ST-008 Appendix IX-A: Laboratory Testing Results by Michigan State University Research Group

Progress Report - Increasing Pavement Performance through Pavement Foundation Design Modulus Verification and Construction Quality Monitoring

Technology and Innovation Deployment Program (TIDP)—Accelerated Innovation Deployment (AID) Demonstration Project

Prepared for

Federal Highway Administration – Iowa Division

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1. INTRODUCTION

Optimal compaction of pavement foundation layers including base, subbase, and subgrade layers during road construction for roadways is very important for maximizing the service life of roads and minimizing the thicknesses of pavement layers. The mechanical and drainage properties of subgrade, subbase, and base layer materials used in mechanistic pavement design are the level one inputs; these properties are significantly affected by compaction and moisture content. One of the primary functions of pavement foundation layers is to act as a foundation to provide adequate mechanical support to the asphalt or concrete layer to prevent fatigue and rutting failures (Cetin et al. 2014). It is well known that the majority of the rutting failures occur due to lack of required mechanical properties of the pavement foundation materials used in highway base layer construction. The density of pavement foundation materials also has a significant impact on the modulus of pavement foundation materials; modulus of soils generally increases when compacted to a higher density (Cetin et al. 2014).

Moreover, in the AASHTOWare Pavement ME Design (PMED) software, resilient modulus (M_R) is considered as one of the most critical input parameters for unbound and subgrade layers (Schwartz et al. 2011, 2013). The M_R properties of unbound and subgrade layers undergo significant seasonal variations. The PMED software internally determines these seasonal variations of M_R properties of these layers using a sophisticated climate modeling module, the Enhanced Integrated Climate Model (EICM). The EICM uses empirical relationships to estimate various unbound and subgrade layer properties including saturated hydraulic conductivity (k_{sat}). The PMED software uses these estimated k_{sat} values to calculate seasonal variations of M_R. The use of unverified M_R values and k_{sat} values in the PMED software substantially undermines the credibility of PMED distress analyses.

Millions of tons of granular aggregates are used in construction of highway bases in the United States due to their satisfactory geomechanical and hydraulic properties, but these laboratory properties may vary significantly depending on the compaction degrees. M_R of these materials are directly impacted by the compaction degree applied (Cetin et al. 2014, Lekarp et al. 2000). Puppala (2008) claimed that stiffness of unbound aggregate materials depends on the moisture content, dry density, soil classification, and plasticity index. Compaction is used to increase stiffness and strength characteristics of highway base and subbase layers as well as these compacted soils need to provide adequate hydraulic conductivity to drain the excess water that infiltrates through the upper pavement layer (asphalt layer). The design of pavement structure highly depends on the laboratory characterization of the materials that are used. This material characterization process includes determination of optimum moisture content, grain size distribution, strength, resilient modulus and hydraulic conductivity of each material that is planned to be used in roadway construction. These physical and mechanical properties are greatly influenced and altered by the compaction degree. Therefore, it is very important to determine how the stiffness (M_R) and hydraulic conductivity (k) of granular and fine-grained materials are impacted with applied compaction degree.

In this project, the impact of compaction degree of M_R and k values of pavement foundation materials under different compaction degrees were evaluated. For this purpose, materials including coarse-grained and fine-grained soil materials were collected from five different counties in the

State of Iowa: (1) Dubuque County (US-52), (2) Plymouth County (US-75), (3) Linn County (US-13), (4) Tama County (US-30), and (5) Des Moines County (US-61).

2. PROJECT STATUS UPDATE

2.1. Summary of Work Accomplished

The Michigan State University (MSU) team collected seven different materials from the previously listed counties in the State of Iowa. These materials included a mixture of reclaimed asphalt pavement (RAP) and reclaimed Portland cement concrete (RPCC) materials (modified subbase from US-52), a RAP material (special backfill from US-75), an RPCC material (granular subbase from US-13), crushed limestone aggregates (referred to as Crushed Limestones – granular subbases from US-30 and US-61), and subgrade (SG) materials (from US-30 and US-61). Then, a series of extensive laboratory characterization tests was performed on these materials. List of these tests are listed below:

- Dry and wet sieve analyses
- Atterberg limits
- Standard Proctor compaction
- Specific gravity (G_s)
- Relative density (D_r)
- Hydraulic conductivity (k) (at compaction degrees of 85%, 90%, 95%)
- Resilient modulus (M_R) (at compaction degrees of 85%, 90%, 95%)

A summary of the testing progress, along with the list of the materials, is shown in Table 1. The MSU team conducted dry and wet sieve analyses and specific gravity tests for all the materials collected. In addition, the team performed standard Proctor compaction tests for all the materials except for US-30 (Crushed Limestone) and US-61 (Crushed Limestone). Relative density tests were conducted for the US-30 (Crushed Limestone) and US-61 (Crushed Limestone) materials since they had very low sand and fines content. For all materials, k and M_R tests were performed on all materials that were compacted at three different degree of compactions including 85%, 90%, and 95%.

Table 1. Summary of testing progress

Test method		Material						
		US-52 (RAP & RPCC Modified Subbase)	**US-75 (RAP Special Backfill)**	**US-13 (RPCC Granular Subbase)**	**US-30 (Crushed Limestone Granular Subbase)**	**US-61 (Crushed Limestone Granular Subbase)**	**US-30 (Subgrade Select Soil)**	**US-61 (Subgrade Select Soil)**
Dry & wet sieve analyses		Done	Done	Done	Done	Done	Done	Done
Proctor compaction/density tests		Done	Done	Done	Done	Done	Done	Done
Specific gravity tests		Done	Done	Done	Done	Done	Done	Done
Permeability tests	95% compaction	Done	Done	Done	Done	Done	Done	Done
	90% compaction	Done	Done	Done	Done	Done	Done	Done
	85% compaction	Done	Done	Done	Done	Done	Done	Done
M_R tests	95% compaction	Done	Done	Done	Done	Done	Done	Done
	90% compaction	Done	Done	Done	Done	Done	Done	Done
	85% compaction	Done	Done	Done	Done	Done	Done	Done

Notes: RAP = reclaimed asphalt pavement; RPCC = reclaimed Portland cement concrete; SG = subgrade; US-52 = Dubuque County; US-75 = Plymouth County; US-13 = Linn County; US-30 = Tama County; US-61 = Des Moines County.

3. LABORATORY CHARACTERIZATION OF MATERIALS

3.1. Sieve Analyses, and Specific Gravity and Atterberg Limits Tests

Particle size distributions of the materials are provided in Figure 1. In addition, their classifications and specific gravity values are summarized in Table 2. Sieve analyses were conducted per ASTM C136/C136M. Each unbound material was washed prior to conducting the sieve analysis to separate fines [silt and clay – particles passing a No. 200 (0.0029 inches) sieve] from the material. Sieve sizes used in the tests ranged from ¾ inches to No. 200 (0.0029 inches). The materials were classified in accordance with the Unified Soil Classification System (USCS) (ASTM D2487) and the American Association of State Highway and Transportation Officials (AASHTO) soil classification system (ASTM D3282 & AASHTO M 145). Per the AASHTO system, US-52 (RAP & RPCC), US-75 (RAP), US-13 (RPCC), US-30 (Crushed Limestone), and US-61 (Crushed Limestone)] were A-1-a. In addition, per the AASHTO system, US-30 (SG) and US-61 (SG) were A-6. According to the USCS, US-52 (RAP & RPCC) and US-75 (RAP) were GW, US-13 (RPCC) and US-61 (Crushed Limestone) were GP-GM, and US-30 (Crushed Limestone) was GP. In addition, per the USCS, US-30 (SG) was CL, and US-61 (SG) was ML.

The specific gravity (G_s) tests were performed in accordance with ASTM C127 and ASTM D854. The oven-dry specific gravity values of the coarse particles ranged from 2.31 to 2.56. The apparent specific gravity values of the fine particles ranged from 2.44 to 2.83. The water absorption values of the coarse particles ranged from 0.51 to 5.07%. G_s of US-30 (SG) and US-61 (SG), were 2.79 and 2.63, respectively. Atterberg limits tests (ASTM D4318) were performed on US-30 (SG) and US-61 (SG) to determine their liquid limit (LL), plastic limit (PL), and plasticity index (PI) values. The results of Atterberg limits tests are summarized in Table 3. The PI values were 13.53 and 11.45 for US-30 (SG) and US-61 (SG), respectively. Fines content of the US-30 (SG) and US-61 (SG) were 55% and 65%, respectively.

Figure 1 shows that subbase and special backfill materials are coarse grained (materials retained over U.S. No 4 sieve vary from 90% to 50%) while subgrade materials are fine-grained as expected.

3.2. Standard Proctor Compaction Tests

Standard Proctor tests were performed per ASTM D698 on all the materials except for US-30 (Crushed Limestone) and US-61 (Crushed Limestone) to determine their optimum moisture content (OMC) and maximum dry unit weight (MDU) values. For US-30 (SG) and US-61 (SG), method A (ASTM D698) was followed. For US-75 (RAP), method B was used. Lastly, method C was followed for US-13 (RPCC) and US-52 (RAP & RPCC).

Standard Proctor compaction test results for US-52 (RAP & RPCC), US-75 (RAP), US-13 (RPCC), US-30 (SG), and US-61 (SG) are shown in Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6, respectively. The OMC and MDU values taken from these figures are summarized in Table 4. The OMC and MDU values of subbase and special backfill materials are at the range of 7%-11% and 117 to 127 pcf respectively while OMC and MDU of subgrade soils were 11%-16% and 117-130 pcf, respectively.

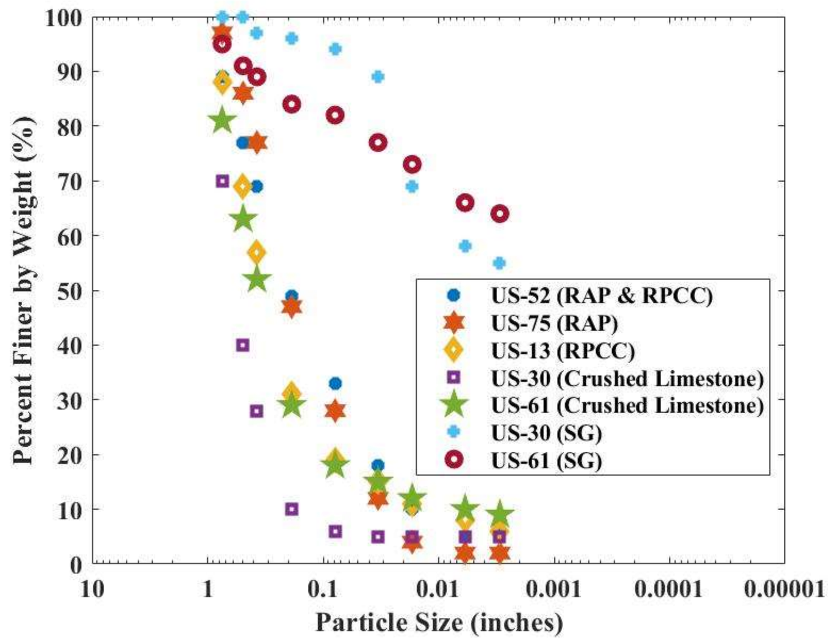


Figure 1. Particle size distributions of materials (RAP = reclaimed asphalt pavement; RPCC = reclaimed Portland cement concrete; SG = subgrade)

Table 2. Classifications and specific gravity values of materials

Material	Gravel (%)	Sand (%)	Fines (%)	AASHTO	USCS	Specific gravity		Water absorption (%)
						Coarse	Fine	
US-52 (RAP & RPCC Modified Subbase)	50.5	44.6	4.9	A-1-a	GW	2.34	2.53	3.01
US-75 (RAP Special Backfill)	52.8	45.4	1.8	A-1-a	GW	2.42	2.44	0.51
US-13 (RPCC Granular Subbase)	68.7	24.8	6.5	A-1-a	GP-GM	2.31	2.53	5.07
US-30 (Crushed Limestone Granular Subbase)	90.3	5.1	4.6	A-1-a	GP	2.56	2.83	2.14
US-61 (Crushed Limestone Granular Subbase)	71.8	20	8.2	A-1-a	GP-GM	2.4	2.82	4.17
US-30 (SG Select Soil)	3.8	41.3	54.9	A-6	CL	N/A	2.79	N/A
US-61 (SG Select Soil)	16.3	20.1	63.6	A-6	ML	N/A	2.63	N/A

Notes: Fines = silt and clay; AASHTO = American Association of State Highway and Transportation Officials; USCS = Unified Soil Classification System; RAP = reclaimed asphalt pavement; RPCC = reclaimed Portland cement concrete; SG = subgrade; N/A = not applicable.

Table 3. Atterberg limits of materials

Material	LL	PL	PI
US-30 (SG Select Soil)	28.65	15.12	13.53
US-61 (SG Select Soil)	37.86	26.41	11.45

Notes: LL = liquid limit; PL = plastic limit; PI = plasticity index; SG = subgrade.

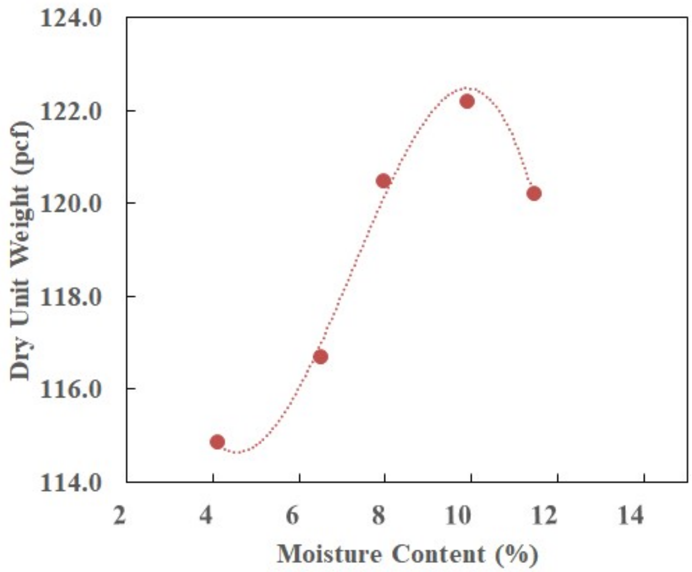


Figure 2. Compaction curve for US-52 (RAP & RPCC)

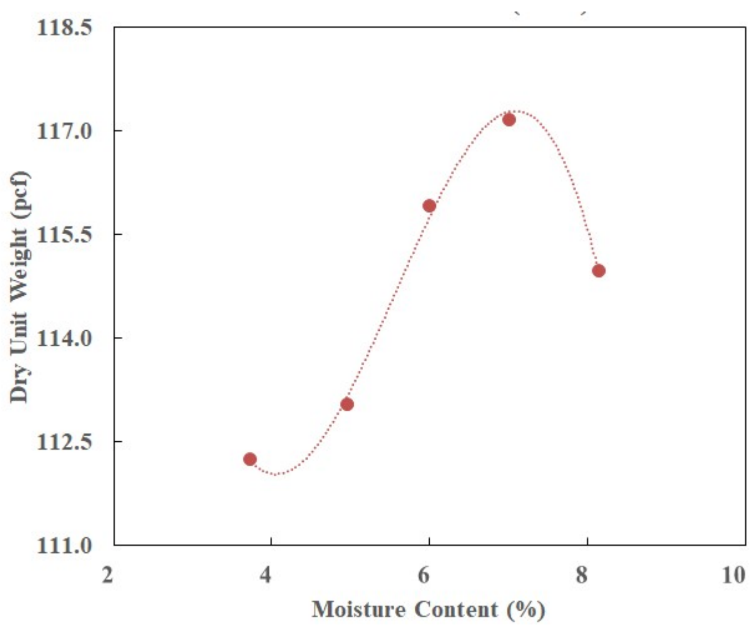


Figure 3. Compaction curve for US-75 (RAP)

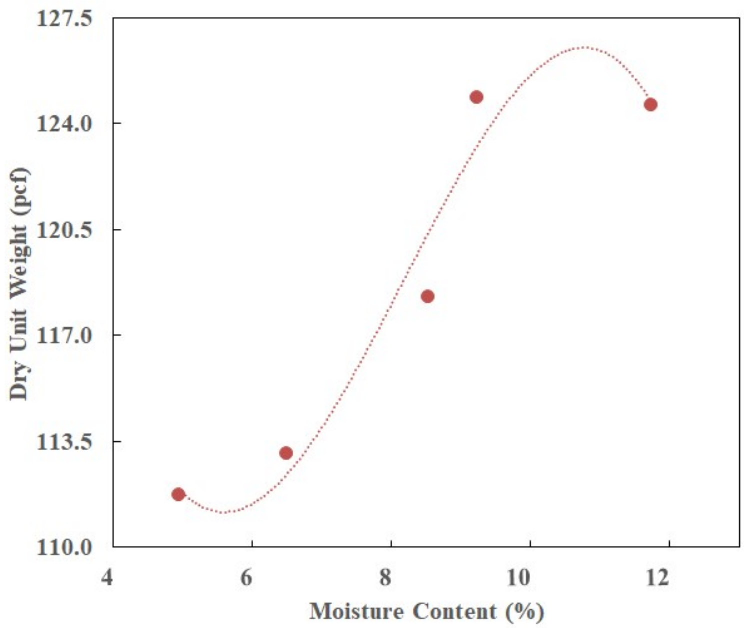


Figure 4. Compaction curve for US-13 (RPCC)

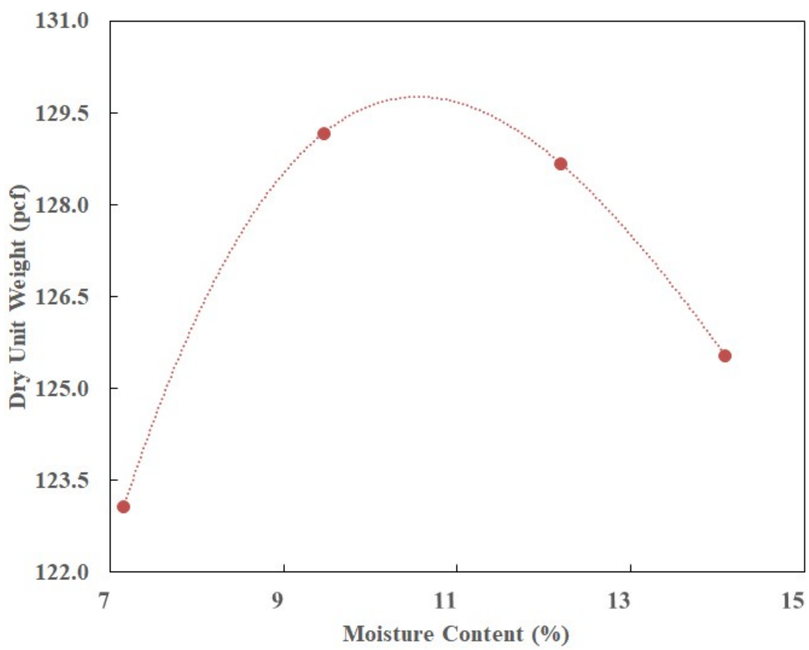


Figure 5. Compaction curve for US-30 (SG)

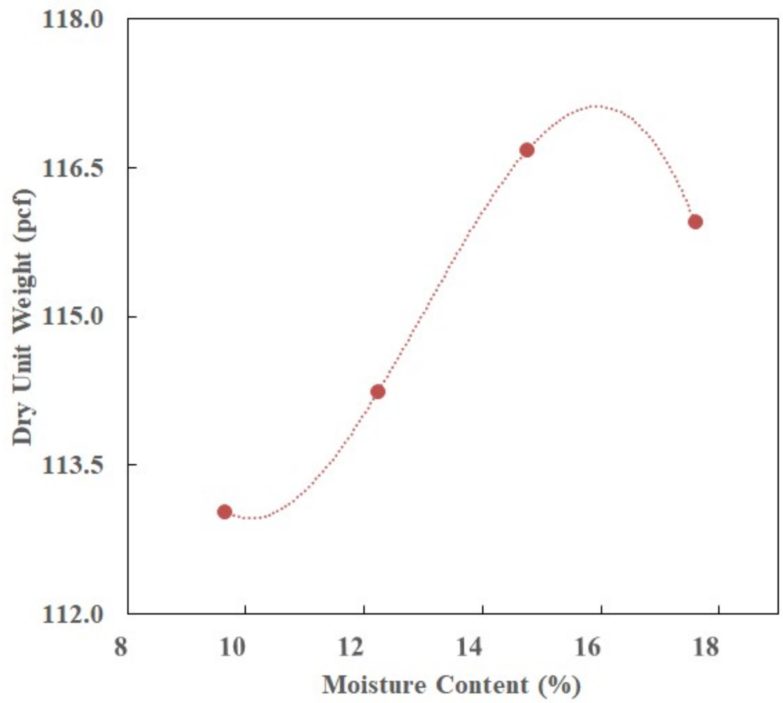


Figure 6. Compaction curve for US-61 (SG)

Table 4. Optimum moisture content (OMC) and maximum dry unit weight (MDU) values of materials

Material	OMC (%)	MDU (pcf)
US-52 (RAP & RPCC Modified Subbase)	10.0	122.36
US-75 (RAP Special Backfill)	7.1	117.35
US-13 (RPCC Granular Subbase)	10.8	126.54
US-30 (Subgrade Select Soil)	10.6	129.75
US-61 (Subgrade Select Soil)	16.0	117.22

Notes: RAP = reclaimed asphalt pavement; RPCC = reclaimed Portland cement concrete; SG = subgrade.

3.3. Permeability Tests

The vertical hydraulic conductivities of the subbase and special backfill materials were determined using a rigid-wall permeameter that was specifically developed for measuring hydraulic conductivity of 6-inches diameter and 6 inches-long specimens compacted in three equal layers. Fig. 7 shows the schematic drawing of the so-called "bubble tube constant head permeameter". The system allows the application of very low hydraulic gradients, accommodates high flow rates that are associated with testing of permeable granular aggregate materials, and significantly minimizes sidewall leakage. The unique design also eliminates the use of valves, fittings and smaller diameter tubings, all which contribute to head losses that interfere with the test measurements yet follows all recommendations in ASTM D2434 (Kutay et al. 2007).

The permeameter was placed in a bath to maintain constant tail water elevation (Fig.7). The tub rim was located less than ½ inch above the specimen top. As water flowed out of the reservoir tube through the specimen, air bubbles emerged from the bottom of the bubble tube. The total head difference through the specimen (H), which was constant during the test, was the height difference between the bottom of the bubble tube and the top of the water bath. The total flow rate through the specimen (i.e., Q_z) was determined by noting the water elevation drop in the reservoir tube and multiplying it with the inner area of the reservoir tube minus the outer area of the bubble tube. Applied hydraulic gradient was maintained at ~1 during the hydraulic conductivity tests. Finally, the vertical hydraulic conductivities were calculated using Darcy's law.

Constant head permeability tests were performed on US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC) in accordance with ASTM D2434. The specimens prepared from US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC) for the tests are shown in Figure 8, Figure 9, and Figure 10, respectively. These specimens were compacted using a vibratory hammer in 3 equal lifts to ensure uniform gradation throughout the specimens.

A summary of hydraulic conductivity test results are provided in Tables 5 and 6. Overall, US-75 (RAP) had the highest k values at each compaction level. The permeability (k) values at 95% compaction level were determined to be 5.8 x 10^{-4}, 0.02, and 3.2 x 10^{-3} inches/sec for US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC), respectively. The k values at 90% compaction level were determined to be 2.6 x 10^{-3}, 0.02, and 4 x 10^{-3} inches/sec for US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC), respectively. Lastly, the k values at 85% compaction level were determined to be 8 x 10^{-3}, 0.04, and 4.4 x 10^{-3} inches/sec for US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC), respectively. Open graded US-30 (CL) and US-61(CL) had the highest k values and their k did not change significantly with an increase in compaction degree. On the other hand, US-30 (SG) and US-61 (SG) had the lowest k as expected and reduced considerably with an increase in compaction degree. While k values of all materials decreased with an increase in compaction level, adequate drainage capacity for granular base materials were still obtained even at the highest compaction level.

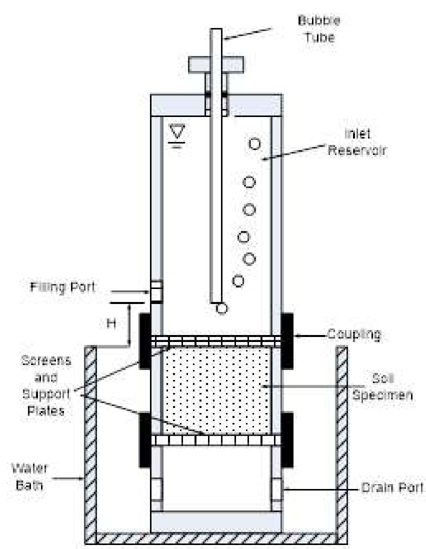


Figure 7. Bubble tube constant head permeameter

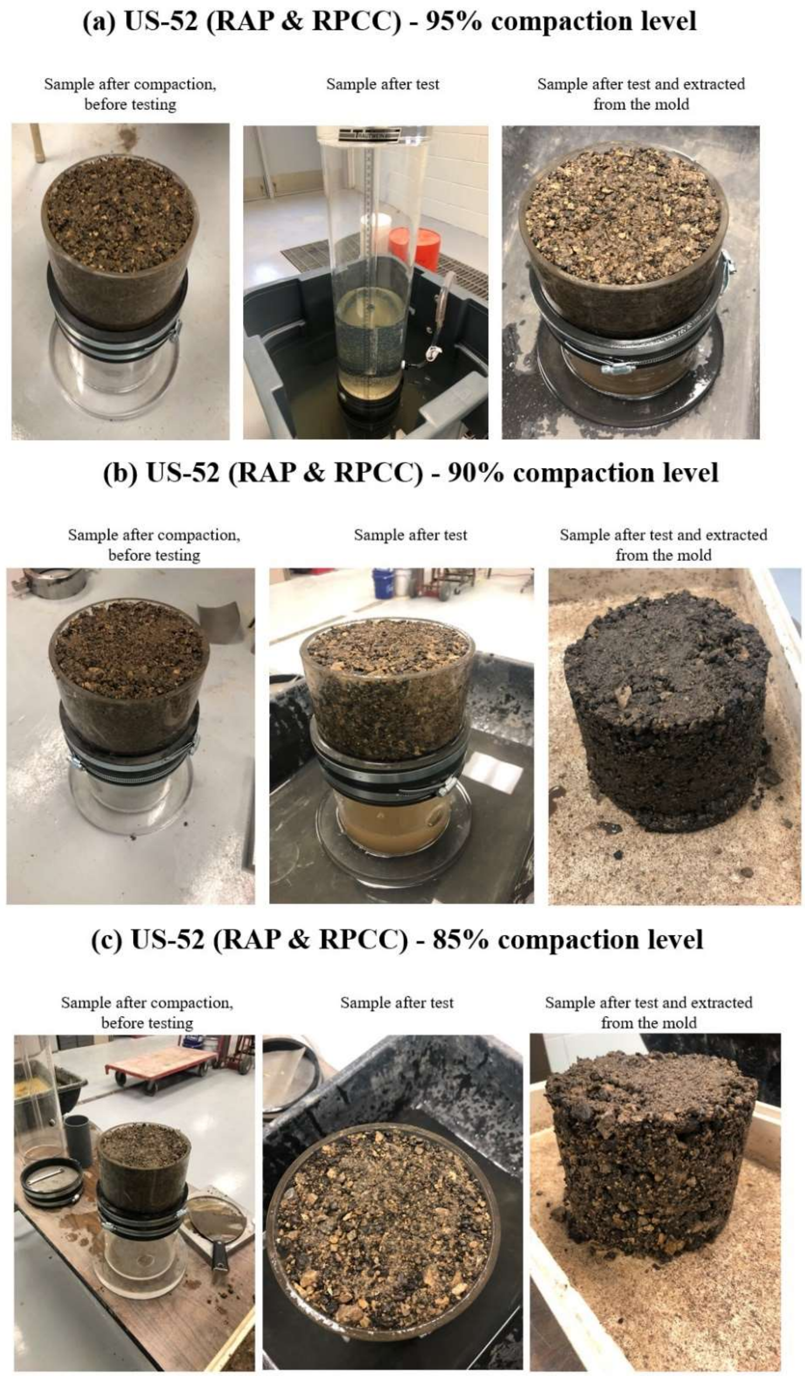
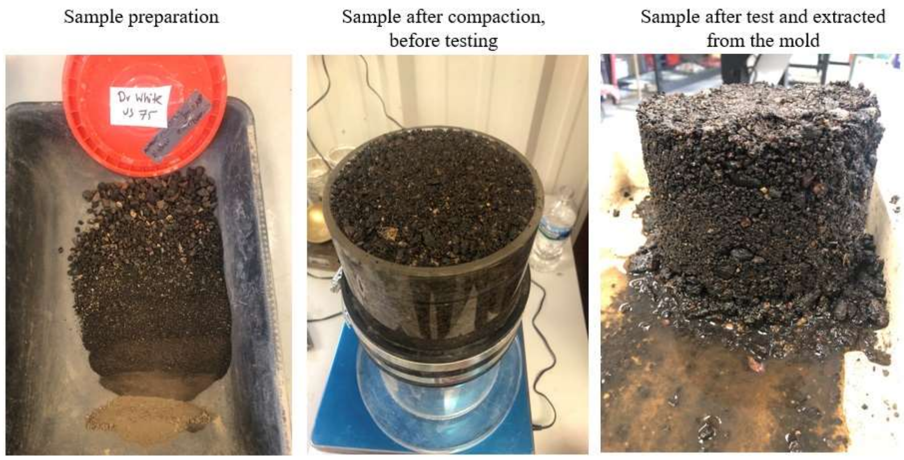
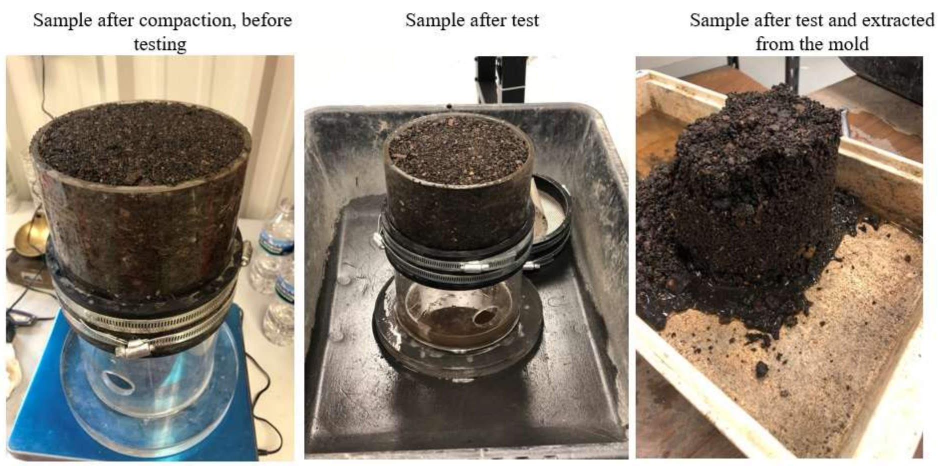


Figure 8. Specimens prepared from US-52 (RAP & RPCC) at (a) 95, (b) 90, and (c) 85% compaction levels

(a) US-75 (RAP) - 95% compaction level



(b) US-75 (RAP) - 90% compaction level



(c) US-75 (RAP) - 85% compaction level

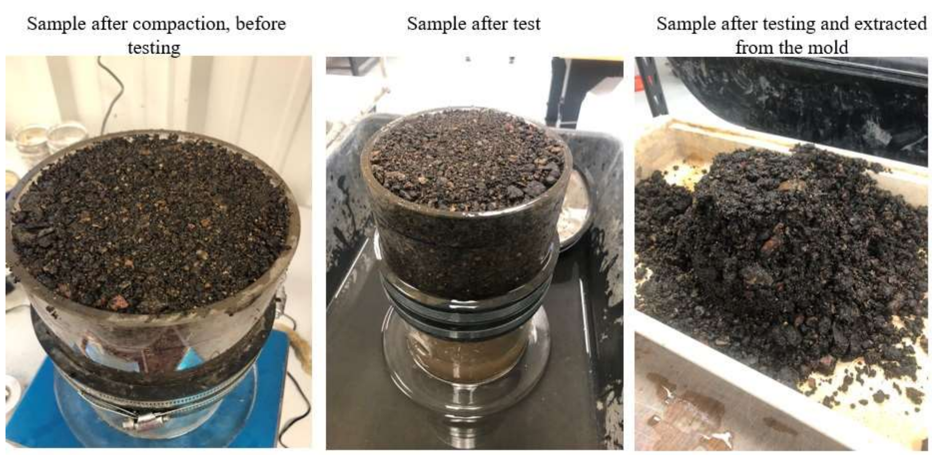


Figure 9. Specimens prepared from US-75 (RAP) at (a) 95, (b) 90, and (c) 85% compaction levels

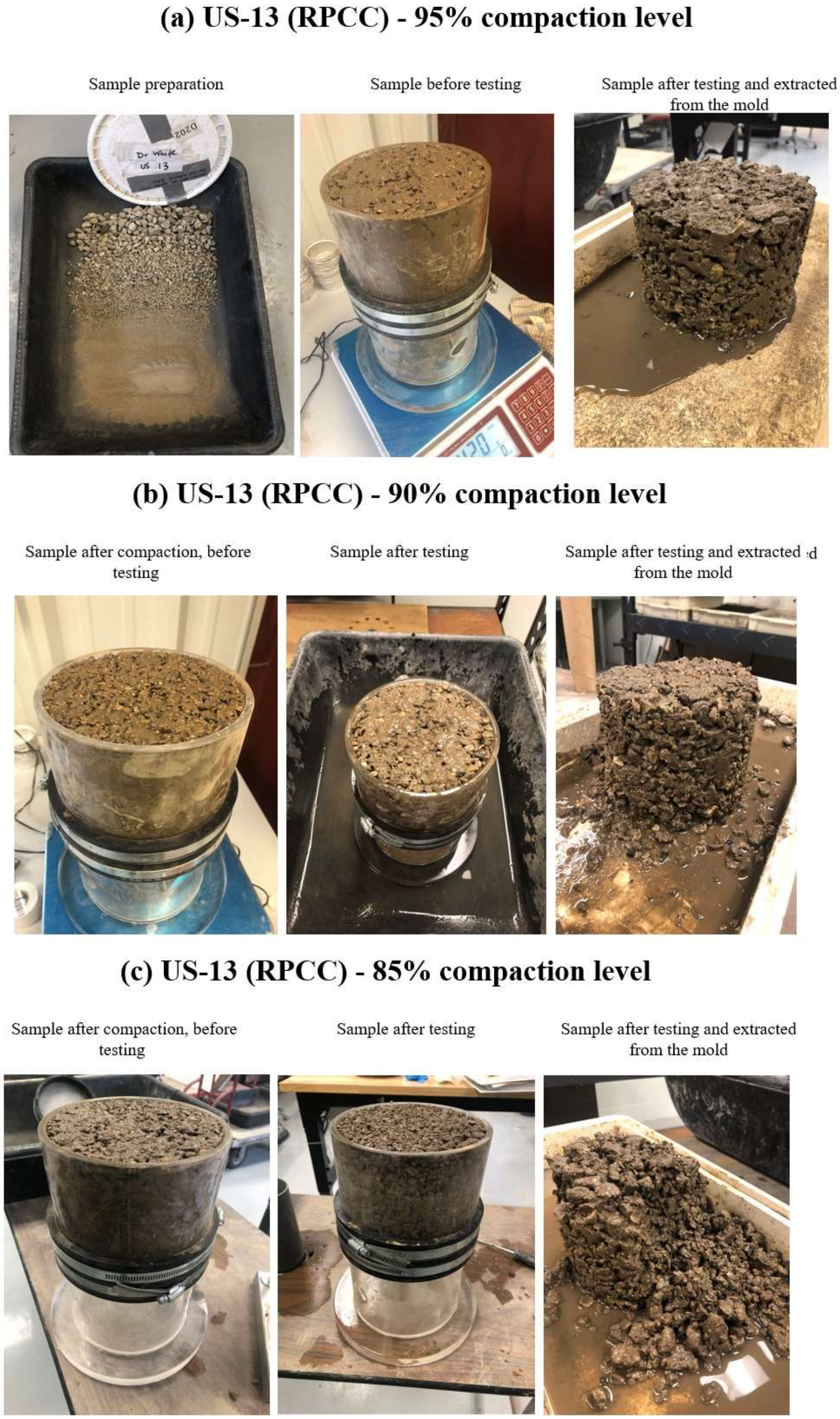


Figure 10. Specimens prepared from US-13 (RPCC) at (a) 95, (b) 90, and (c) 85% compaction levels

Table 5. Hydraulic conductivity test results for subbase and special backfill materials

Compaction level (%)	Permeability, k (inches/sec)				
	US-52 (RAP & RPCC Modified)	US-75 (RAP Special)	US-13 (RPCC Granular)	US-30 (CL Granular)	US-61 (CL Granular)
95	5.8×10^{-4}	0.02	3.2×10^{-3}	0.1	0.06
90	2.6×10^{-3}	0.02	4×10^{-3}	0.4	0.09
85	8×10^{-3}	0.04	4.4×10^{-3}	0.5	0.15

Notes: RAP = reclaimed asphalt pavement; RPCC = reclaimed Portland cement concrete.

Table 6. Hydraulic conductivity test results for subgrade materials

Compaction level (%)	Permeability, k (inches/sec)	
	US-30 (SG Select Soil)	US-61 (SG Select Soil)
95	1×10^{-5}	1.3×10^{-5}
90	5×10^{-5}	2×10^{-4}
85	2×10^{-4}	6×10^{-4}

Notes: SG = subgrade

3.4. Resilient Modulus (M_R) Tests

3.4.1. Methodology

A total of five materials, US-52 (RAP & RPCC), US-75 (RAP), US-13 (RPCC), US-30 (SG), and US-61 (SG), were tested for M_R at varying compaction levels in accordance with AASHTO T 307. 6-in × 6-in × 12-in specimens were prepared in a prismatic mold and compacted by a vibratory hammer in 6 equal lifts (approximately 2-in thickness per lift) to ensure uniform gradation within each compaction layer. Figure 11 shows the materials prepared for each lift of one prismatic specimen. Similar to permeability tests, the specimens were compacted at 95, 90, and 85% compaction levels.

Figure 11. Materials prepared for each lift of one prismatic specimen for resilient modulus (M_R) testing

After compaction, each specimen was attached to a testing cell to assemble the testing equipment. Figure 12 shows the specimen assembly steps for M_R testing.

(a) (b) (c)

Figure 12. Specimen assembly for resilient modulus (M_R) testing: (a) specimen attached to the bottom and top platens, (b) specimen in the testing chamber, and (c) specimen attached to the vertical load actuator

AASHTO T 307 testing programs for base/subbase and subgrade materials were adopted for M_R testing. Table 7 shows the loading sequences used for base/subbase and subgrade materials.

Table 7. Resilient modulus (M_R) testing programs for base/subbase and subgrade materials

Loading Sequence No.	Base/Subbase		Subgrade		Number of load applications
	Confining Pressure σ_c (σ_y) psi	Cyclic Stress, $\Delta\sigma_v$ psi	Confining Pressure σ_c (σ_y) psi	Cyclic Stress, $\Delta\sigma_v$ psi	
0	15	15	6	4	500
1	3	3	6	2	100
2	3	6	6	4	100
3	3	9	6	6	100
4	5	5	6	8	100
5	5	10	6	10	100
6	5	15	4	2	100
7	10	10	4	4	100
8	10	20	4	6	100
9	10	30	4	8	100
10	15	10	4	10	100
11	15	15	2	2	100
12	15	30	2	4	100
13	20	15	2	6	100
14	20	20	2	8	100
15	20	40	2	10	100

3.4.2. Test Results

M_R values were calculated as the average M_R of the last five cycles at each loading sequence. The average M_R values obtained from the tests were used to determine the regression coefficients of the modified universal model [Equation (1)], as recommended by PMED (AASHTO 2002).

$$M_R = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2} \left(\frac{\tau_{oct}}{P_a} + 1\right)^{k_3} \quad (1)$$

where θ is the bulk stress, P_a is the atmospheric pressure, τ_{oct} is the octahedral shear stress, and k_1, k_2, and k_3 are the regression coefficients.

Figure 13, Figure 14, and Figure 15 show M_R test results for US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC), respectively. Test results revealed that the M_R values of US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC) increased with increasing bulk stress due to the stress-hardening behavior of coarse-grained materials (Ceylan et al. 2009; Salour and Erlingsson 2013; Ahmed et al. 2016).

Table 8 shows the model parameters and the summary resilient modulus (SM_R) values for US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC) corresponding to the 6^{th} loading sequence (Table 7). With respect to SM_R, it was concluded that US-75 (RAP) provided the highest values (28, 26, and 25 ksi at 95, 90, and 85% compaction levels, respectively), while US-13 (RPCC) showed the lowest values (18, 17, and 13 ksi at 95, 90, and 85% compaction levels, respectively). Overall, it was concluded that a decrease in the compaction level caused a decrease in the SM_R values for US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC).

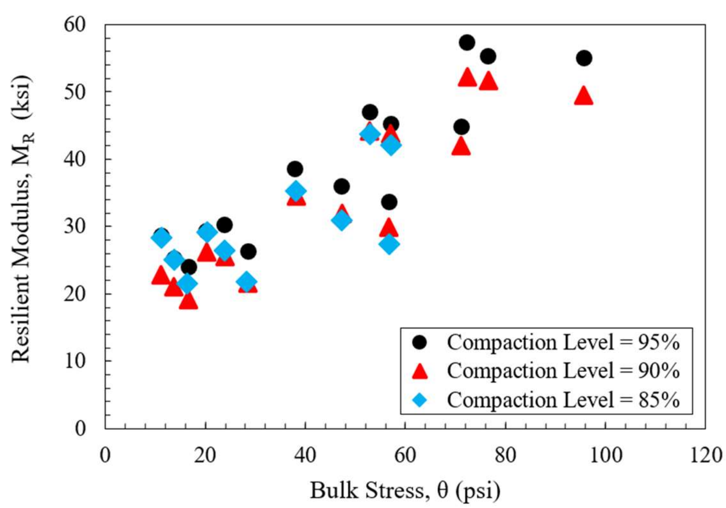


Figure 13. Resilient modulus (M_R) test results for US-52 (RAP & RPCC)

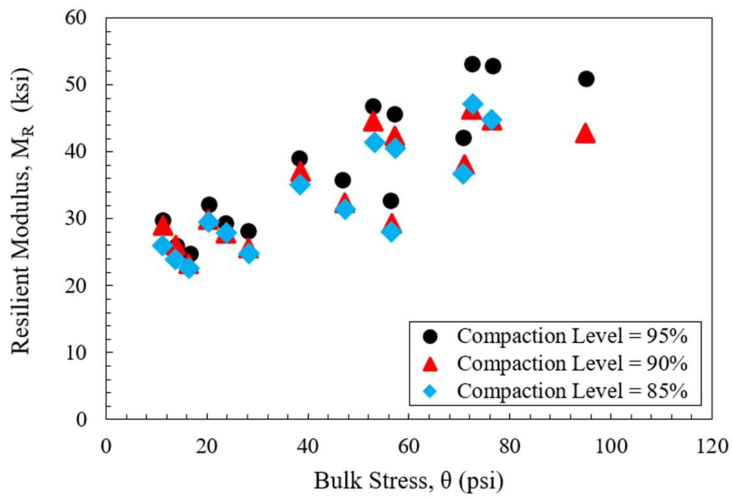


Figure 14. Resilient modulus (M_R) test results for US-75 (RAP)

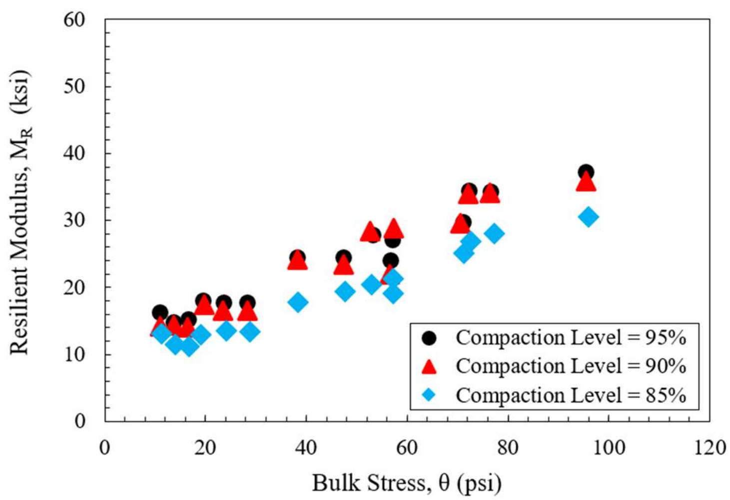


Figure 15. Resilient modulus (M_R) test results for US-13 (RPCC)

Table 8. Model parameters and summary resilient modulus (SM_R) values of subbase materials

Material	**Compaction level (%)**	**Model parameters**			**SM_R (ksi)**
		k_1	**k_2**	**k_3**	
US-52 (RAP & RPCC Modified Subbase)	95	1,774	0.60	-0.64	26
	90	1,479	0.71	-0.78	22
	85	1,565	0.62	-0.72	22
US-75 (RAP Special Backfill)	95	1,912	0.54	-0.70	28
	90	1,932	0.49	-0.81	26
	85	1926	0.53	-1.08	25
US-13 (RPCC Granular Subbase)	95	1,022	0.55	-0.27	18
	90	980	0.63	-0.45	17
	85	739	0.57	-0.12	13

RAP = reclaimed asphalt pavement; RPCC = reclaimed Portland cement concrete.; SM_R = M_R corresponding to the 6th loading sequence (Table 6).

Figure 16 and Figure 17 show M_R test results for US-30 (SG) and US-61 (SG), respectively. Test results showed that the M_R values of US-30 (SG) and US-61 (SG) decreased with increasing bulk stress due to the stress-softening behavior of fine-grained materials (Ceylan et al. 2009; Salour and Erlingsson 2013; Ahmed et al. 2016).

Table 9 shows the model parameters and the SM_R values for US-30 (SG) and US-61 (SG) corresponding to the 13^{th} loading sequence (Table 6). In terms of SM_R, it was concluded that US-30 (SG) yielded higher values (12, 11, and 9 ksi at 95, 90, and 85% compaction levels) than US-61 (SG) (9, 7, and 8 ksi at 95, 90, and 85% compaction levels). Similar to the previously observed trend for US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC), it was concluded that a decrease in the compaction level caused a significant reduction in the SM_R values for US-30 (SG) and US-61 (SG).

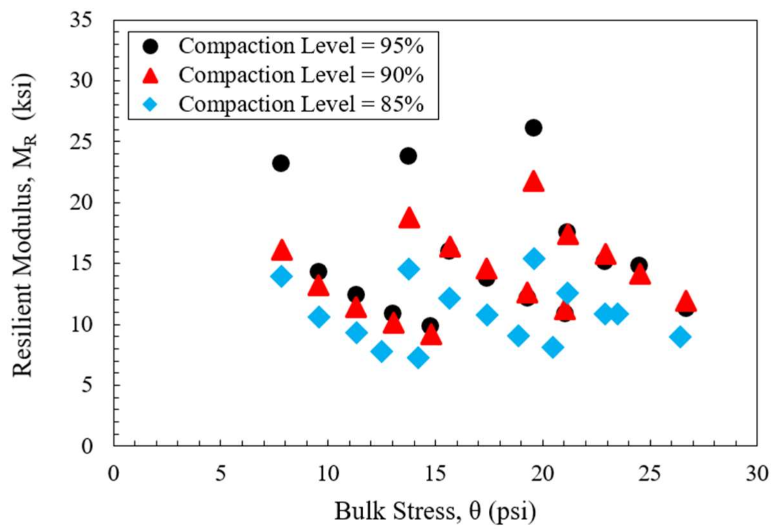


Figure 16. Resilient modulus (M_R) test results for US-30 (SG)

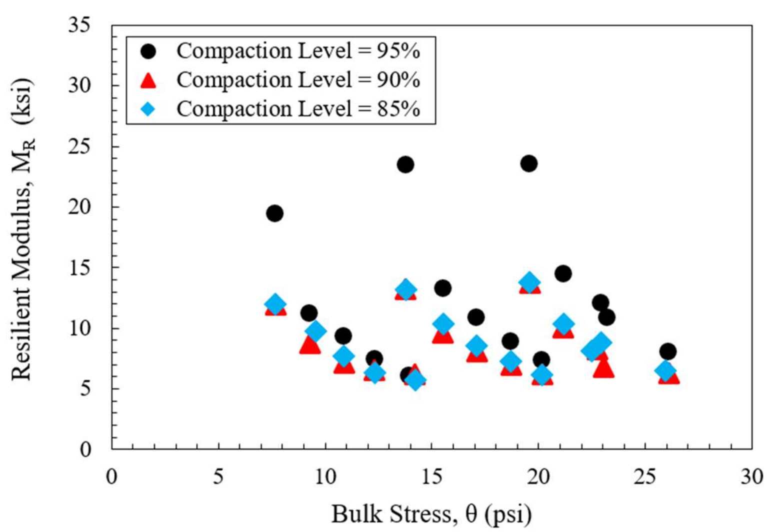


Figure 17. Resilient modulus (M_R) test results for US-61 (SG)

Table 9. Model parameters and summary resilient modulus (SM_R) values of subgrade materials

Material	Compaction level (%)	Model parameters			SM_R (ksi)
		k_1	k_2	k_3	
US-30 (SG)	95	2,215	0.26	-5.34	12
	90	1,594	0.37	-3.63	11
	85	1,215	0.19	-3.69	9
US-61 (SG)	95	2,213	0.29	-7.71	9
	90	1,114	0.15	-4.9	7
	85	1,139	0.14	-4.77	8

SG = subgrade; SM_R = M_R corresponding to the 13th loading sequence (Table 6).

4. CONCLUSIONS

In this report, the results of sieve analyses and specific gravity, Atterberg limits, standard Proctor compaction, permeability, and resilient modulus (M_R) tests are presented for the materials collected from 5 counties in the State of Iowa [Dubuque County (US-52), Plymouth County (US-75), Linn County (US-13), Tama County (US-30), and Des Moines County (US-61)]. These materials were a mixture of reclaimed asphalt pavement (RAP) and reclaimed Portland cement concrete (RPCC) materials (modified subbase from US-52), a RAP material (special backfill from US-75), an RPCC material (granular subbase from US-13), crushed limestone aggregates (referred to as Crushed Limestones – granular subbases from US-30 and US-61), and subgrade (SG) materials (from US-30 and US-61).

Dry & wet sieve analyses and specific gravity and Atterberg limits tests were performed to classify these materials based on their index properties. Then, standard Proctor compaction tests were conducted to determine the optimum moisture content (OMC) and maximum dry unit weight (MDU) values of these materials. Based on standard Proctor compaction test results, a series of permeability and M_R tests were performed.

Hydraulic conductivity tests were conducted on all materials at 95, 90, and 85% compaction levels to see the effect compaction on permeability (k). Test results showed that a decrease in the compaction level caused an increase in the k values. However, this reduction in drainage characteristics was not as significant and impactful compared to the reduction in stiffness values of the materials at lower compaction levels. Open graded materials (US-30 (CL) and US-61 (CL)) had the highest k values at each compaction level.

M_R tests were performed on US-52 (RAP & RPCC), US-75 (RAP), US-13 (RPCC), US-30 (SG), and US-61 (SG) at 95, 90, and 85% compaction levels to see the effect of compaction on M_R. Overall, test results showed that a decrease in the compaction level caused a significant decrease in the SM_R values. While the M_R values of US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC) increased with increasing bulk stress due to the stress-hardening behavior of coarse-grained materials, the M_R values of US-30 (SG) and US-61 (SG) decreased with increasing bulk stress due to the stress-softening behavior of fine-grained materials. Among US-52 (RAP & RPCC), US-75 (RAP), and US-13 (RPCC), US-75 (RAP) provided the highest SM_R values, while US-13 (RPCC) showed the lowest SM_R values. In addition, US-30 (SG) yielded higher SM_R values than US-61 (SG).

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