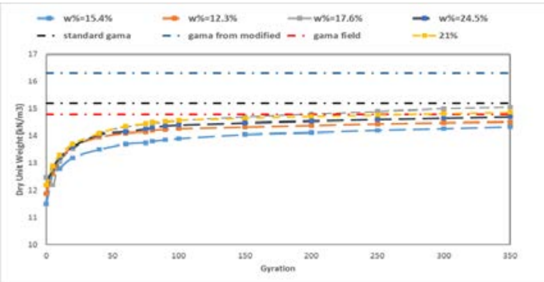

Figure 12: UWCC for (A-7-6) soil under 300 kPa and different moisture

When pressure was raised from (300 kPa) to (600 kPa), the dry density was higher by (1.23%) as shown in Fig. (13), where the maximum dry density becomes (16.35 kN/m^3) at an optimum moisture content of (18%).

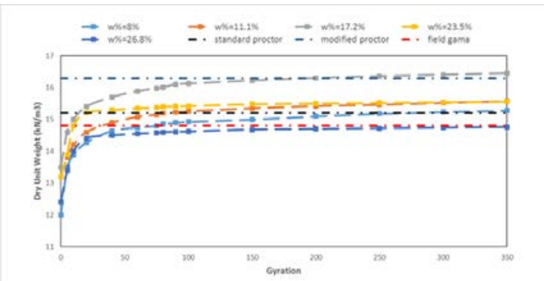

Figure 13: UWCC for (A-7-6) soil under 600 kPa and different moisture

The effect of the number of gyrations under (300 and 600 kPa), for soil type (A-7-6), are shown in Figures (14) and (15) respectively. It was clear that the gyratory compaction at higher pressure was more effective for this type of soil.

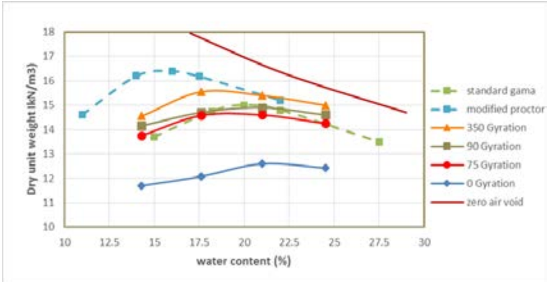

Figure 14: Compaction curves for (A-7-6) soil under 200 kPa

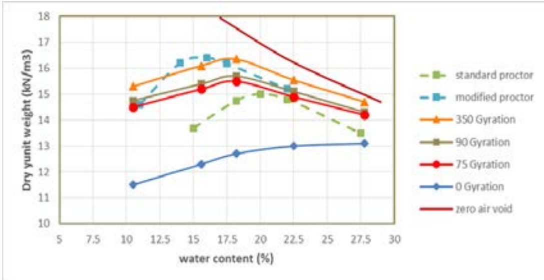

Figure 15: Compaction curves for (A-7-6) soil under 600 kPa

A comparison of the dry densities obtained under (300 kPa) and (600 kPa) is shown in Fig. (16). The maximum dry density under (600 kPa) at (350) gyrations was closer to the maximum dry density obtained by modified Proctor test.

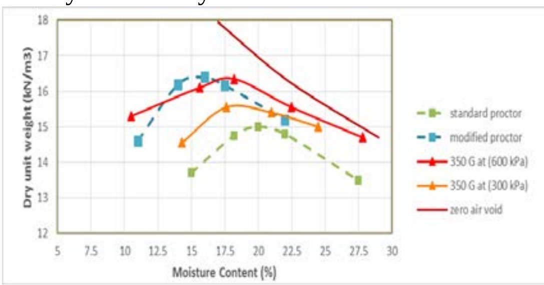

Figure 16: Compaction Curves for (A-7-6) soil at 350 gyrations

8. Conclusions

- It was found that dry densities of soil type (A-4) and type (A-7-6) obtained using (SGC) were slightly closer to field densities than those obtained by impact compaction. This is because of the effect of higher shear forces applied on the compacted soil specimens generated from inclined loads due to angle of gyration. Nevertheless, these results seem to be insignificant compared to the higher effort needed for using (SGC) compactors.
- The effect of confinement pressure on dry density was higher than the effect of the number of gyrations for both types of soil.
- Dry densities of both soil types increase as much as the number of gyrations increases until (350) gyrations where additional gyrations have no significant effect.

References

[1] Cheng Liu, and Jack B. Evett, (2008), "Soils and Foundations", 7th edition, The University of North Carolina at Charlotte.

[2] AASHTO, (2011), "Standard Specifications for Transportation Materials and Methods of Sampling and Testing", 22nd edition, Parts 2A and 2B Tests, Washington, D.C.

[3] Department of Soil Investigation in the National Center for Construction Laboratories and Research (NCCLR), (2012), "Report of Soil Investigation no. 1/1/143/2012", Baghdad, Iraq.

[4] Ping, W. V., Xing, G., Leonard, M., and Yang, Z., (2003) "Evaluation of Laboratory Compaction Techniques for Simulating Field Compaction (Phase II)," Department of Civil and Environmental Engineering, Florida A&M University - Florida State University, Tallahassee, Florida.

[5] Sebesta S., Guthrie W. S., and Harris J. P., (2004), "Gyratory Compaction of Soils for Laboratory Swell Tests", Transportation Research Board 83rd Annual Meeting, Washington D.C.

[6] Browne M., (2006), "Feasibility of using a Gyratory Compactor to Determine Compaction Characteristics of Soil", MSc Thesis, Dept. of Civil Engineering, Montana State University, Bozeman, Montana.

[7] Panko, M., McGarvey, K., Stevenson, G., Coffey, S. and Sukumaran, B., (2011), "Compaction of Granular Soils Using Superpave Gyratory Compactor at Higher Confining Pressures", Proceedings of the TRB annual conference, 2011.

[8] Perez, N., Garnica, P., Mendoza, I. and Reyes, M. A., (2013), "Behavior of fine-grained soils compacted with high shear stresses", Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris.

[9] Cooper Company a British company for the design and manufacture of high performance testing equipment for asphaltic and unbound materials used in highway construction.

جدوى استعمال جهاز الرص الدوار لمحاكاة الرص الحقلي للتربة ناعمة الحبيبات

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الخلاصة

إن معدات الرص الحقلي التي تستعمل لرص الترب ناعمة الحبيبات عادة ما تحدث عملية عجن أو اهتزاز لحبيبات التربة مسببة قوى قص من شأنها أعادة تنظيم حبيبات التربة. الأمر الذي قد لا يمكن محاكاته بشكل تام عند استعمال فحصي بروكتر مختبرياً. تهدف هذه الدراسة الى بحث جدوى استعمال جهاز تكساس الحديث المعدل للرص الدوار (SGC) لمحاكاة الرص الحقلي للتربة ناعمة الحبيبات لما له من قدرة على تسليط الأحمال بزوايا مختلفة مما يسلط قوى قص على عينات التربة عند رصها. وقد تم استعمال نوعين من الترب الناعمة نوع (A-4) ونوع (A-7-6) لإجراء فحص الرص المختبري باستعمال ثلاثة طرق هي بروكتر القياسي وبروكتر المعدل وجهاز الرص الدوار. ثم تم مقارنة النتائج مع نتائج الفحوصات الحقلية. لقد وجد ان الكثافة الجافة العظمى للتربة من نوع (A-4) التي تم الحصول عليها باستعمال (SGC) تحت ضغط (200 كيلو باسكال) تقل بنسبة (2.07٪) عن الكثافة الجافة العظمى التي تم الحصول عليها باستعمال فحص بروكتر القياسي، وتزيد تحت ضغط (600 كيلو باسكال) بنسبة (1.35٪) عن الكثافة الجافة العظمى التي تم الحصول عليها باستعمال فحص بروكتر المعدل. كما وجد أن الكثافة الجافة العظمى للتربة من نوع (A-7-6) التي تم الحصول عليها باستعمال (SGC) تحت ضغط (300 كيلو باسكال) تقل بنسبة (1.02٪) عن الكثافة الجافة العظمى باستعمال فحص بروكتر القياسي وتزيد تحت ضغط (600 كيلو باسكال) بنسبة (1.23٪) عن الكثافة الجافة العظمى المستحصلة باستعمال فحص بروكتر المعدل لنفس النوع من التربة. وقد تم تعيين قيم الضغط المذكورة آنفاً بحيث تحقق كثافة جافة مساوية لما هي عليه في فحصي بروكتر. وعند مقارنة النتائج المختبرية مع الكثافة الجافة الحقلية وجد ان نتائج (SGC) اقرب اليها قليلاً من نتائج فحوصات بروكتر. ومع ذلك فإن الفرق بين فحص الرص الدوار وفحصي بروكتر يبدو غير ذي جدوى لهذين النوعين من التربة قياساً بالجهد الأعلى المطلوب لاجراء الفحص الدوار.