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# COMPARISON BETWEEN COMPACTION OF SUBBASE MATERIAL BY PROCTOR TESTS AND SUPERPAVE GYRATORY COMPACTOR

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**KEYWORDS:** Subbase material, SGC, CBR, materials passing sieve No.4, dry density.

## ABSTRACT

Proctor impact compaction tests represent the most commonly used laboratory method to determine the maximum dry unit weight and optimum moisture content of soils. One shortcoming of the Proctor test is that it uses impact loads to compact the soil in a stiff non-yielding mold. This technique may not accurately simulate modern field compaction methods so, a more appropriate method of compacting soils in the laboratory is needed. The research presented herein explores the feasibility of using a superpave gyratory compactor (SGC) to compact subbase material. The subbase is brought from Badra area, east of Wasit governorate. Type (B) subbase is used in this research, with three percentages of aggregate passing sieve No. 4, (30, 50 and 60) %. Before the SGC tests were implemented on the subbase material, Proctor tests (ASTM D-1557) (ASTM D-698-12) were performed on it to obtain the optimum moisture content and maximum dry density.

It was concluded that the SGC is capable of achieving higher densities than the standard and modified Proctor methods even at moisture contents lower than optimum conditions. These density levels are similar to those achieved by modern heavy compaction equipment in the field. The dry density increases with the increase of the number of gyrations, so, the higher the number of gyrations, the higher the dry density that can be achieved because as the gyrations increases the particles continued to rearrange themselves subsequently better interlock and maximum dry density were achieved. All samples achieved at least 90% of total compaction in the first 50 gyrations, although dry unit weights continued to gradually increase at a rather slow rate until compaction was terminated at 500 gyrations.

## INTRODUCTION

Pavement structure response under load is very sensitive to the properties of the materials used in the base and subbase layers. The quality of pavement design is greatly dependent on the accuracy and manner in which the material properties are evaluated. A realistic characterization of layer materials is needed for the success of pavement design, especially for the mechanistic design approach. The subbase layer in a pavement improves the supporting capacity, provides drainage, minimizes the detrimental effects of frost action, and provides uniform support to the upper layers. The subbase generally has the maximum thickness of all the layers of a flexible pavement, and therefore economy of road construction would depend upon maximum utilization of locally available material in the subbase construction.

Browne (2006) evaluated the feasibility of using SGC to compact soil specimens. Tests were performed on soil types (A-1-a, A-3, A-4 andA-7-6) that represented a broad range of soils encountered during construction with varying moisture contents. When soil is compacted with moisture content, dry unit weights obtained from gyratory compaction surpass the dry unit weights of traditional compaction methods for the majority of soil tested. Therefore, gyratory compaction was considered a feasible and effective method of laboratory soil compaction, which is recommended using the following SGC parameters during experimental research in Table (1).

*Table 1 Recommended gyratory test parameters by Browne (2006).*

| | |
|---|---|
| Vertical pressure (kPa) | 600 |
| Number of Gyration | 500 |
| Angle of gyration (degree) | 1.25 |
| Rate of gyration (gyration/min.) | 30 |

High numbers of gyrations allow a more understanding of the soil densification that occurs during compaction. This should be performed until a reliable trend indicating a realistic number of gyrations can be established using several soil types (Browne, 2006).

A separate phase of the study performed at Florida State University by Ping et al., (2003) investigated the effect of increased energy input on the dry density of the sample. In this phase, the pressure, number of gyrations, angle of gyration and gyration rate vary. By keeping the moisture content similar throughout testing, the study focused on varying the compactive energy input into the sample. A test performed on A2-4 sand shows that 40 varying the gyration rate from 10 to 20 to 30 gyrations per minute has no effect on the final dry density when all other variables are held constant. Additionally, findings showed that the number of gyrations has a significant impact on the final dry density of the sample as was concluded from the previous study; more gyrations result in higher densities. Additionally, at low gyration numbers, the gyration angle has a significant impact on the densification, but this impact diminishes as the gyration count increases. In the 2003 study, an increase in vertical pressure did not have a major influence on the final dry density (Ping, et al., 2003).

Fattah *et al*., (2016, 2019) targeted two primary purposes: First evaluating the effect of water content on compaction characteristics, second investigating the effect of fine material on dry density and CBR value of subbase material. To meet these research objectives, various water contents and percent of fine materials were used to compact the specimens. The results showed that the subbase material becomes stiffer when the fine materials increase, from 5 % to 10 % and 13 % and the dry density increases which leads to increase in CBR value. Both dry density and CBR decrease with the increase of water content above the optimum water content.

The objectives of the present study is to explore the feasibility of using the superpave gyratory compactor to compact subbase material with direct percentages of fine materials passing sieve No. 4.

## EXPERIMENTAL WORK

### Subbase Used

The subbase course is the layer of material under the base course. The use of two different granular materials is more economic instead of using the more expensive base course material for the entire layer, cheaper and local materials can be used as a subbase course on top of the subgrade. The surveys showed that the subbase serves as a filter between the subgrade and the base course, if the base course is open graded (Huang, 2004). Mechanical sieve analyses were carried out to determine the grading of subbase material shown in Table 2 and Figure 1 according to the limits of the Iraqi specification requirements for gradation of subbase (R6). The subbase is brought from Badra area, east of Wasit governorate east of Baghdad city capital of Iraq. Type (B) is used in this research, with three percentages of aggregate (Passing sieve No. 4), (30, 50 and 60)%. A mass of (5000 g) of subbase is loosely placed in one lift into the gyratory mold of 150 mm internal diameter.

The subbase sample was subjected to routine laboratory tests to determine its properties. The tests included, sieve analysis, dry unit weight, California bearing ratio with compaction to 95% of the maximum dry density, and specific gravity for three percentage of aggregate (passing sieve No. 4), according to the specification of the State Organization of Roads and Bridges, Standard Specification for Roads and Bridges (SORB, 2003), Table 3 presents the physical properties of subbase material with the corresponding specification during the standard compaction test while Table 4 presents the properties of the material subjected to modified compaction test. The dry material was thoroughly mixed with water and compacted in the SGC with a vertical pressure of 600 kPa.

***Table 2 Gradation of sub-base material with limits of Iraqi specification requirements for gradation of sub-base (R6).***

| **Seive size (mm)** | **Iraqi specification % passing (Type B)** | **Sample 1 % passing** | **Sample 2 %passing** | **Sample 3 %passing** |
|---|---|---|---|---|
| **75** | - | - | - | - |
| **50** | 100 | 100 | 100 | 100 |
| **25** | 75-95 | 94 | 94 | 94 |
| **9.5** | 40-75 | 70 | 70 | 70 |
| **4.75** | 30-60 | 30 | 50 | 60 |
| **2.36** | 21-47 | 42 | 42 | 42 |
| **0.3** | 14-28 | 26 | 26 | 26 |
| **0.075** | 5-15 | 8 | 8 | 8 |

During preliminary testing, the specimens were subjected to 50 gyrations. Later, it was decided to increase the gyrations to 100 and 500 in order to input more energy and achieve higher densities. During compaction, the longitudinal axis of the mold is gyrated at a fixed angle from the vertical axis while the top and bottom platens are kept parallel and horizontal. The samples are compacted at optimum water content and at (90, 95%).

***Table 3 Physical properties of subbase subjected to standard compaction***

| **Laboratory test** | **ASTM Designation** | **Test results** | | |
|---|---|---|---|---|
| | | **30 % passing sieve No. 4** | **10 % passing sieve No. 4** | **13 % passing sieve No. 4** |
| **California bearing ratio (CBR)** | D1883-05 | 53% | 66 % | 39 % |
| **Optimum moisture content (O.M.C)** | D1557 – 12 | 8.65 | 8.9 | 7.5 |
| **Specific gravity** | D-854-14 | 2.205 | 2.485 | 2.742 |
| **Atterberg Limits**<br>**a. liquid limit (L.L)**<br>**b. Plastic limit (P.L)** | D 4318-10 | a. 27<br>b. NP | | |

| | | |
|---|---|---|
| **Salinity**<br>**a. Gypsum**<br>**b. $SO_3$** | B.S.I 1377, part 3 | a. 0.00623<br>b. 0.00289 |

*Table 4 Physical properties of subbase subjected to modified Proctor compaction.*

| Laboratory test | ASTM Designation | Test results | | |
|---|---|---|---|---|
| | | **30 % passing sieve No. 4** | **10 % passing sieve No. 4** | **13 % passing sieve No. 4** |
| **California bearing ratio (CBR)** | D1883-05 | 96% | 96 % | 90 % |
| **Optimum moisture content (O.M.C)** | D1557 – 12 | 6.5 | 5.5 | 6.98 |
| **Specific gravity** | D-854-14 | 2.205 | 2.485 | 2.742 |
| **Atterberg Limits**<br>**a. liquid limit (L.L)**<br>**b. Plastic limit (P.L)** | D 4318-10 | c. 27<br>d. NP | | |
| **Salinity**<br>**c. Gypsum**<br>**d. $SO_3$** | B.S.I 1377, part 3 | a. 0.00623<br>b. 0.00289 | | |

**Testing Results**

***Compaction Curve***

Before SGC tests were run on material, standard and modified Proctor tests (ASTM D-1557) (ASTM D-698-12) were performed on it to obtain the optimum moisture content and maximum modified Proctor density. The water content – dry density relations are drawn as shown in Figures 1 to 3 from which the optimum water content and maximum dry density were obtained. Table 5 shows the optimum water content value for subbase materials with different percents of aggregate passing sieve No.4 (30%, 50% and 60%).

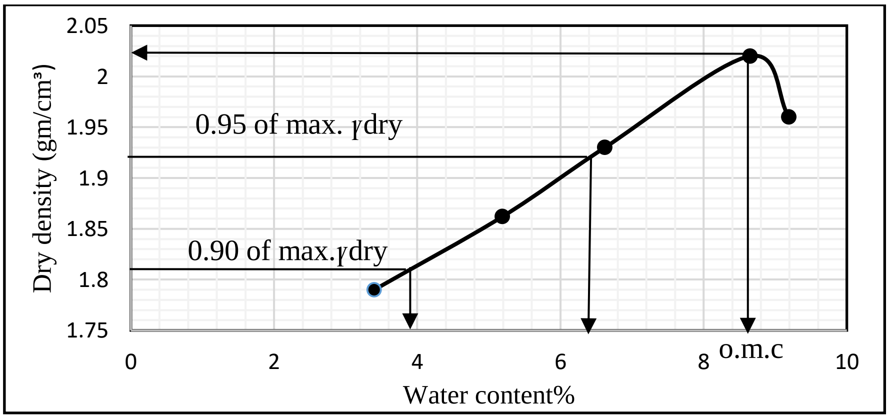

*Figure 1 Water content-dry density relationship for sub-base material with 30% of aggregate (passing sieve No. 4).*

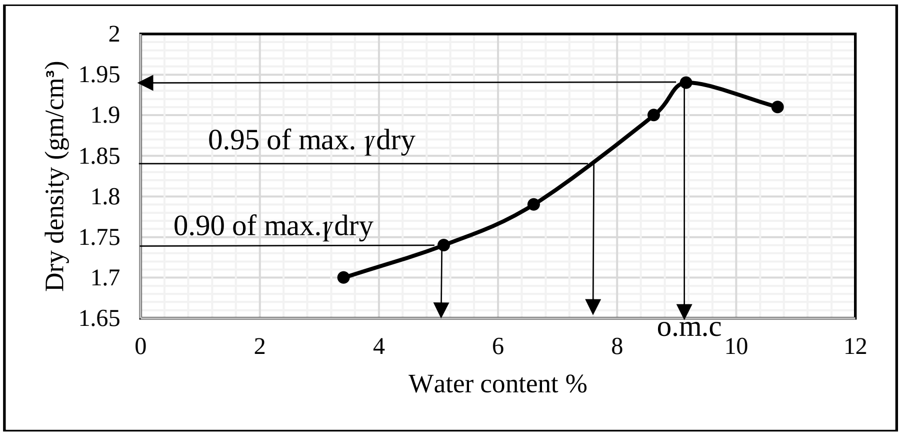

*Figure 2 Water content-dry density relationship for sub-base material with 50% of aggregate (passing sieve No. 4).*

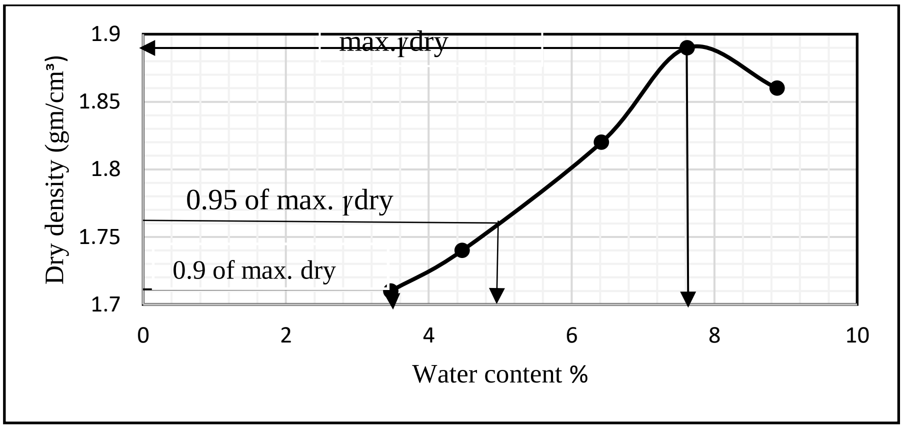

*Figure 3 Water content-dry density relationship for sub-bas material with 60% (passing sieve No. 4).*

*Table 5 Summary of the results of standard Proctor compaction test.*

| % of material passing sieve (No. 4) | Optimum water content (%) | Max. dry density (gm/cm³) |
|---|---|---|
| 30% | 8.65 | 2.02 |
| 50% | 8.9 | 1.94 |
| 60% | 7.5 | 1.89 |

The results of modified compaction test are presented in Figures 4 to 6 and Table 6 presents a summary of these test results.

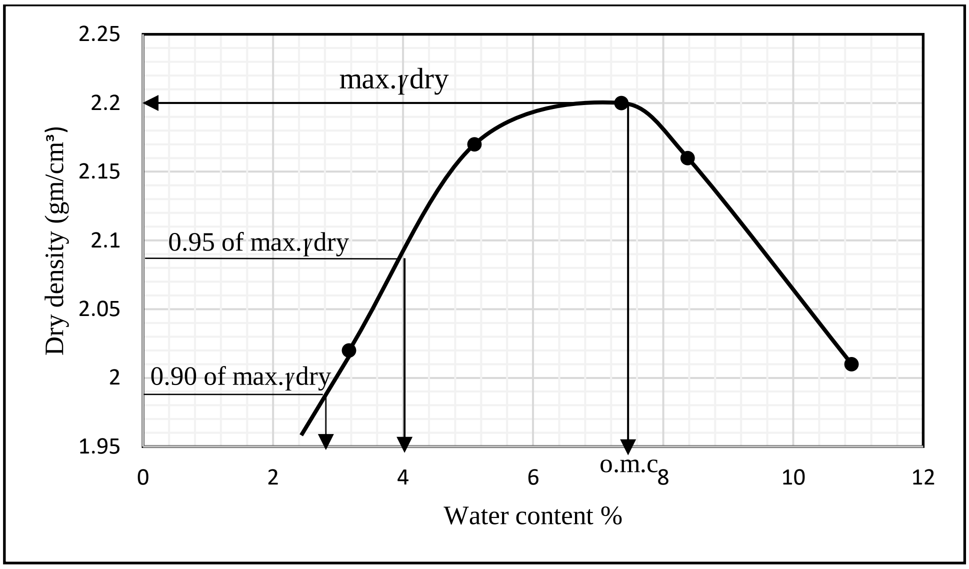

*Figure 4 Water content-dry density relationship for sub base material with 30% (passing sieve No. 4).*

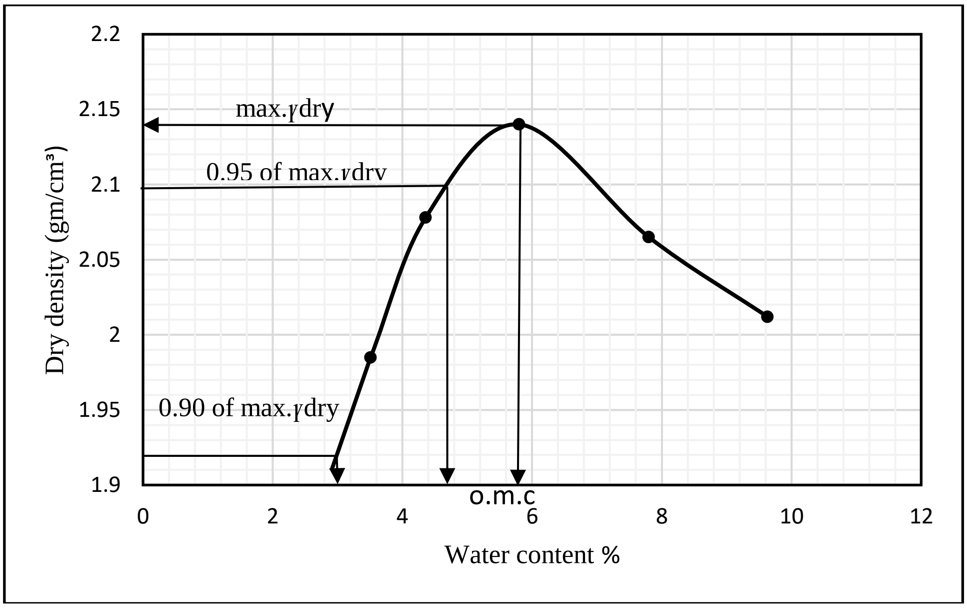

*Figure 5 Water content-dry density relationship for sub-base material with 50% (passing sieve No. 4).*

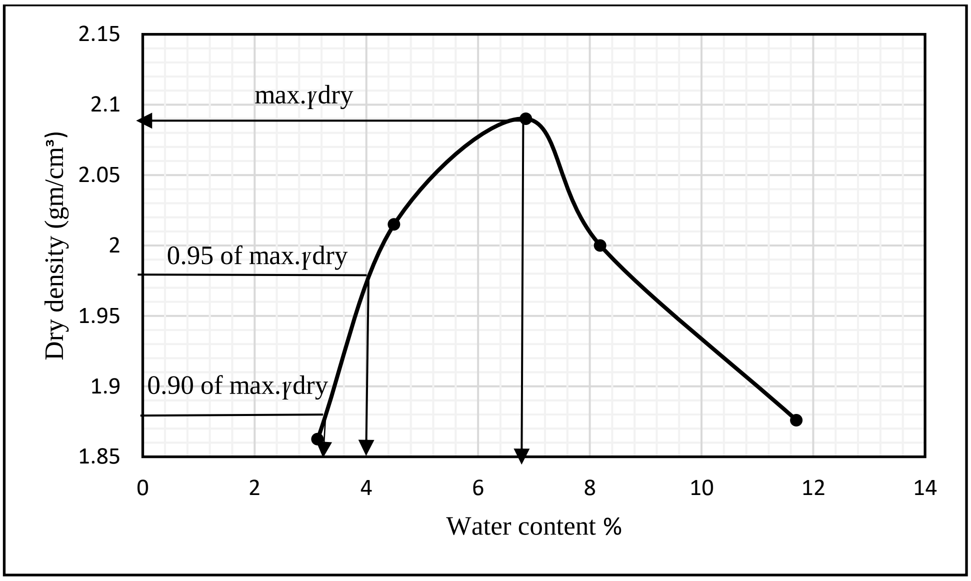

*Figure 6 Water content-dry density relationship for sub-base material with 60% (passing sieve No. 4).*

In the modified Proctor test, the increase of passing sieve (No. 4) material results in a decrease in the optimum water content at 50% then increases at 60%, while the maximum dry density increases for all cases.

*Table 6 Summary of the results of modified Proctor compaction test.*

| % of material passing sieve (No. 4) | Optimum water content (%) | Max. dry density (gm/cm³) |
|---|---|---|
| 30% | 6.5 | 2.20 |
| 50% | 5.5 | 2.14 |
| 60% | 6.98 | 2.09 |

**Compaction Using Gyratory Compactor**

Increasing the moisture content of soil lubricates the particles and allows them to be more easily rearranged into a denser state, while minimizing the amount of breakage. The problem stands that the accepted testing methods such as the standard and modified Proctor tests that use vertical impact loading and cause fracturing of the particles; do not closely simulate the actual forces, such as shear force, seen during construction. Simulation of shear forces and compressive loading exerted by moving machinery and vehicles are more closely done by the Superpave gyratory compactor.

In this research, the SGC test results for each percentage of aggregate passing sieve No.4 (30%, 50%, 60%) are presented. The dry soil mass utilized for all tests was 5000 grams. Once weighed, the dry material was thoroughly mixed with water and compacted at optimum water content and at (90, 95) % of maximum dry density which is obtained from the Proctor compaction tests according to ASTM (D-1557) and ASTM (D-698). The samples are tested in the SGC with a vertical pressure of 600 kPa.

Figures 7 to 9 present the variation of the dry density with number of gyrations for samples having different percents of material passing sieve No. 4 compared to dry density from standard compaction test. The comparison is made in Figures 10 to 12 with the dry density obtained from the modified Proctor test. The results of gyratory compaction test show that the dry density increases at the first number of gyrations then becomes stable after about 50 gyrations in all tests. The dry density for all samples is larger in the SGC than those from standard and modified Proctor tests due to large energy induced by the gyratory compactor.

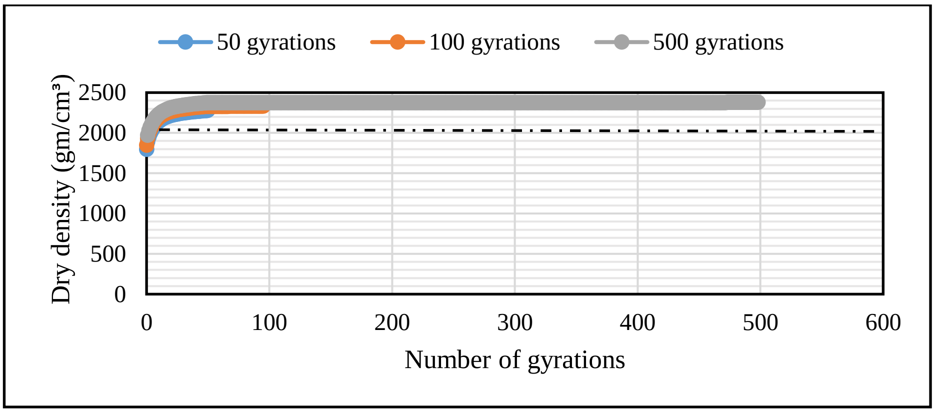

*Figure 7 Comparing the dry density for subbase material with 30% aggregate passing sieve No. 4 between the gyratory compaction and standard Proctor compacted at optimum water content.*

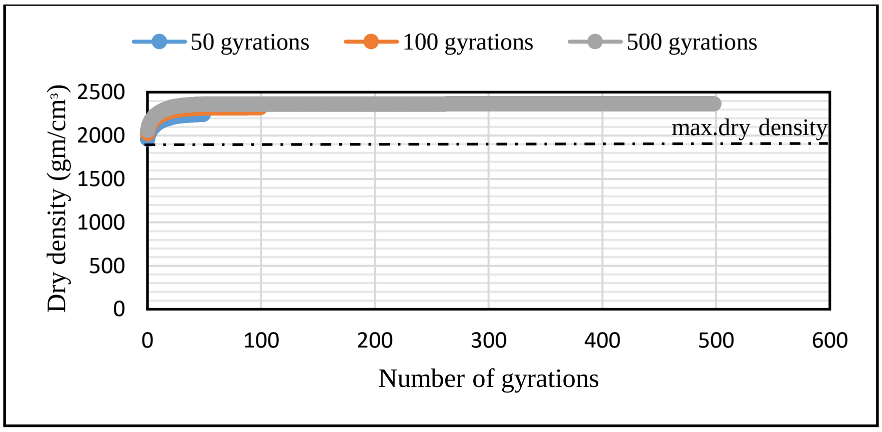

*Figure 8 Comparing the dry density for subbase material with 50% aggregate passing sieve No. 4 between the gyratory compaction and standard Proctor compacted at optimum water content.*

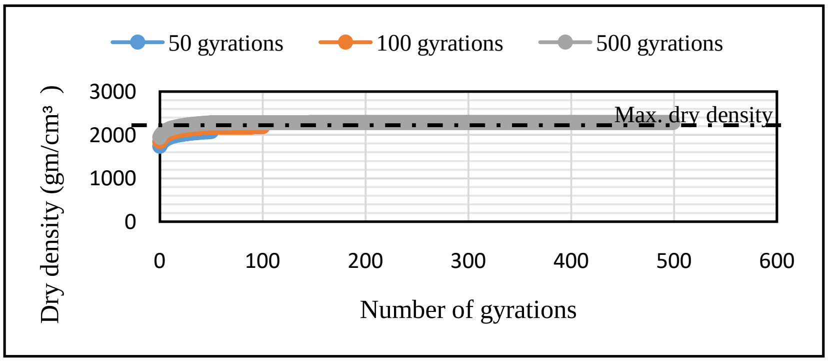

*Figure 9 Comparing the dry density for subbase material with 60% aggregate passing sieve No. 4 between the gyratory compaction and standard Proctor compacted at optimum water content.*

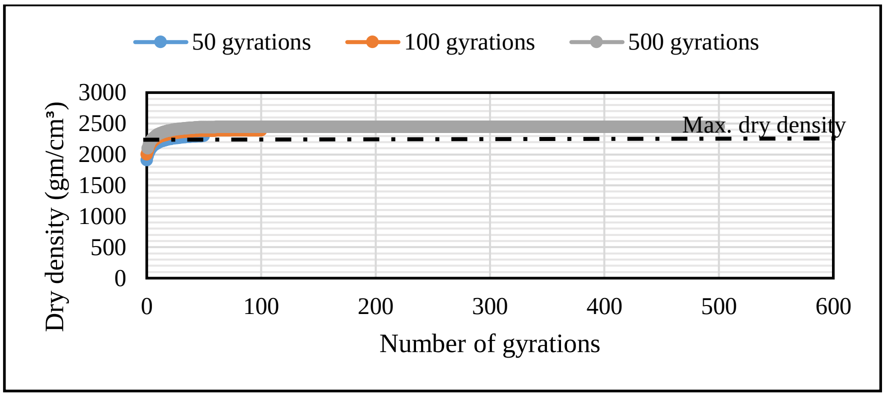

*Figure 10 Comparing the dry density for subbase material with 30% aggregate passing sieve No. 4 between the gyratory compaction and modified Proctor compacted at optimum water content.*

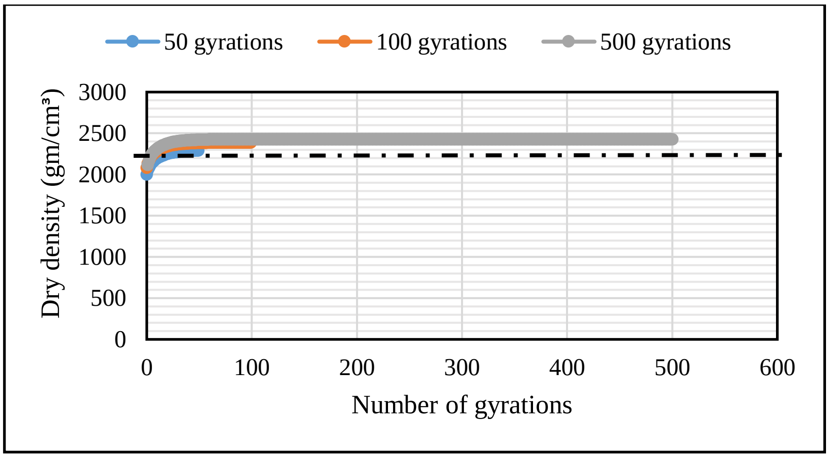

*Figure 11Comparing the dry density for subbase material with 50% aggregate passing sieve No. 4 between the gyratory compaction and modified Proctor compacted at optimum water content.*

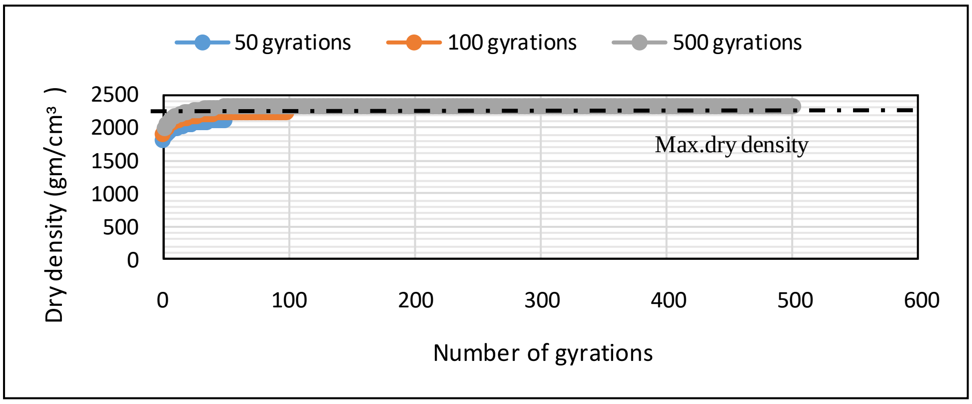

*Figure 12 Comparing the dry density for subbase material with 60% aggregate passing sieve No. 4 between the gyratory compaction and modified Proctor compacted at optimum water content.*

## CONCLUSIONS

1. Calculation of soil dry unit weights proved to be the most practical method of analyzing and comparing the gyratory results to traditional compaction test results.
2. The SGC is capable of achieving higher densities than the standard and modified Proctor methods even at moisture contents lower than optimum conditions. These density levels are similar to those achieved by modern heavy compaction equipment in the field.
3. The dry density increases with the increase of the number of gyrations, so, the higher the number of gyrations, the higher the dry density that can be achieved because as the gyrations increases the particles continued to rearrange themselves subsequently better interlock and maximum dry density were achieved. Furthermore, the dry density decreases with the increase in percent of aggregate passing sieve No. 4. The reason is that the percent of 30% passing sieve No. 4 provides proper particle size distribution and better interlocking.
4. All samples achieved at least 90% of total compaction in the first 50 gyrations, although dry unit weights continued to gradually increase at a rather slow rate until compaction was terminated at 500 gyrations.

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