Boudreau Engineering, Inc.
Pavement Design, Evaluation & Materials Consultants

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Subject: Laboratory Research – Executive Report
URETEK Deep Injection (UDI) Process
Unbound Pavement Base Layers
BEI Project No. 11-033

Dear Dr. Brown:

Boudreau Engineering, Inc. (BEI), in association with Testing, Engineering and Consulting Services, Inc. (TEC) has completed the Phase 1 Test Plan. This executive report provides a summary of this work.

Project Approach:

In order to evaluate the effectiveness of the URETEK Deep Injection (UDI) process, fundamental properties of materials were essential to understand. We required knowledge of density, strength and expansive force properties of the injection product (expanding urethane foam), which was explored first. The 2-part urethane was evaluated in both a free-rise and restrained (confined) curing condition in order to document these properties.

Once the urethane products were reasonably understood, treatment with various geo-materials commonly used as base layers in flexible and rigid pavement systems were explored. A testing matrix was established in order to evaluate the effectiveness of the UDI process using comparisons between untreated and treated test specimens. Two tests, both of which are useful to characterize performance of pavement layers, were selected, and are summarized in the following paragraphs.

The *resilient modulus test (AASHTO T307-99)* is used to characterize the stiffness of the layered material, and is used in several design methodologies (notably the AASHTO 1993 Pavement Design Guide as well as the new M-E PDG) for the structural design of pavements. This test consists of measuring the stress-strain response of a material as it is subjected to a specified array of vertical and horizontal stress. The vertical stress is applied to a triaxial test specimen and the recoverable deformation is recorded. The relationship of stress/strain is the resilient modulus ($M_r = \sigma/\varepsilon$). The lower the strain at a given vertical stress, the stiffer the material (higher resilient modulus).

The *repeated-load permanent deformation test (NCHRP598)* is quite similar to the resilient modulus test; however, more cycles of vertical stress at higher magnitudes are applied to the test specimen. This test is considered a torture test, and materials capable of withstanding higher stresses and more applications are considered to be capable of resisting rutting behavior.

Material Selection:

<u>Polymers</u>: Fundamental properties (density, strength, and expansive force) were established for two URETEK polyurethane products during this study. They were:

1) URETEK 486 STAR 4 pcf free-rise density (Regular formulation), and
2) URETEK 486 STAR 4 pcf free-rise density (Green Dot formulation).

<u>Geo-materials</u>: Three geo-materials were selected for this study; (1) a graded aggregate base, or GAB, (2) a 57 stone, and (3) a natural sand. Following discussions with personnel from the Alabama Department of Transportation (ALDOT), it was decided to use a graded aggregate base (GAB) material produced by Wade Sand & Gravel-East Thomas Quarry near Birmingham, Alabama. This material was selected primarily because of troubles[1] encountered during the construction of Corridor X. In order to expedite construction, ALDOT elected to treat the GAB with cement to overcome these difficulties, again reported as compaction issues. The 57 stone and natural sand products were conveniently selected from stockpile sources at a local concrete readi-mix plant in Carrollton, Georgia. The selected geo-materials are shown in Photo 1.

Photo 1 ï Geo-Materials (l-r: GAB, Sand, #57 stone)

Testing and Results

<u>Polymers</u>: The purpose of this testing was to establish fundamental properties (density, compressive strength, and expansive force) for the two URETEK polyurethane products under controlled laboratory conditions. URETEK 486 STAR 4 pcf free-rise density (Regular formulation) and URETEK 486 STAR 4 pcf free-rise density (Green Dot formulation) were selected for this study due to their high volume usage in the field. Visual observations of the reactions and properties were also noted throughout the testing process. Samples for density and compressive strength were fabricated by two methods: confined and unconfined (or free rise). Testing was also performed on samples fabricated using the same equipment regularly used in the field.

note 1: related to compaction issues

Samples for compressive strength were fabricated using 50 ml centrifuge tubes (Photo 2).

Photo 2 ï Centrifuge Tubes for Molding

These tubes were then either capped or left open for the reactions to take place, and allowed to cure for 24 hours in the centrifuge tubes. A detailed description of the mixing, molding, curing, and test specimen preparation methods is provided in a separate report. Test results for density, compressive strength, and expansive forces are reported in Tables 1, 2 and 3, respectively.

Table 1 ï Specimen Properties

Formulation (Condition)	Specimen ID	Height (in)	Diameter (in)	Weight (g)	Density (pcf)
Regular - Laboratory (Confined)	1	1.872	1.028	4.577	11.23
	2	1.971	1.033	5.514	12.74
	3	1.971	1.036	5.637	12.95
	4	1.847	1.033	5.529	13.62
	Average	**1.915**	**1.032**	**5.314**	**12.63**
Regular - Laboratory (Free Rise)	1	3.468	1.999	15.403	5.40
	2	1.768	2.200	9.947	5.64
	3	2.970	2.000	13.526	5.53
	4	2.860	2.000	13.006	5.52
	Average	**2.767**	**2.050**	**12.970**	**5.52**
Green Dot - Laboratory (Confined)	1	1.988	1.020	5.557	13.05
	2	1.991	1.033	5.148	11.77
	3	2.027	1.030	5.362	12.10
	4	1.963	1.026	5.564	13.08
	Average	**1.992**	**1.027**	**5.408**	**12.50**
Green Dot - Laboratory (Free Rise)	1	2.775	1.999	11.926	5.22
	2	2.023	1.994	9.196	5.55
	3	2.320	2.000	10.821	5.66
	4	1.540	2.000	7.427	5.85
	Average	**2.164**	**1.998**	**9.843**	**5.57**
Regular - Field (Free Rise)	1	2.400	2.340	15.501	5.72
	2	2.900	2.320	19.974	6.21
	3	3.490	2.274	24.460	6.58
	Average	**2.930**	**2.311**	**19.979**	**6.17**

Table 2 ï Compressive Strength

Formulation (Condition)	Specimen ID	Diameter *(in)*	Area *(in2)*	Yield Load *(lb)*	Peak Load *(lb)*	Stress at Yield *(psi)*	Compressive Strength *(psi)*	Compressive Modulus *(psi)*
Regular - Laboratory (Confined)	1	1.028	0.830	178	215	214	259	10,944
	2	1.033	0.837	175	315	208	376	9,914
	3	1.033	0.837	223	356	266	426	14,124
	4	1.036	0.842	213	306	252	364	14,455
	Average	**1.032**	**0.837**	**197**	**298**	**235**	**356**	**12,359**
Regular - Laboratory (Free Rise)	1	2.000	3.142	155	234	49	75	3,419
	2	2.000	3.142	186	253	59	81	3,168
	3	1.994	3.121	204	319	65	102	1,943
	4	1.978	3.073	177	341	58	111	1,930
	Average	**1.993**	**3.119**	**181**	**287**	**58**	**92**	**2,615**
Green Dot - Laboratory (Confined)	1	1.020	0.816	131	232	161	285	8,146
	2	1.033	0.837	110	201	131	240	6,051
	3	1.023	0.822	110	172	133	210	6,493
	4	1.026	0.826	130	262	158	317	8,625
	Average	**1.025**	**0.825**	**120**	**217**	**146**	**263**	**7,329**
Green Dot - Laboratory (Free Rise)	1	2.000	3.142	185	223	59	71	3,089
	2	2.000	3.142	230	243	73	77	2,440
	3	2.000	3.142	195	235	62	75	2,828
	4	2.000	3.142	175	233	56	74	3,469
	Average	**2.000**	**3.142**	**196**	**233**	**62**	**74**	**2,956**
Regular - Field (Free Rise)	1	2.340	4.301	405	937	94	218	4,693
	2	2.320	4.227	350	497	83	118	4,353
	3	2.274	4.060	302	395	74	97	3,947
	Average	**2.311**	**4.196**	**352**	**609**	**84**	**144**	**4,331**

Table 3 ï Expansive Force

Formulation	Specimen ID	Diameter *(in)*	Area *(in2)*	Peak Expansive Force *(lbs)*	Peak Expansive Pressure *(psi)*
Regular	1	1.05	0.87	26.9	31.1
	2	1.05	0.87	26.2	30.3
	3	1.05	0.87	26.5	30.6
	4	1.05	0.87	26.7	30.8
	Average	**1.05**	**0.87**	**26.6**	**30.7**
Green Dot	1	1.05	0.87	23.9	27.6
	2	1.05	0.87	24.7	28.5
	3	1.05	0.87	24.6	28.4
	4	1.05	0.87	24.2	27.9
	Average	**1.05**	**0.87**	**24.3**	**28.1**

Visual Observations and Data Interpretation

- The Regular formulation was more exothermic than the Green Dot formulation.
- The reaction time and rate of the Green Dot formulation is faster than the Regular formulation.

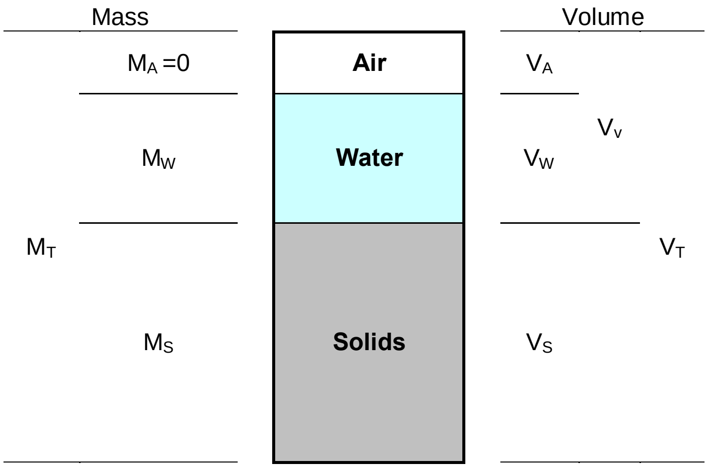
- The Green Dot formulation exhibits an elongated cell structure as compared with the Regular formulation.
- In comparison to field samples, the laboratory samples have significantly larger void structure. This could be attributed to the introduction of air into the mixture during field application by the use of a jet nozzle.
- The Regular formulation exhibits an initial expansion followed by a slight secondary expansion, most likely due to the elevated temperature produced by the reaction. This secondary reaction occurs very close to the time that the material is reaching final set time, thus tends to create voids and large horizontal gaps/delaminations in the material as a whole in the free-rise condition. The secondary reaction occurs near the source of the initial mixture so by the time the top begins to set the bottom is still reacting. **The cured polymer matrix is more uniform when curing is confined**.
- The confined density is roughly 2.25 times that of the free-rise density for both formulations. The polymer matrix is much more uniform (air voids without horizontal voiding/delamination) for the confined condition when compared to the free-rise condition (Table 1 data).
- The compressive strength is roughly 3.6-3.9 times greater for the specimens confined during the expansion process, compared to those allowed free-rise conditions (Table 2 data).
- These materials would expect to produce roughly 30psi of expansive pressure (4,320psf). These forces can easily densify materials in a lateral direction, or lift significant overburden loads or pavement structures (Table 3 data).

Geo-materials: In order to evaluate the effectiveness of UDI foam treatment, comparisons must be made with benchmark tests. Benchmark tests for this study were established using each of the three geo-materials in their natural, unmodified state (Control) other than mechanical stabilization, or compaction. After the Control benchmark data was established, the materials placed at similar densities to the benchmarks were treated with polyurethane (only the Regular formulation was pursued in this portion of the study), prepared for testing, and tested. Thus, comparisons can readily be made on whether the treatment has an effect on any of these three geo-materials. A detailed description of the test specimen preparation methods is provided in a separate report.

Other than triplicate testing of the GAB Control benchmark (3 replicate specimens prepared for both the T307 resilient modulus test as well as the NCHRP598 permanent deformation test), all other tests were conducted on single specimens due to budget constraints.

The diagram on the next page shows the composition of a traditional geo-material, which is comprised of solids, liquid (water), and gas (air). Common physical properties, such as moisture content, density, void ratio, porosity, specific gravity, and saturation are all derivatives of this phase composition. Particular to this work, it is understood that the polyurethane product infiltrates the void structure (displacing air and most of the free water) to create a bound matrix. If the polyurethane product completely infiltrates the voids occupied by air and water, the volume containing free water (62.4pcf) and air (0pcf) would be replaced with an equal volume of expanded foam (5.5pcf free-rise to 12.5pcf confined, according to Table 1 data).

3-Phase Composition



<u>Fundamental Properties</u>

$M_S = M_T - M_W$

Wet Density = M_T / V_T

Dry Density = M_S / V_T

Moisture Content (w) = M_W / M_S x100%

Porosity (n) = V_V / V_T

Void Ratio (e) = V_V / V_S

Specific Gravity of Solids (G_S) = $(M_S * V_W) / (V_S * M_W) = M_S / (V_S * \gamma_W)$

Unit Weight of Water (γ_W) = 62.4 pcf

Resilient Modulus (AASHTO T307). The resilient modulus test was conducted in accordance with procedures contained within the referenced test standard. The specimen is subjected to a series of load pulses at a variety of axial stresses and confining pressures (15 specific combinations of stress levels), and recoverable deformation resulting from these load pulses are measured. Although the test standard specifies a tabular summary of results (as shown in Table 4), this summary is not terribly useful to a pavement designer. Rather, the data is used to fit a constitutive model, where resilient modulus can be predicted for any level of stress the pavement designer wishes to consider in his/her design.

Table 4 ï Summary of AASHTO T307 Test Results

		GAB CONTROL (Rep1)			GAB CONTROL (Rep2)			GAB CONTROL (Rep3)			Treated GAB (Rep1)		
Load Seq	Conf. Press (psi)	Cyclic Stress (psi)	Bulk Stress (psi)	Resilient Modulus (psi)	Cyclic Stress (psi)	Bulk Stress (psi)	Resilient Modulus (psi)	Cyclic Stress (psi)	Bulk Stress (psi)	Resilient Modulus (psi)	Cyclic Stress (psi)	Bulk Stress (psi)	Resilient Modulus (psi)
1	3	2.66	8.66	13,077	2.64	8.64	13,299	2.65	8.65	13,303	2.58	8.58	20,637
2	3	5.42	11.42	14,161	5.38	11.38	15,200	5.40	11.40	14,995	5.21	11.21	21,400
3	3	8.32	14.32	15,647	8.20	14.20	17,044	8.21	14.21	16,613	7.87	13.87	22,639
4	5	4.55	14.55	17,231	4.49	14.49	17,088	4.50	14.50	17,174	4.38	14.38	23,290
5	5	9.08	19.08	20,159	9.17	19.17	20,593	9.17	19.17	20,374	8.86	18.86	25,439
6	5	13.73	23.73	22,791	13.71	23.71	22,840	13.68	23.68	22,107	13.44	23.44	27,379
7	10	9.13	29.13	28,654	9.06	29.06	26,761	9.16	29.16	26,511	8.97	28.97	29,773
8	10	18.39	38.39	34,359	18.28	38.28	32,521	18.30	38.30	31,011	18.03	38.03	33,489
9	10	27.51	47.51	37,990	27.40	47.40	35,108	27.29	47.29	33,511	27.12	47.12	34,896
10	15	9.25	39.25	33,863	9.11	39.11	30,318	9.17	39.17	30,509	9.02	39.02	31,476
11	15	13.70	43.70	37,695	13.71	43.71	33,230	13.77	43.77	33,101	13.58	43.58	33,652
12	15	27.50	57.50	46,590	27.40	57.40	42,137	27.39	57.39	39,768	27.11	57.11	37,780
13	20	13.79	53.79	43,946	13.75	53.75	38,499	13.76	53.76	37,892	13.57	53.57	36,457
14	20	18.38	58.38	48,188	18.38	58.38	42,477	18.32	58.32	40,656	18.12	58.12	38,426
15	20	36.63	76.63	58,077	36.47	76.47	51,336	36.44	76.44	48,083	36.16	76.16	41,231

		Sand-CONTROL			Treated Sand			57 stone-CONTROL			Treated 57 stone		
Load Seq	Conf. Press (psi)	Cyclic Stress (psi)	Bulk Stress (psi)	Resilient Modulus (psi)	Cyclic Stress (psi)	Bulk Stress (psi)	Resilient Modulus (psi)	Cyclic Stress (psi)	Bulk Stress (psi)	Resilient Modulus (psi)	Cyclic Stress (psi)	Bulk Stress (psi)	Resilient Modulus (psi)
1	3	2.63	8.63	7,722	2.59	8.59	27,818	2.60	8.60	8,212	2.56	8.56	12,401
2	3	5.33	11.33	8,888	5.33	11.33	34,035	5.36	11.36	9,512	5.18	11.18	13,626
3	3	7.92	13.92	9,593	8.08	14.08	39,511	8.15	14.15	10,732	7.91	13.91	14,848
4	5	4.58	14.58	11,231	4.44	14.44	35,811	4.53	14.53	11,901	4.37	14.37	14,849
5	5	9.15	19.15	12,190	9.01	19.01	44,823	8.97	18.97	13,529	8.88	18.88	16,762
6	5	13.40	23.40	12,197	13.64	23.64	51,431	13.56	23.56	14,331	13.52	23.52	18,503
7	10	9.17	29.17	16,080	9.06	29.06	50,986	9.10	29.10	17,607	9.02	29.02	20,143
8	10	18.24	38.24	17,413	18.24	38.24	62,462	18.37	38.37	19,545	18.08	38.08	23,014
9	10	26.62	46.62	16,831	27.37	47.37	69,369	27.59	47.59	20,669	27.32	47.32	24,132
10	15	9.23	39.23	18,230	9.09	39.09	54,805	9.15	39.15	20,176	9.08	39.08	22,111
11	15	13.86	43.86	19,325	13.67	43.67	61,172	13.73	43.73	21,363	13.57	43.57	23,558
12	15	27.44	57.44	21,125	27.38	57.38	73,621	27.71	57.71	24,152	27.29	57.29	26,204
13	20	13.92	53.92	21,337	13.69	53.69	65,543	13.78	53.78	23,799	13.61	53.61	25,484
14	20	18.54	58.54	22,383	18.25	58.25	70,567	18.41	58.41	25,008	18.15	58.15	26,814
15	20	36.60	76.60	24,383	36.54	76.54	82,813	36.94	76.94	27,900	36.50	76.50	28,571

There are several constitutive models that can be used to predict the resilient modulus. Each considers the stress regime (vertical and horizontal) as independent variables (either separately ï S_c = cyclic stress and

S_3 = confining pressure, or combined - θ = bulk stress estimated as $S_c + 3S_3$ and τ_{oct} = octahedral shear stress estimated as S_c x $2^{0.5}/3$), and resilient modulus (M_r) as the dependent variable. These take the following forms:

SHRP Model: $M_r = K1(S_C)^{K2}(S_3)^{K5}$

Bulk Stress Model: $M_r = K1\ (\theta)^{K2}$

Universal Model: $M_r = K1p_a\ (\Theta/p_a)^{K2}\ ((\tau_{oct}/p_a)+1)^{K3}$

Each model produces widely varied regression constants and coefficients, as seen in Table 5. However, these models predict resilient modulus similarly for any given stress regime. It is the data from these predictive models that a pavement designer will utilize for a particular pavement design.

Table 5 ï Summary of Constitutive Model Parameters

Model	Parameter	GAB-CONTROL (Rep1)	GAB-CONTROL (Rep2)	GAB-CONTROL (Rep3)	Treated GAB (rep1)
SHRP [1]	K1	5,782	6,775	6,960	13,974
	K2	0.23733	0.25316	0.21732	0.13573
	K5	0.46805	0.35318	0.37134	0.19869
	R^2	1.00	1.00	1.00	0.99
Bulk Stress [2]	K1	2,494	3,339	3,491	9,580
	K2	0.71787	0.61776	0.59734	0.33604
	R^2	0.99	0.99	1.00	0.99
Universal [3]	K1	1,179	1,161	1,183	1,591
	K2	0.72982	0.57918	0.59765	0.32161
	K3	-0.04741	0.15345	-0.00126	0.05781
	R^2	0.99	1.00	1.00	0.99

Model	Parameter	Sand-CONTROL	Treated Sand	57 stone-CONTROL	Treated 57 stone
SHRP [1]	K1	4,661	17,291	4,709	8,059
	K2	0.12482	0.29513	0.18668	0.16880
	K5	0.40373	0.18337	0.38136	0.23492
	R^2	0.99	1.00	1.00	1.00
Bulk Stress [2]	K1	2,485	10,863	2,502	5,243
	K2	0.53176	0.46598	0.56226	0.39718
	R^2	0.98	0.97	0.99	1.00
Universal [3]	K1	763	2,417	808	1,041
	K2	0.63553	0.37504	0.62539	0.40171
	K3	-0.41329	0.36176	-0.24919	-0.01806
	R^2	0.99	0.99	1.00	1.00

1. $M_R = K1(S_c)^{K2}\ (S_3)^{K5}$
2. $M_R = K1(\Theta)^{K2}$
3. $M_R = K1p_a\ (\Theta/p_a)^{K2}\ ((\tau_{oct}/p_a)+1)^{K3}$

For this project, it is useful to plot the predictive modulus in graphical form to compare values, in this case, with and without polyurethane treatment. Figure 1 illustrates the test results in graphical form.

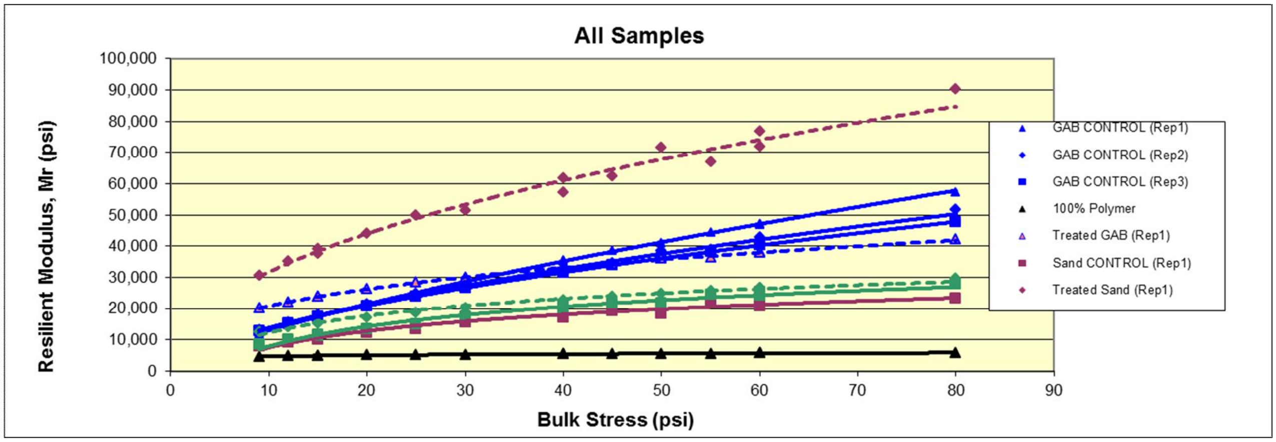


Figure 1 ï Resilient Modulus Predicted by the Universal Model (Based on AASHTO T307 Results).

Discussion of Resilient Modulus Results. Although there are a few constitutive models available for fitting laboratory test data, the data graphically depicted in Figure 1 is from the Universal Model. The Universal Model is the one currently integrated in the M-EPDG.

The graphic shown above (Figure 1) illustrates results of the resilient modulus test (AASHTO T307). This graphic allows a quick comparison between the untreated (Control benchmark) and the treated specimens. **The polyurethane treatment appears to have very little effect on the resilient modulus for the GAB and 57 stone materials; however, it does seem to have a pronounced effect on the natural sand (200-300% improvement).** It is noteworthy to point out the relatively low stiffness of the polyurethane in pure form (black triangles in Figure 1). It is clear that the geo-materialôs structural matrix remains intact following the polyurethane injection, rather than the injection product controlling the structural matrix.

The data can be used to estimate a structural layer coefficient by using the formula provided in the *1993 AASHTO Guide for Design of Pavement Structures* for granular base layers, a_2 (page II-20):

$$a_2 = 0.249*\mathrm{Log}M_R - 0.977 \text{ (Figure 2)}$$

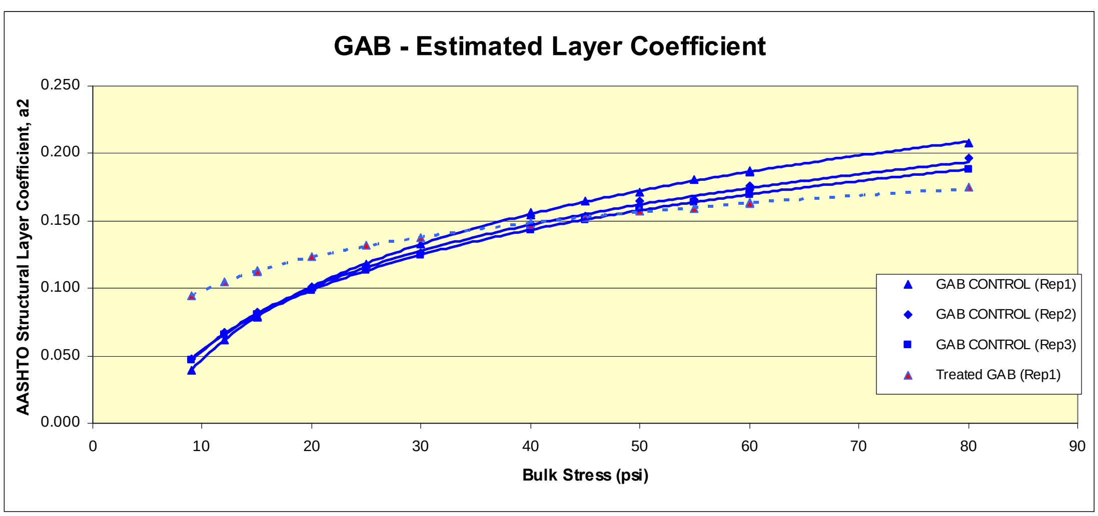


Figure 2 ï Estimated Granular Base Structural Layer Coefficient (GAB materials only).

The GAB material provides a similar level of pavement support with respect to resilient modulus, or derived layer coefficient. As an example, when evaluating the Control versus treated materials at a bulk stress of 40psi, a structural layer coefficient of 0.15 for each condition seems warranted.

An interesting behavior can readily be seen when looking at the results of the quick shear test. The quick shear test is prescribed in AASHTO T307 as a simple shear controlled by rate of axial deformation (1%/minute up to 5% strain) following the 15 stress sequences of the repeated load testing. Figure 3 graphically depicts the results of this test, and clearly demonstrates the positive influence of the polyurethane injection. **The <u>ultimate strength</u> is increased by 500 percent or more and the stiffness (as measured by the secant modulus) is improved by 700 to 1,000 percent for the 57 stone and GAB material, and nearly 8,000 percent for the sand.** It is noted that each of the polyurethane-treated geo-materials tested exceeded the 5,000-lb capacity of the load cell utilized for this test prior to reaching the requisite 5% axial strain level, and consequently the test was intentionally halted.

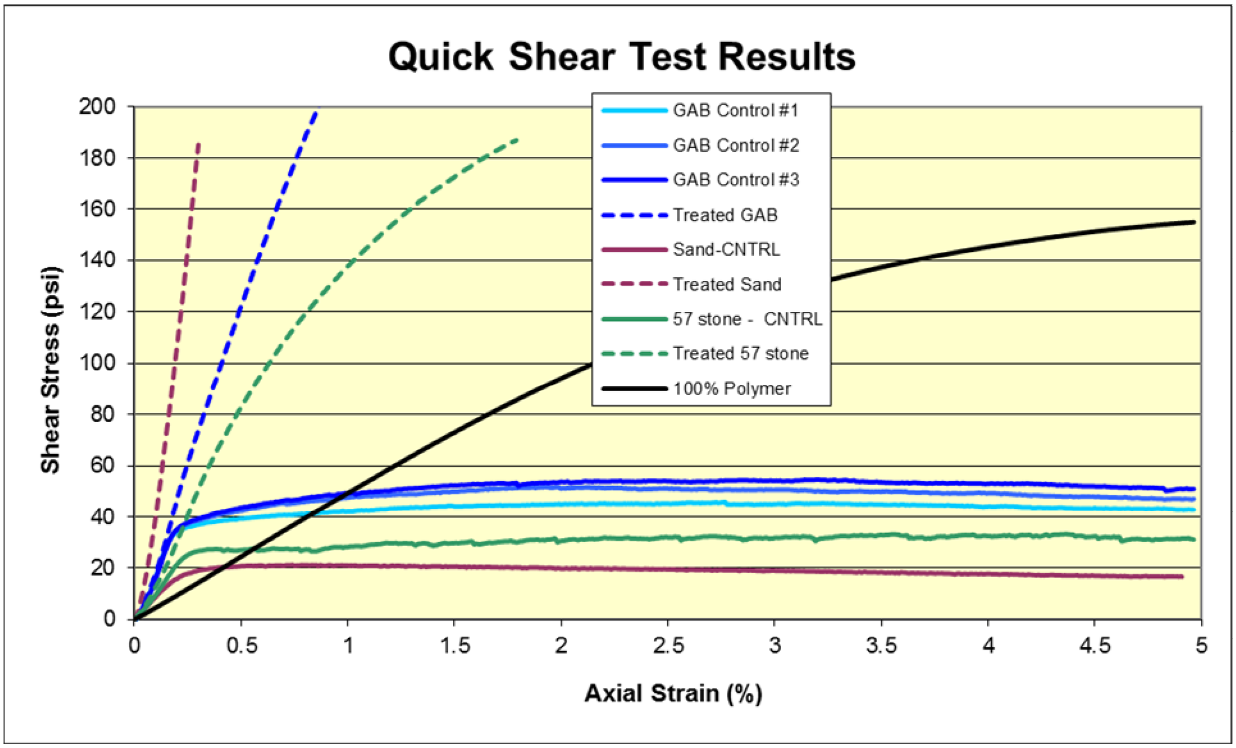


Figure 3 ï Quick Shear (Based on T307 Results).

*Repeated Load Permanent Deformation (NCHRP 598)***.** The permanent deformation test was conducted in accordance with procedures documented in NCHRP Report No. 598. The results are graphically depicted in Figure 4 shown on the next page. The NCHRP598 test specifies 1,000 cycles of axial load be applied in a step-sequence of axial stress (10, 20, 40, 60, 80, 100, 120, 140, 160, and 180 psi). This translates into 10,000 cycles of loading to complete the test. During the test, axial strain is monitored. If an axial strain of 10 percent is reached prior to the completing the regimen of 10,000 cycles, the specimen is considered to have failed, and the test is halted. This test is intended to be a ótortureô test for aggregate base layers.

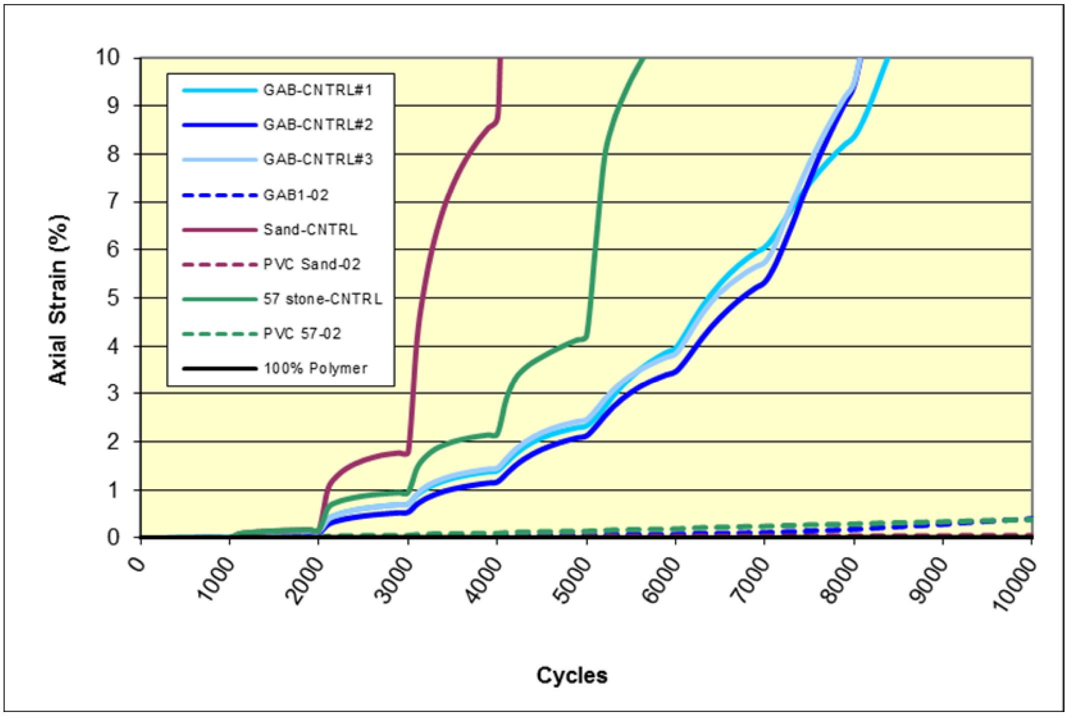


Figure 4 ï Repeated Load Permanent Deformation (Based on NCHRP598 Results).

Discussion of Repeated Load Permanent Deformation Results. Each of the three Control benchmarks established for the 3 geo-materials were unable to survive the test. However, each of the three geo-materials withstood the rigors of the NCHRP598 test (and exhibited only minor amounts of accrued axial strain) following injection of the Regular formulation. **This indicates polyurethane injection promotes a very high resistance to strains. These strains often produce pavement distresses such as rutting (flexible pavements) and faulting (rigid pavements).**

Conclusions

The following conclusions can be drawn from this study:

1. There appears to be very little difference between the Regular and Green Dot formulations with respect to density and expansive forces. There does appear to be a difference between the 2 formulations with respect to compressive strength. Specifically, the Regular formulation exhibited greater compressive strength than the Green Dot formulation in both the confined and unconfined (free rise) condition (Table 2).
2. The Regular formulation is more exothermic than the Green Dot formulation. The reaction time and rate of expansion of the Green Dot formulation is faster than the Regular formulation.
3. The polyurethane treatment appears to have little effect on the **<u>resilient modulus</u> (stiffness)** for the GAB and 57 stone materials; however, it does seem to have a **pronounced effect for the natural sand (200 to 300% improvement)**. These stiffness properties are for very small induced axial strains, which contribute to the overall pavement structure.
4. **The <u>ultimate strength</u> is increased by 500%** or more and the stiffness modulus (as measured by the secant modulus) is improved by 700 to 1000% for the GAB and 57 stone materials, and nearly 8000% for the natural sand.
5. **Polyurethane-injection of traditional geo-materials used as base layers provides significant benefit to a pavement system by increasing the injected layer's ability to resist large vertical strains**, as indicated by the Quick Shear portion of the resilient modulus test (Figure 3) and the repeated load permanent deformation test (Figure 4). This benefit will contribute positively in the injected layerôs ability to resist deformations that contribute to surface rutting (flexible pavements) and faulting (rigid pavements).
6. **The stiffness of the pure polymer, as measured by the resilient modulus, is about 5,000psi** (Figure 1), which is approximately that of a relatively soft to firm subgrade soil.

If you have any questions or require additional information, please contact us at your earliest convenience at 404.388.1137.

Sincerely,

Richard L. Boudreau, P.E.
Director of Engineering

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