Use of the Superpave Gyratory Compactor as a Predictor of Field Performance of Unbound Material

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INTRODUCTION

With continuous and repeated loading of runways and the introduction of larger planes, such as the Boeing-747 and Airbus A380, which weighs approximately 1.3 million pounds, a runway's ability to resist rutting becomes even more critical. The Federal Aviation Administration (FAA) has been testing airport pavements under heavy aircraft loading with a wander pattern at the National Airport Pavement Test Facility (NAPTF) in order to improve airport pavement design for these heavy planes. The loads and the load wander of these large aircrafts have a dramatic effect on the stability and strength of the unbound aggregate layers because it causes constant particle rearrangement and compaction [1]. In earlier testing cycles of the pavement systems, the subbase layer compacted excessively past the maximum Modified Proctor Density (ASTM D1557) during the simulated trafficking [2]. The densification of this material caused the pavement system to rut [3]. In order to monitor the performance of the runway, stress, strain, deflection, temperature, and other environmental gauges have been placed in the various layers of the pavement [4]. Another problem that has been encountered during the previous construction cycles is moisture migration to the subgrade layer. Moisture migration causes a shear slip plane between the subbase and subgrade layer [5]. The shear failure can increase the rate of deformation in the runway pavement. This study is focused on studying the compaction characteristics of the subbase material during aircraft trafficking using a combination of laboratory tests and field data.

Two subbase materials, P-154 and DGA, which are being used in Construction Cycle 5 (CC5) will be analyzed in this paper. The properties for both these subbase soils are listed in Table 1. The Superpave Gyratory Compactor (SGC) is utilized to study the compaction characteristics of the subbase layer. The gyratory compactor is currently used in the Superpave mix design method, (AASHTO M323), which only applies to asphalt, concretes, and not unbound materials. The gyratory compactor has the ability to simultaneously apply a vertical load in addition to a self adjusting kneading action which simulates the moving traffic load experienced by a flexible pavement system [6].

Table 1.
FAA P-154 and DGA Material Properties and Classification Properties Results

Properties	P-154	DGA
Maximum Modfied Proctor (kN/m^3)	20.4	24.2
Optimum Moisture content (%)	6.9	5
Coefficient of Uniformity, C_u	26	169
Coefficient of Curvature, C_c	3.25	24
Mean Particle Size, D_{50}	1.5 mm	10 mm
AASHTO	A-1-b	A-1-a
USCS Soil Classification	SP-SM	GW

The objective of this study was to determine the relationship between the compaction that occurs in the field and the "simulated" compaction in the laboratory. The main limitation of this approach is that the stress regime of the subbase in the field is different from the stress regime in the laboratory because the unbound aggregate in the lab is confined in the Proctor and SGC mold, whereas in the field the aggregate has more freedom to rearrange.

The SGC has several variables that can be changed in order to closely imitate the conditions of field compaction. These variables include confining pressure, angle of gyration, number of gyrations, and gyration rate. The tests were conducted at pressure values ranging from 600 to 1000 kPa. The gyration angle used for all tests was 1.25 degrees. The densification rate of the granular subbase is sensitive to the number of gyrations being used as would be expected [7]. Therefore, the gyration values were varied between 200 and 500 gyrations. The gyratory compactor outputs the height versus the number of gyrations of the compaction mold. Using this, the volume of the material, and in turn, the density can be calculated.

The field compaction methods used in this study were based on the methods chosen at the NAPTF. The majority of the compaction data collected in this study was below the Optimum Moisture Content (OMC). This is due to the moisture migration to the subgrade level, as mentioned previously. The primary compactor used for the subbase material is a Pneumatic tire roller, which was configured to weigh 46,200 lb giving it a ground contact pressure per wheel ranging from 345 kPa (50 psi) to 965 kPa (140 psi) depending on the tire pressure [8]. The vibratory drum roller used on the subbase during construction, has an 84 in. wide, single-drum with an operating weight of 26,433 lb and centrifugal weight of 57,600 lb. Each roller makes a predetermined number of passes until the maximum achievable density has been reached. As with the gyratory compactor, the material will eventually reach a point where additional passes will no longer increase the density. The density obtained in the field was obtained using a nuclear density gauge, and secondary measurements are also obtained using a Sand Cone test (ASTM D1556-82).

P-154 SUPERPAVE GYRATORY COMPACTOR RESULTS

To get a baseline of comparison for the SGC compaction tests, Modified Proctor tests, ASTM D1557-07, at different moisture contents were performed. The first set of SGC tests were conducted on the P-154. These tests were conducted at a gyration angle of 1.25 degrees. Two different pressures were used, 600 kPa and 1000 kPa. The results of these tests at various moisture contents are listed in Table 2. Eighty-five percent Modified Proctor density was considered the baseline for loose compaction from the field compaction results. Due to the fact that tests conducted at a moisture content below three percent were unable to exceed 100% maximum Modified Proctor density after more than 200 gyrations at a pressure of 600 kPa, it is evident that the pressure applied by the gyratory compactor and the moisture content both affect the compaction rate. The average number of gyrations to compact the aggregate from one level to another is shown in Table 2 for different moisture contents and pressure applied in the SGC.

Table 2.
SGC Results for P-154 Field Compaction Comparisons

Pressure (kPa)	1000	1000	1000	1000	1000	1000	600	600
Moisture (%)	6.0 – 7.0	5.0 – 6.0	4.0 – 5.0	3.0 – 4.0	2.0 – 3.0	1.0 – 2.0	2.0 – 3.0	1.0 – 2.0
No. of Tests	3	4	6	5	3	7	2	4
% Mod. Proctor	**Average Number of Gyrations**							
85 - 90%	3.00	3.25	3.83	6.20	5.67	6.57	10.00	14.25
90 - 95%	6.67	7.00	10.00	23.40	23.00	33.00	53.50	81.25
95 - 100%	22.33	19.25	34.33	50.75	-	-	-	-
100 - 105%	95.67	94.00	216.17	264.00	-	-	-	-

The sample sizes tested in the SGC were also varied with both 3000 g and 5000 g samples being tested. The different sample sizes were used to simulate the different lift height in the field. Three-thousand grams translates to 4 inches and 5000 g translates to 6 inches. Figure 1 shows the results of the SGC tests relative to the Modified Proctor density curve. At approximately the same water content, the 3000 g sample after 300 gyrations has much higher density than the 5000 g sample at 500 gyrations. It was determined from the gyratory compaction data that the compacted height of the 3000 gram sample was three inches where as the compacted height of the 5000 gram sample was five inches. Based on these results, the FAA decided that at least the top layers of the subbase for CC5 would be compacted at smaller lift heights of 4 inches at 4% moisture content. The 4% was chosen based on the results showing that Maximum Modified Proctor (MMP) density can be achieved, even though it is below the optimum moisture content. The FAA decided to go lower than the optimum because moisture migration to the subgrade layer may causes a shear slip plane. It was also decided that smaller lift heights would be used based on the results shown in Figure 1, which clearly show that compacting the sample to the Maximum Modified Proctor density can be achieved at lower than optimum moisture contents.

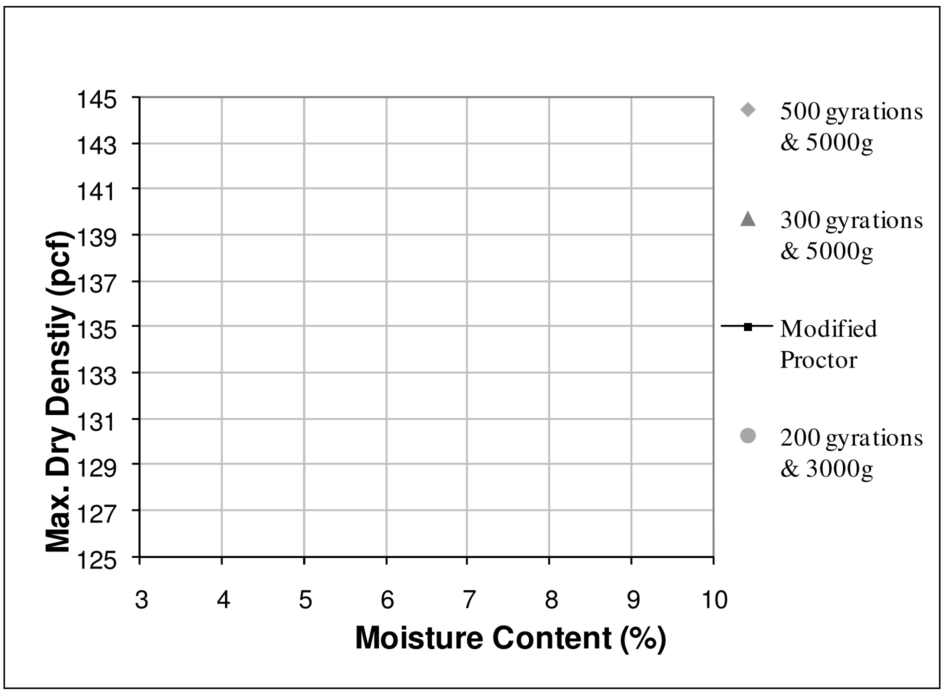

Figure 1. Evaluation of P-154 SGC results Below OMC with Simulated Lift Height (1 pcf = 16.02 kg/m^3).

P-154 CONSTRUCTION FIELD COMPACTION CHARACTERISTICS

During CC5 testing at the NAPTF, the field compaction was closely monitored. Density measurements were taken using a nuclear density gauge and Sand Cone tests. Elevation measurements were taken using a total station. The density measured in the field was below the MMP density. This lower density could be due to the lower than optimum moisture content to prevent over saturation of the weak subgrade. The results from lifts one, two, four, and five are shown in Figure 2. Lift three was excluded from the graph because the material used was from a different screening which resulted in a density higher than the MMP. Only six passes, four of the static drum and two passes of the vibratory drum roller were used on Lift 1 to prevent penetrating the clay subgrade layer and resulted in a lower density. After a specific number of passes with the roller, the change in height and density were measured at six separate locations of the NAPTF. The placement and testing of each point was not the same and it is therefore more useful to look at the average for a series of points to find any trend in compaction. Lift 4 was done on two separate days, so there is a gap in the data. For P-154 analysis, Lift 4 day two was not used in finding the compaction characteristics but shown in the figure for completeness.

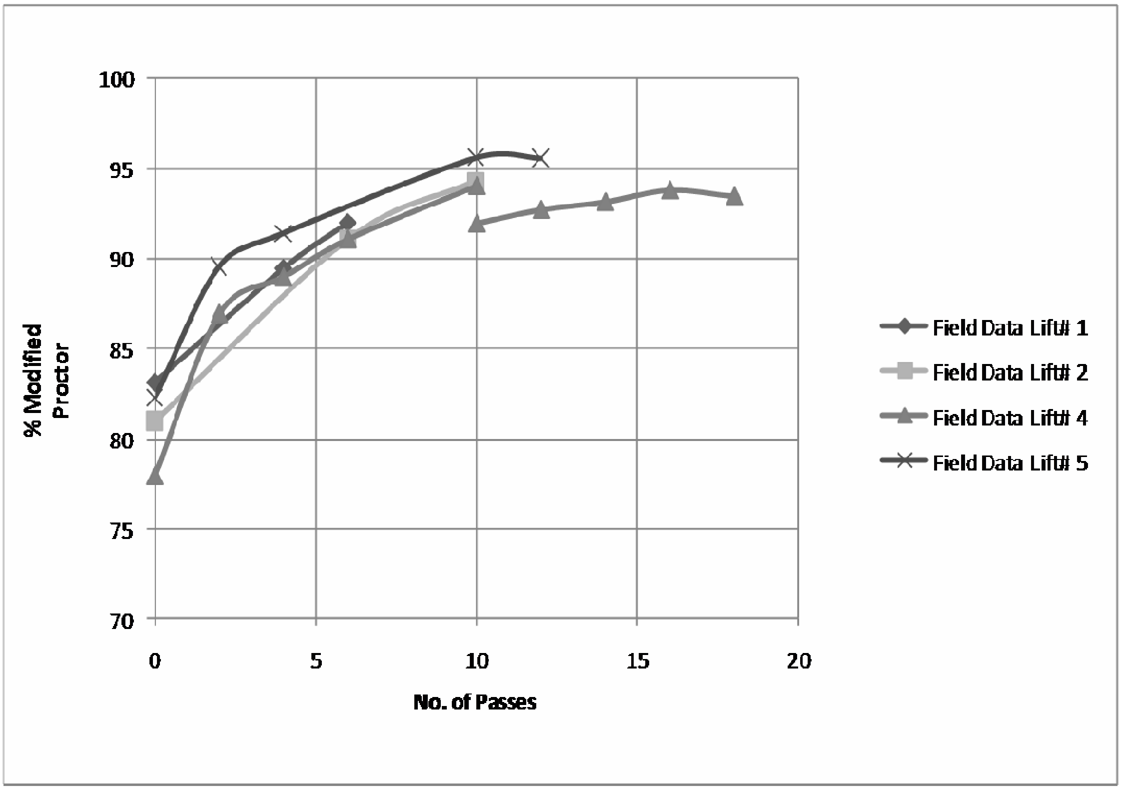

Figure 2. Field Construction Compaction Results for P-154 during CC5 with the Following Moisture Contents: Lift 1 – 2.9%, Lift 2 – 2.6%, Lift 4 – 2.5% and 3.4% Lift 5 – 3.0%.

To investigate the correlation between the SGC results and the number of passes of the roller, the % MMP density was plotted against the number of gyrations and number of passes of the roller on the x-axis. Figure 3 shows one of the sample plots that were generated for both 600kPa and 1000 kPa pressure. It can be seen that the field data is more closely captured by the SGC at 1000 kPa, not 600 kPa, confining pressure, and this trend was seen for all the other lifts also.

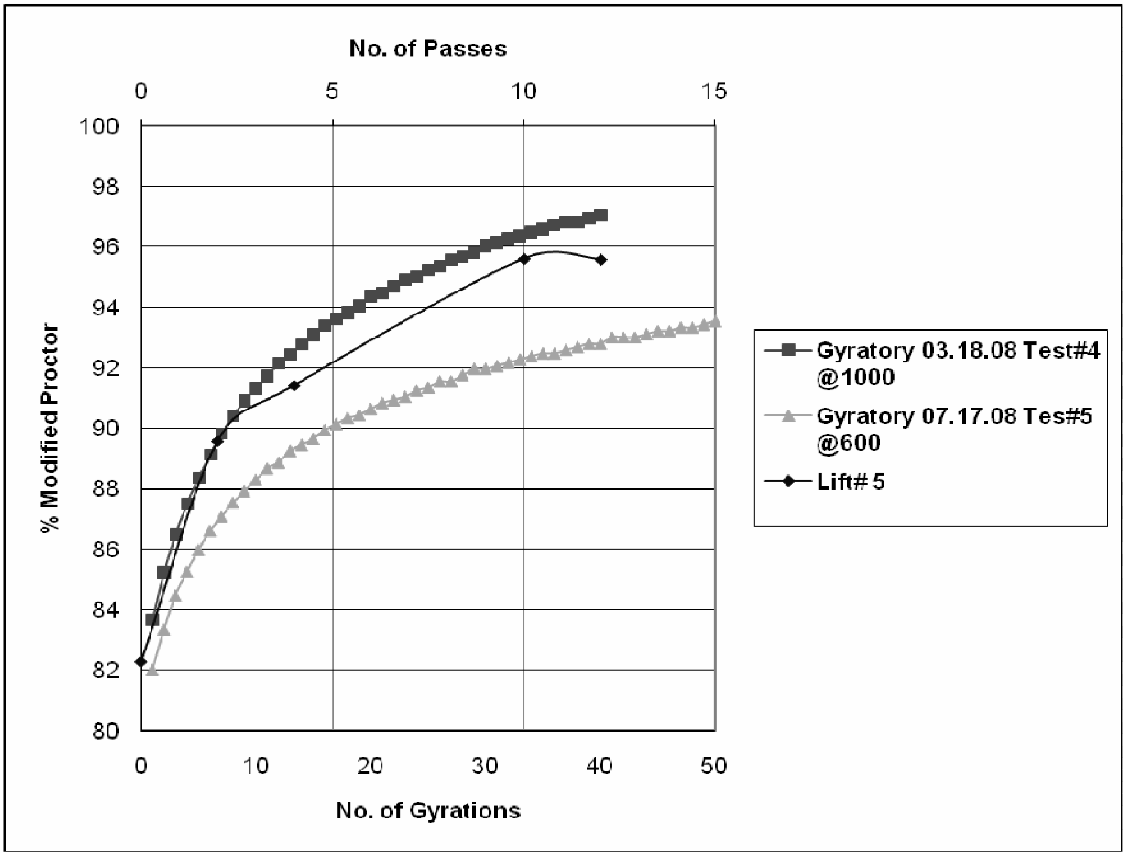

Figure 3. Comparison of P-154 Gyratory Compactor Results and Field Construction Compaction from Lift # 5 during CC5 (1 pcf = 16.02 kg/m3).

P-154 TRAFFICKING AND SUPERPAVE GYRATORY COMPACTOR COMPARISON

The CC5 pavement has been operational for a year and the performance is monitored using various gages including Multi Depth Deflectometers (MDD's). These are located in the subbase and subgrade of CC5, and the deflection over about 13,000 passes of the six wheel gear configuration has been measured. Figure 4 shows the deflection of the subbase using a MDD located 1 inch into the P-154. In this case, the MDD is located 13.75 feet off the centerline of the test runway, and is directly between the wheels when they are set on their middle line, or track 0. This figure shows the displacement over the complete testing period of the trafficking cycle. The event number refers to the number of passes of the six wheel gear configuration and the displacement plotted is the vertical displacements measured by the MDD.

The SGC can be used to replicate the field results, once the correct parameters are used. The moisture content used in CC5 was 3-4%, so during SGC tests, the moisture content used for comparison to the field was 3-4%. Figure 5 shows the results of two laboratory tests compared to MDD's that are located in the P-154 in the field, where a 6-wheel gear configuration was trafficked simulating the Boeing 777 aircraft. After testing and comparing, the tests that have the best resemblance to the field results are tests conducted at 1000 kPa of pressure as was the case with the field compaction. As can be seen in Figure 6, the results of the SGC tests are within 0.1 inches of the final displacement from the field.

To determine the mechanism contributing to compaction and densification of the subbase material, a wash sieve analysis was conducted on the material before and after compaction in the

SGC. It was determined that there was a 1% increase in the fines indicating attrition and abrasion of the aggregate, as reported in Ramamurthy and Prakash [9]. This mostly contributes to decreased angularity of the aggregates reducing interlock and the tendency of the aggregate to move into a denser, more closely spaced packing. This was also evidenced from image analysis of the aggregates before and after compaction.

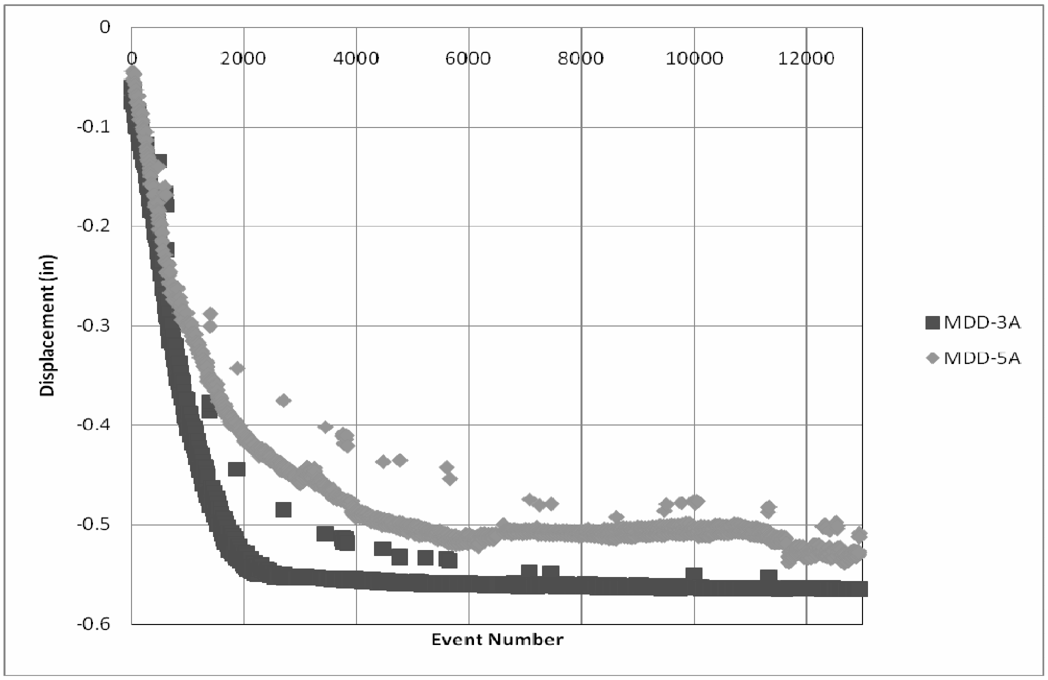

Figure 4. MDD Deflection During CC5 Trafficking (1 inch = 2.5 cm).

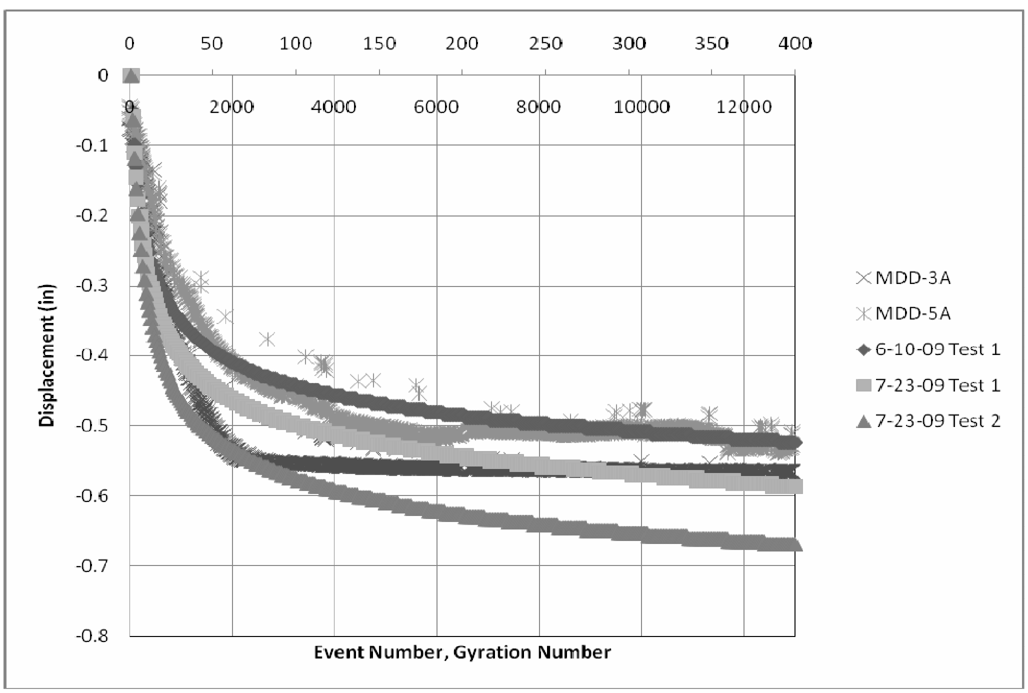

Figure 5. P-154 SGC at 1000 kPa and Field Trafficking Comparison.

DGA SUPERPAVE GYRATORY COMPACTOR RESULTS

The testing process adopted for the P-154 was repeated for the DGA, but the water content used for analysis was similar to that adopted in the field. Figure 6 shows the SGC test data as compared to the Modified Proctor tests conducted on the DGA. As can be seen, most of the samples tested in the SGC were at moisture contents ranging from 2 to 3% to simulate the water contents used in the field compaction.

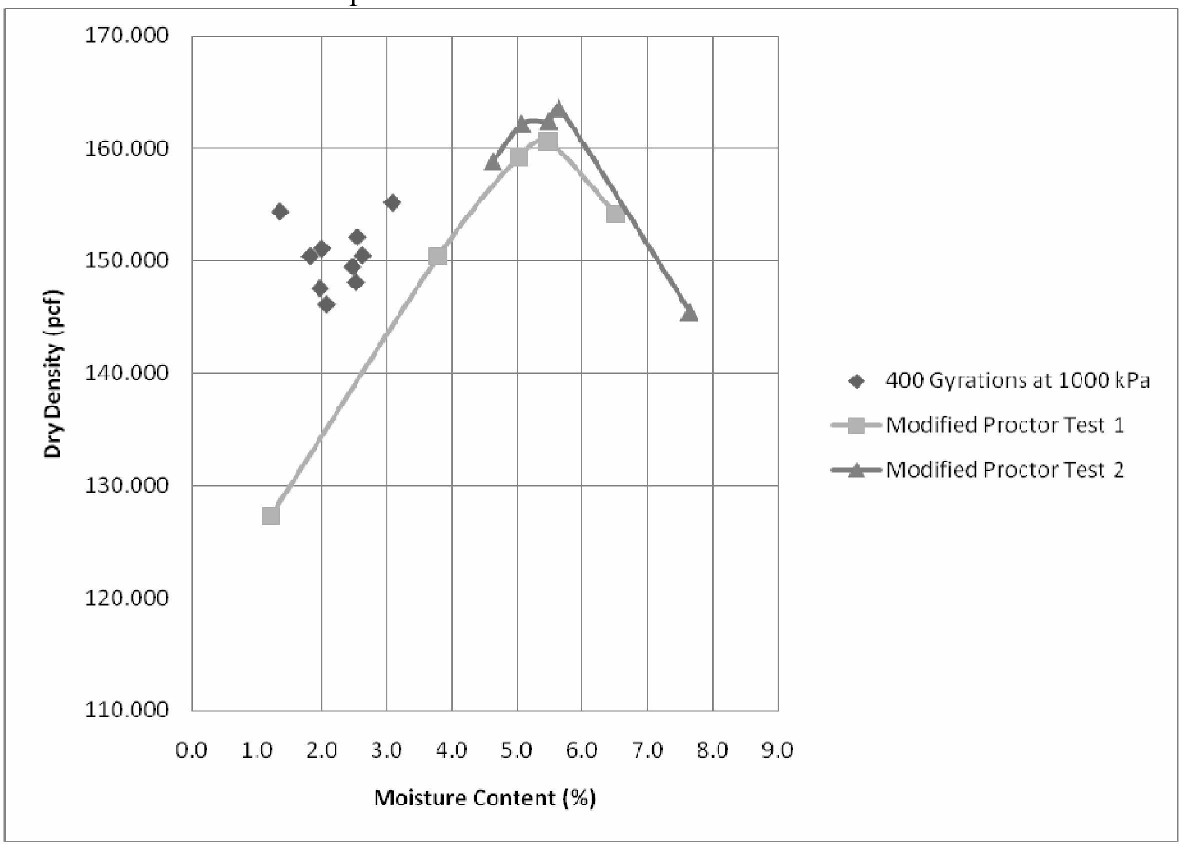

Figure 6. Evaluation of DGA SGC results Below OMC with Simulated Lift Height (1 pcf = 16.02 kg/m^3).

Figure 7 shows the compaction curves for the DGA with a moisture content range of 2-3% as obtained from the SGC. The tests are repeatable. Some of the problems encountered include moisture migration due to the large aggregate composition of the DGA material.

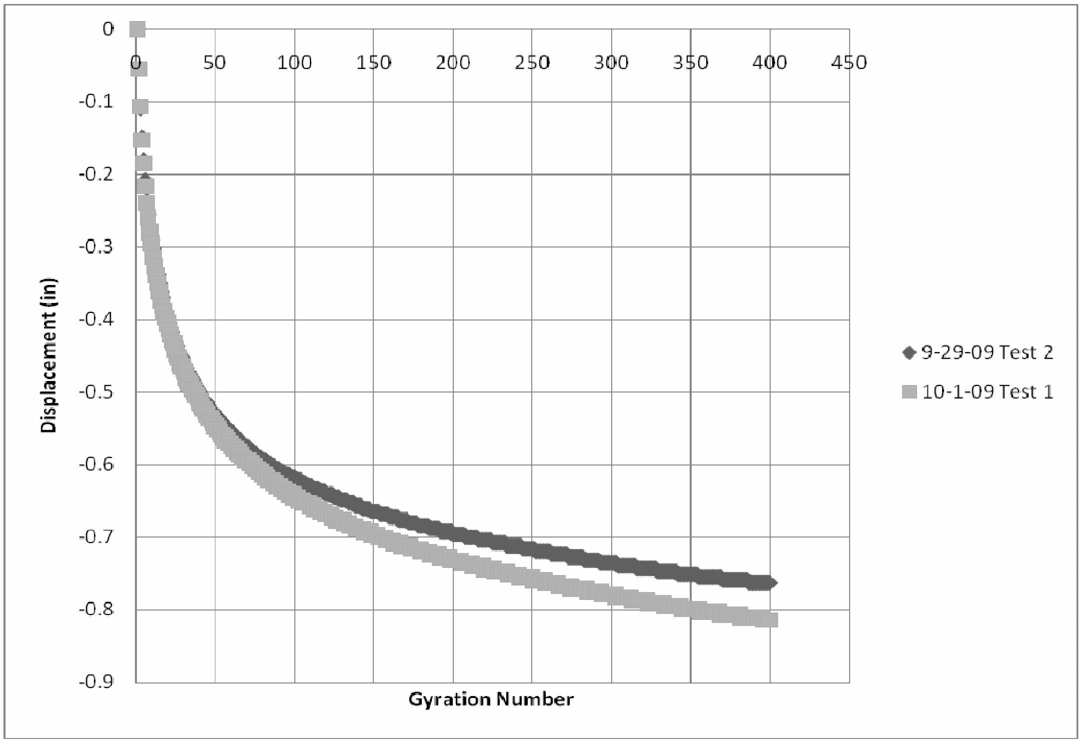

Figure 7. DGA SGC Compaction Tests at 1-2% Moisture Content

DGA TRAFFICKING AND SUPERPAVE GYRATORY COMPACTOR COMPARISON

Figure 8 shows the result of two laboratory tests compared to MDD's that are located in the DGA in the field, where a 6-wheel gear configuration was trafficked simulating the Boeing 777 aircraft. Much like the P-154, the best results of the SGC came at 1000 kPa with 400 gyrations. Figure 8 shows that MDD-9A and MDD-11A are within 0.1 inches of the two laboratory tests. MDD-9B and MDD-11B, however, are approximately 0.3-0.4 inches away from the laboratory tests. The SGC results were considered acceptable because the only two MDD's in the DGA have varying results. The SGC tests were aimed at MDD-9A and MDD11A because they have smoother compaction curves and less scatter than the curves for MDD-9B and MDD-11B. The reasons for the difference in compaction are not clear, due to the fact that they are both located 16 feet off the centerline. One possible explanation could be that MDD-9A and MDD-11A are located only 1 inch deep into the DGA, while MDD-9B and MDD-11B are 33 inches and 31 inches deep into the DGA, respectively. This means that MDD-9B and MDD-11B are close to the border of the low-strength subgrade, which may explain the larger displacement.

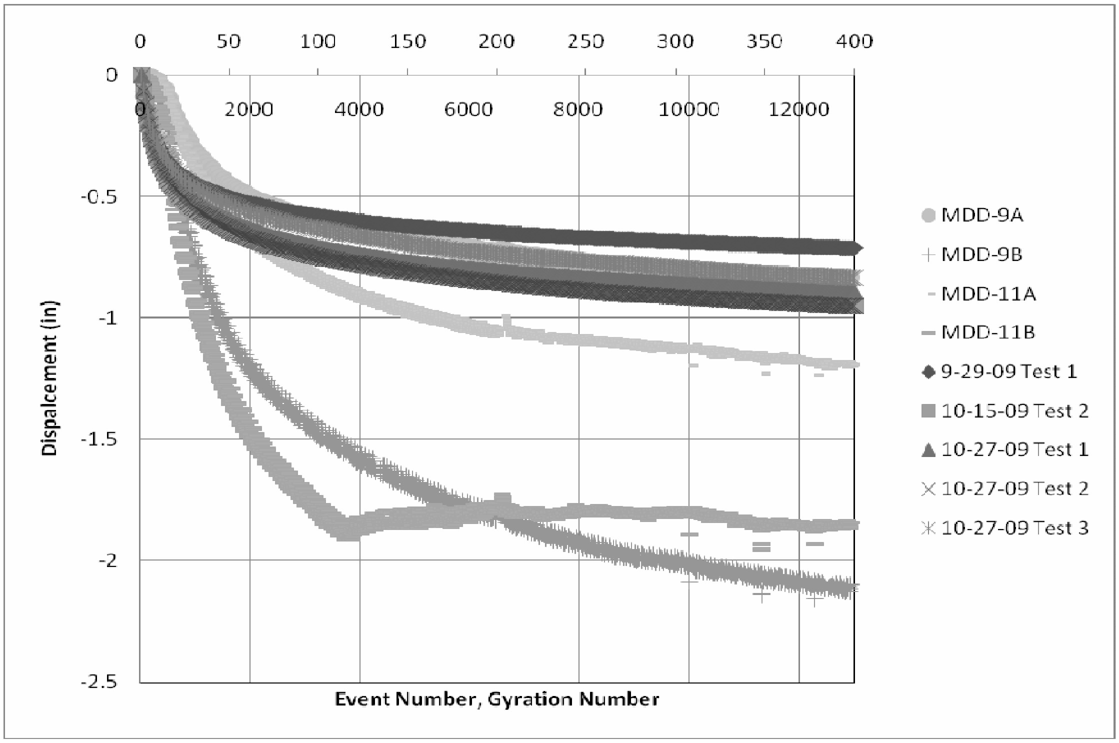

Figure 8. DGA SGC results at 1000 kPa and Field Trafficking Comparison.

CONCLUSIONS

Based on the study comparing the SGC results with field compaction results, it can be seen that the SGC results are promising and based on more extensive testing can be shown to be capable of replicating field compaction results even with different field compaction equipment being used. It is also capable of achieving much higher densities than the Modified Proctor test, where a standard energy input is used.

It has also been shown that the SGC can be used effectively for unbound materials in addition to bound material in predicting its performance during compaction and trafficking. It could prove to be a useful tool to predict field compaction performance and can be used more effectively than the Proctor tests in providing recommendations about lift heights and achievability of maximum Proctor density at less than optimum moisture content.

Field deflection data obtained using a six wheel aircraft gear configuration at the National Airport Pavement Facility also indicates that the SGC is capable of replicating the behavior of the subbase material during trafficking. With further studies, it will be possible to obtain the equivalency between the number of gyrations in the SGC and the number of passes of an aircraft wheel. The mechanism of compaction during trafficking for the aggregate tested is due to attrition and abrasion of the aggregate reducing angularity and therefore interlocking of aggregate.

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