Construction and Performance of Inverted Pavements in Georgia

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ABSTRACT

Inverted Pavement (IP) is an innovative highway pavement design where the rigidity of the lower, supporting layers is significantly greater than that of the upper, structural layers. Developed by South Africa in the early 1970's, this design is being investigated for various roadway applications in the United States, while variations of it have been used since the 1980's. By utilizing native crushed stone and less imported bitumen, South Africa has reported a 20-25% cost savings compared with conventional concrete and/or bituminous pavements. After being introduced to the IP design, Georgia Department of Transportation (GDOT) assisted the Georgia Construction Aggregates Association with construction of an IP test section on a private quarry haul road. Based on excellent performance of the test section over 10 years, GDOT constructed its own test section on a new bypass road near LaGrange, Georgia. The successful completion of the project and the cost savings therein prompted GDOT to allow IP as an optional construction method on future projects.

INTRODUCTION

Inverted Pavement (IP) is an innovative highway pavement design where the rigidity of the lower, supporting layers is significantly greater than that of the upper, structural layers. Developed by South Africa in the early 1970's, this design is also referred to as G1-Base, Inverted Base, Sandwich Pavement, and Upside Down Pavement. Depending upon traffic loading, typical design thickness of an IP ranges from 32 to 48 in. (800-1200 mm). The process begins with 6-12 in. (150-300 mm) of stabilized subbase, followed by 6-12 in. of cement-treated aggregate base, and then by 4-6 in. (100-150 mm) of unbound graded aggregate base, with a thin layer of bituminous mix (18-50 mm) completing the design. Since the 1970's, South Africa has used IP as its primary pavement structure for both local and highway systems (*1*). IP variants have also been successfully used on rural routes, state routes, and interstate systems in the United States since the 1980's (*2*,*3*).

South African Experience

IP was developed in South Africa to reduce pavement costs by utilizing (1) abundant native aggregate products and (2) less imported bitumen. South Africa has reported a 20-25% cost savings compared with conventional portland cement concrete (PCC) or hot mix asphalt (HMA) pavements. To confirm the performance of the innovative pavement, South Africa conducted extensive full-scale accelerated pavement research using a Heavy Vehicle Simulator. It was determined that the IP roadways actually provided better structural performance than conventional pavement systems. Most importantly, construction costs were reduced by the need for only a thin asphaltic surface overlay of 0.75-2 in. (18-50 mm) (*1*).

Based on a 10-year research period, the South African Pavement Design Catalogue listed IP as having a bearing capacity of 1-50 million Equivalent Standard Axle Loads (ESAL's), assuming effective surface maintenance over the design period and considering climate. Numerous examples exist in South Africa where IP was used in heavily trafficked roads. The N1 (Ben Schoeman) Freeway between the metropolitan areas of Johannesburg and Pretoria, with an average rainfall of 25.5 in. (650 mm) per year, carried more than 15 million ESALs over a period of more than 20 years before it was structurally strengthened (*1*).

Technology Transfer to Georgia

In the spring of 1999, GDOT engineers became familiar with IP technology while attending an international transportation symposium in South Africa. In November 1999, GDOT met with the Georgia Construction Aggregate Association (GCAA) to discuss rising construction costs and the need to pursue alternative, cost-effective construction materials and methods. The IP system was introduced, and the GCAA expressed much interest.

The meeting was followed by the construction of an IP test section at the Lafarge Building Materials quarry near Madison, Georgia (Morgan County). GDOT worked closely with GCAA and Lafarge on the design, construction, and testing of the IP test section. Based on the success of the pilot project, as described herein, and due to the rising cost of asphalt cement, GDOT built its own IP test section on the South LaGrange Loop in Troup County. This paper summarizes construction of both the Lafarge quarry road and South LaGrange Loop test sections. Emphasis is on the concept for each test section, construction operations and observations, and performance data as available. This data is being provided to support IP as a potentially viable alternative pavement choice for roadways in Georgia.

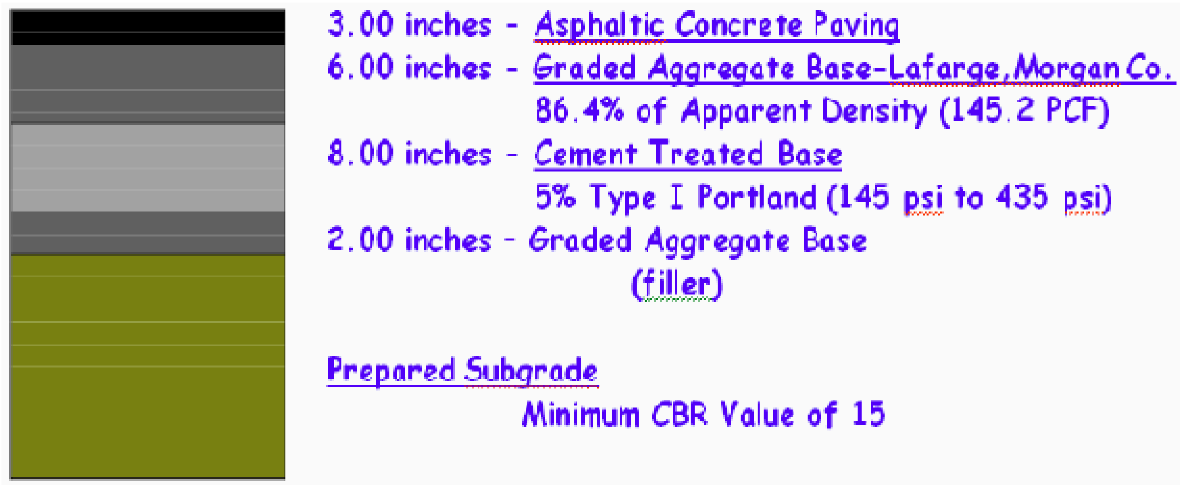
LAFARGE QUARRY TEST SECTION

As above, GDOT chose to assist GCAA with a pilot IP application, following discussion with GCAA in late 1999. An 800-ft. (244 m) test section was constructed using the South African IP process on a new access road at the Lafarge Building Materials quarry near Madison, Georgia (Morgan County). This test section, which was completed in December 2001, served as an excellent pilot because of the (1) loading that the haul road is subjected to each year; and (2) ease of tracking this loading in the test section. As discussed below, the test section utilized guidelines and procedures established by the South African Roads Board. Also, the data collected from those test sections was used to write a special provision (#320) regarding Inverted Pavements in the GDOT specifications. This project is hereafter referred to as the Morgan County Project (MCP).

Explanation of Test Section and IP Cross-Section

The total length of the haul road was approximately 1200 ft. (366 m), which was divided into three 400-ft. (122-m) sections for the pilot project. The entire road required as much as 6 feet (1.8 m) of fill, which consisted of mostly waste aggregate (pit overburden and weathered rock). To ensure that the load carrying capacity of the subgrade met a minimum California Bearing Ratio (CBR) value of 15, 100% granitic aggregate was used in lieu of the poor soil at the quarry. CBR values obtained from the MCP all exceeded 50. An additional 2 in. (51 mm) of graded aggregate base (GAB) was placed so that all three sections would have a consistent subbase.

The first 400 ft. (122 m), beginning at Seven Islands Road, was called the “conventional” section and was completed using 6 in. (150 mm) of compacted surge stone followed by 8 in. (200 mm) of compacted GAB. The remaining 800 ft. (244 m) was divided into two, 400-ft. (122 m) IP test sections. Both IP sections where completed with an 8 in. (200 mm) cement treated base (CTB) layer and 6 in. (150 mm) GAB layer. The only difference between the two IP sections was in the construction of the GAB: the first section was constructed with the “slushing” method (described in the following section) the second section using conventional construction methods. The cross-section for both IP sections on the MCP is shown in Figure 1. Both the conventional and IP sections were overlaid with 3 in. (75 mm) of 19 mm Superpave hot mix asphalt (HMA).



1 in. = 25.4 mm
1 pcf = 16 kg/m^3
1 psi = 0.006985 MPa

FIGURE 1 Inverted Pavement Cross-Section: Morgan Co. Project.

Graded Aggregate Base (GAB) Construction

The GAB construction was the most critical and experimental part of the IP tested on the MCP. The rationale for the different GAB construction methods used in the two 400-ft. (122-m) IP test sections is explained in the following paragraphs. These two sections are hereafter referred to as (1) the South Africa section (the first section, in which "slushing" was used); and (2) the Georgia section (the second, in which conventional methods were used).

In South African practice, the GAB layer is compacted to 86% - 88% of apparent density, otherwise referred to as compacted to *solid particle density*. Research conducted during the MCP showed that 86% of apparent gravity was equivalent to approximately 101% - 106% maximum dry density for a GDOT Group II (granite-gneiss) aggregate. According to information obtained from South Africa, this apparent gravity is only achieved through a process referred to as "slushing." The purpose of slushing is to knit different sized aggregate particles into a firmly interlocked mass. Saturated fines serve as a lubricant in the slushing process, and the volume of voids between aggregate particles diminishes when the fines are expelled to the surface (*1*).

To test this theory, GDOT first obtained samples of GAB from South Africa and conducted extensive testing on the aggregate to determine if it was comparable in mineralogy and gradation to that commonly used in GDOT construction. The results indicated that it would indeed meet GDOT Standard Specification (Section 815) requirements for a Group II GAB. The next step was to determine if slushing was necessary in achieving 86% of apparent gravity or if conventional construction methods could accomplish the same result. Consequently, two 400-ft. (122-m) IP test sections were established on the MCP, with the slushing method being used to compact the GAB in the first.

Using common construction equipment, the GAB was saturated with numerous applications of water and compacted until air bubbles began to form on the surface. Per South African experience, the expelled fines will appear to be coarser at the end of the slushing process than initially, and no air bubbles or movement will be seen behind the wheels of the roller (*1*). The second 400-ft. (122-m) test section was constructed using conventional methods, with the moisture content being maintained at 100% - 120% optimum throughout construction. Testing was conducted using the in-situ, sand cone density method, and results are shown in Table 1. Samples were taken at random locations within the slushing and conventional sections. All compaction tests were determined using an apparent gravity of 168.9 pcf (2706 kg/m^3) and a theoretical maximum dry density of 135.3 pcf (2168 kg/m^3). The optimum moisture was determined by the flame dry method at each test location. As anticipated, 86% of apparent gravity was achieved in both test sections, confirming that slushing was not necessary. The consensus of both GDOT and GCAA was that compacting the GAB on a rigid CTB was most likely the contributing factor.

TABLE 1 IP Density & Apparent Gravity Results: Morgan Co. Project

Sample	In-Place Density (pcf)	% Compaction: Apparent Gravity	% Compaction: Maximum Dry Density (pcf)
Slushing 1	144.9	85.8	104.1
Slushing 2	144.6	85.6	103.2
Slushing 3	145.9	86.4	101.8
Conventional 1	146.7	86.9	104.5
Conventional 2	147.6	87.4	106.5

1 pcf = 16 kg/m^3

Post-Construction Performance Data

A five-year evaluation was conducted on the MCP consisting of calculation of ESAL's, string-line rutting measurements, visual inspection, and falling weight deflectometer (FWD) testing. The results of the evaluation are summarized below. Information on performance to-date is also included in this section. The test section has performed remarkably well for over 10 years, with no maintenance or resurfacing required.

Equivalent Single Axle Loads

Loading data supplied by Lafarge, in tonnage of crushed stone, concrete, and asphalt hauled, indicated that approximately 854,000 ESAL's traversed the MCP during the first five years of its life, or 63.38% of the design ESAL's (*4*). Design life was based on an annual average daily traffic (AADT) of 146 (100% trucks), with an annual growth of 4.5%. A summary of the ESAL's from 2001-2011, based on the annual growth rate, is shown in Table 2. As of March 2011, an estimated 1,139,968 ESAL's had traversed the MCP.

TABLE 2 Equivalent Single Axle Loads, 2001-2011: Morgan Co. Project

<table>
<tr><th rowspan="3"></th><th colspan="7">YEAR</th><th rowspan="3">TOTAL</th></tr>
<tr><th colspan="6">5-Year Evaluation</th><th></th></tr>
<tr><th>2001</th><th>2002</th><th>2003</th><th>2004</th><th>2005</th><th>2006</th><th>2006 - 2011</th></tr>
<tr><td>ESAL's</td><td>2,840</td><td>127,496</td><td>312,676</td><td>119,373</td><td>134,155</td><td>157,215</td><td>286,249</td><td>1,139,968</td></tr>
</table>

Rutting Measurements

Rutting measurements were made from Station 0+50 through Station 18+00 on the MCP on December 3, 2003 and November 13, 2006. Measurements were taken every 50 feet (15 m) along all three sections of the project, as outlined below.

- Sta. 0+00: intersection with Seven Islands Rd.
- Sta. 0+50 - 10+00: conventional haul road section
- Sta. 10+50 - 14+00: South Africa section
- Sta. 14+50 - 18+00: Georgia

Rutting measurements for the conventional section are shown in Table 3, while measurements for the South Africa and Georgia sections are shown in Table 4. In each table, the left number for each station is the 2003 measurement, while the right number is the 2006 measurement.

TABLE 3 Rutting Measurements (in./16), Conventional Haul Road, Morgan Co. Project

Sta. #	15 ft. Left of C/L (2003/2006)	10 ft. Left of C/L (2003/2006)	5 ft. Left of C/L (2003/2006)	Centerline (C/L) (2003/2006)	5 ft. Right of C/L (2003/2006)	10 ft. Right of C/L (2003/2006)	15 ft. Right of C/L (2003/2006)
0+50	0/0[1]	5/5	0 / 8	0/0	0/1	4/4	0/0
1+00	0/16+	16/16	14/14	0/0	0/0	3/3	0/0
1+50	0/0	0/0	0/ 0	0/0	0/0	0/0	0/2
2+00	0/0	0/0	0/ 0	0/0	0/0	0/0	0/0
2+50	0/0	0/2	0/0	0/0	0/0	0/0	0/0
3+00	0/0	0/0	0/0	0/0	0/0	0/2	0/0
3+50	0/0	0/0	0/0	0/0	0/0	0/0	0/0
4+00	0/0	0/0	0/0	0/0	0/0	0/0	0/0
4+50	0/0	0/0	0/0	0/0	0/0	0/0	0/0
5+00	0/0	2/2	0/0	0/0	0/0	0/0	0/0
5+50	0/0	0/4	0/0	0/0	0/0	0/0	0/0
6+00	0/0	0/3	0/0	0/0	0/0	0/0	0/0
6+50	0/2	0/4	0/0	0/0	0/1	0/0	0/0
7+00	0/n/a	3/n/a	0/n/a	0/n/a	0/n/a	0/n/a	0/n/a
7+50	0/0	1/1	0/0	0/0	0/0	0/2	0/0

8+00	0/0	0/0	0/0	0/0	0/0	0/0	0/0
8+50	0/0	0/0	0/0	0/0	0/0	0/0	0/0
9+00	0/0	1/1	1/1	0/0	0/0	0/0	0/0
9+50	0/0	0/2	0/0	0/0	0/0	0/0	0/0
10+00	0/0	0/0	1/1	0/0	0/0	0/0	0/0

[1]Units are in 1/16 in. (1.6 mm).

TABLE 4 - Rutting Measurements (in./16), South African Base (10+50 to 14+00) and Georgia Base (14+50 to 18+00), Morgan Co. Project

Sta. #	15 ft. Left of C/L (2003/2006)	10 ft. Left of C/L (2003/2006)	5 ft. Left of C/L (2003/2006)	Centerline (C/L) (2003/2006)	5 ft. Right of C/L (2003/2006)	10 ft. Right of C/L (2003/2006)	15 ft. Right of C/L (2003/2006)
10+50	0/3[1]	0/0	0/0	0/0	0/0	0/0	0/0
11+00	0/4	3/6	0/0	0/0	0/0	0/0	0/0
11+50	0/0	1/1	0/0	0/0	0/0	0/0	0/0
12+00	0/1	0/0	0/0	0/0	0/1	0/0	0/0
12+50	0/3	0/1	0/0	0/0	0/0	0/0	0/0
13+00	0/2	0/1	0/0	0/0	0/1	0/0	0/0
13+50	0/0	0/2	0/0	0/0	0/0	0/0	0/0
14+00	0/0	0/0	0/0	0/0	0/0	0/0	0/0
14+50	0/0	0/0	0/0	0/0	0/0	0/0	0/0
15+00	0/0	0/0	0/0	0/0	0/0	0/0	0/0
15+50	0/0	0/0	0/0	0/0	0/0	0/0	0/0
16+00	0/0	0/0	0/0	0/0	0/0	0/0	0/0
16+50	0/0	0/0	0/0	0/0	0/0	0/0	0/0
17+00	0/0	0/0	0/0	0/0	0/0	0/0	0/0
17+50	0/0	0/0	0/0	0/0	0/0	0/0	0/0
18+00	0/0	0/0	0/0	0/0	0/0	0/0	0/0

[1]Units are in 1/16 in. (1.6 mm).

The rutting observed in the two IP sections was insignificant; however, minor and *major* rutting was found within the conventional section, especially in the eastbound lane, in which the haul trucks are loaded. Rutting levels over 1 in. (25 mm) were measured at the quarry gate where trucks stop.

Visual Inspection

No cracking in the asphaltic concrete layer was observed in the IP test sections during observations on December 3, 2003 and November 13, 2006 (*4*). Extensive cracking, however, was observed in the conventional haul road section, as shown in Figure 2. Most of the extensive cracking was located in the eastbound lane, and advanced deterioration was observed where loaded trucks were stopping at the quarry gate.

FIGURE 2 - Rutting and cracking on conventional haul road section: Morgan Co. Project.

Annual inspections have been conducted since the five-year evaluation, and the IP test sections continue to perform well with no rutting or cracking being observed. Within the past five years, a secondary road which crosses over the IP sections was built for off-road trucks to carry pit overburden to a waste site. When loaded, these trucks weigh over 40 tons, and it is estimated that several hundred loads have traveled across the IP test sections. Visually, no distresses can be observed in the crossing area.

Falling Weight Deflectometer Testing

FWD testing was conducted in November, 2007 on the MCP. This testing was conducted to examine how the IP sections compared with the conventional haul road section. At each drop location, two seating drops, at a target load of 7,000 lbf, were used, and twelve (12) recorded drops (three each at target loads of 7000 lbf (3150 kg), 9000 lbf (4050 kg), 11000 lbf (4950 kg) and 16000 lbf (7200 kg)).

After analysis of the deflection data collected using the program ModTag and its supporting program ModCOMP, the Subgrade Modulus, Effective Structural Number, Remaining Life (RL) as a percentage of the original pavement life, and the Layer Moduli were calculated. The assumptions used during the analysis process are as follows:

- Conventional Haul Route Pavement (drop stations 0 - 1000) - flexible pavement with 3 in. (75 mm) asphaltic concrete (AC) and 8 in. (200 mm) GAB; 6 in. (150 mm) surge stone

- South African IP (drop stations 1000 - 1400) - flexible pavement with 3 in. (75 mm) AC, 6 in. (150 mm) GAB, and 10 in. (250 mm) CTB (8 in. CTB combined with 2 in. GAB filler);
- Georgia IP (drop stations 1400 to 1800) – same as South African IP

Figure 3 shows the normalized (9 kips) deflections for both entering and exiting segments of the MCP. Based on the deflection data gathered for the loading above, the IP sections were determined to be in excellent condition. The average RL determined by ModTAG for the Georgia IP was 99.34% of the original design life, 94.61% for the South African IP, and 67.92% for the conventional haul route pavement (*5*).

FIGURE 3 Normalized Deflections: Entering and Exiting Morgan Co. Project.

SOUTH LAGRANGE LOOP TEST SECTION

Based on the success of the MCP, and due to the rising cost of asphalt cement, GDOT decided to fund and build its own IP test section on the South LaGrange Loop in Troup County. This project, hereafter referred to as the LaGrange Bypass Project (LBP), was one of several for the preparation of the Kia automotive plant being built in the neighboring town of West Point, Georgia, and it connects the Kia plant with a newly developed industrial park. The two-lane, 2.03-mi. (3.24 km) roadway was constructed with a conventional, portland cement concrete (PCC) pavement structure, except for the 3,434-ft. (1047-m) IP test section.

Construction of the LBP began in January 2008, including the IP test section, which consisted of (1) stabilized subgrade; (2) cement-treated base (CTB); (3) graded aggregate base (GAB); and (4) HMA. The subgrade, CTB, and GAB courses were constructed in accordance with GDOT Specifications Special Provision 320 (Inverted Pavements). The IP and PCC cross-sections on the LBP are shown in Figure 4.

1 in. = 25. 4 mm

FIGURE 4 Inverted Pavement and Portland Cement Concrete Pavement Cross-Sections: South LaGrange Loop (*6*).

Construction Details: Test Section on LaGrange Bypass Project

Stabilized Subgrade Course

For the IP section, the soil's load carrying capacity was critical. The California Bearing Ratio (CBR) test (AASHTO T-193) is used to determine this capacity, as with the MCP, and GDOT specifications include a Soil Support Value (SSV) based on the CBR test. The objective of the subgrade course construction was to achieve an SSV of 5.0 (CBR = 15) or greater in the top 6 in. (150 mm) of the subgrade as required by the project plans for both excavation and embankment areas. To achieve this, the plans called for the incorporation of a stabilizer aggregate uniformly throughout this course.

Originally, GDOT intended to give contractor the opportunity to choose between chemical stabilization (lime or cement) or mechanical stabilization (aggregate). Prior to the bidding process, several interested contractors suggested that GDOT list only one stabilization process so all bidders would bid on the same process. Since it was uncertain if high quality material was available for chemical stabilization, GDOT decided to specify mechanical stabilization, since the project was near aggregate quarries.

The top 6 in. (150 mm) of the embankment is considered subgrade and had to be, per GDOT soil classification, a IIB4 (Type IA best, Type IIIC worst) or better before stabilization. The specifications for a IIB4 soil are 0-75% passing the #200 sieve, a percent volume change of 0-25%, and a dry maximum density of 90 pcf (1440 kg/m^3). Eight test locations were established, and all eight embankment samples were IIB4 or better, per Table 5.

TABLE 5 Soil Classification Sampling: LaGrange Bypass Project

Sieve Size					% Clay	% Vol. Δ	% Swell	% Shrinkage	Dry Max. ρ (pcf)	% Optimum Moisture
1.5 in.	#10	#40	#60	#200						
100	95	88	81	69	54	13.9	9.8	4.1	96.0	22.0
100	100	89	83	69	50	25.0	21.6	3.4	94.0	24.0
100	89	79	73	61	42	23.4	20.7	2.7	96.0	23.0
100	99	86	80	65	38	9.9	7.1	2.8	92.0	24.0
100	99	80	71	54	35	13.8	9.3	4.5	91.0	25.0
100	96	80	72	58	37	23.4	19.6	3.8	98.0	21.0
100	99	82	69	52	32	25.0	23.0	2.0	107.0	15.0
100	99	84	73	55	34	24.2	20.5	3.7	99.0	19.0

1 in. = 25. 4 mm
1 pcf = 16 kg/m^3

Soil samples for CBR testing were then obtained throughout the test section and CBR tests performed using varying percentages of GAB. It was determined that a 50/50 blend (i.e. 3 in. (75 mm) GAB to 3 in. soil) achieved the SSV required, and this blend was used by the contractor. Follow up gradation and classification of the in-situ blended subgrade indicated that the blend met GDOT specifications. Figure 5 shows the blending of the subgrade with GAB from two angles: before and during blending.

FIGURE 5 Mechanical Subgrade Stabilization with Graded Aggregate Base: LaGrange Bypass Project

Cement Stabilized Graded Aggregate Construction

This work included constructing a premixed, CTB course composed of GAB, Type I Portland cement, and water, which needed to be proportioned, uniformly blended, placed, compacted and cured in accordance with the project specifications. On the MCP, the CTB was mixed in-place, with excellent performance and large cost savings; however, GDOT required plant-mixed CTB on the LBP to ensure a consistent mix. Using a portable plant was more expensive but helped ensure best results for the test section. The contractor was again required to submit a CTB mix design for review and approval before construction. The mix design was performed in accordance with GDOT Test Method GDT-65 (Laboratory Design of Soil-Cement and Cement Stabilized Graded Aggregate). With 4% cement and an optimum moisture content of 7%, the minimum required laboratory unconfined compressive strength of 450 psi (3.1 MPa) was achieved. Acceptance testing required a minimum unconfined compressive strength of 300 psi (2.1 MPa).

It took only three days to place 2,355 yd.^{3} (1800 m^3) of CTB in the test section, and on the first day the moisture content was adjusted significantly to accommodate field conditions. Overall, the production and placement of the CTB went well with very little problems encountered. The cement content ranged from 3.82 % to 3.93% ($\bar{x}$ = 3.89%), and the moisture content ranged from 5.54% to 7.69% ($\bar{x}$ = 6.2%).

The CTB was mixed using a continuous mix batch plant and placed with a paver equipped with high-density, vibratory, dual tamping bars. These tamping bars were capable of compacting the CTB to within 90% of the maximum dry density. Compaction was completed with two vibratory steel wheel rollers (one rubber-coated) and a pneumatic rubber tire roller. Six compaction tests were performed using a nuclear density gauge and by in-situ, sand-cone density testing. The average dry density of the six compactions was 153.2 lb/ft^3 (2451 kg/m^3) at an average moisture content of 4.60%. The CTB was kept continuously moist through the process and was clipped to final grade using a trimmer equipped with electronic slope controls.

Once the CTB conformed to the grade, thickness, and cross-section shown in the project plans, another application of water was applied followed by a bituminous prime coat to seal in the moisture. After seven days of curing the CTB, five 6-in. (150 mm) cores were extracted and tested for unconfined compressive strength. Values ranged from 446 psi (3.1 MPa) to 723 psi (5 MPa), well above the minimum strength required for acceptance (300 psi/2.1 MPa).

Graded Aggregate Base (GAB) Construction

The data collected on the MCP was used to prepare the Special Provision for GAB construction on the LBP**.** During the pre-bidding process, much concern was expressed by potential contractors with the unfamiliar compaction requirement. Subsequently, a provision was provided to allow a 100% of maximum dry density requirement in lieu of 86% of apparent gravity if problems were encountered.

After the project was awarded, extensive apparent gravity testing was conducted on the contractor's source of GAB. It was decided to run these tests with both the South African method for determining apparent gravity and with AASHTO T-85, which is used by GDOT. Three additional sources with different mineral compositions were also tested for comparison. With the South African method, testing was performed using variances in water temperatures, soaking periods, and sample weights. From all 58 tests performed, it was determined that both test procedures produced repeatable and comparable results. For the GAB that was used in the test section, the apparent gravity was 166.9 pcf using the South African method and 165.4 pcf using

AASHTO T-85. The GAB was placed, compacted, graded, and primed using typical construction equipment. The moisture was kept within 100% - 120% through the process. The results of all quality acceptance field testing are shown in Table 6**.**

TABLE 6 IP Compaction Results: LaGrange Bypass Project

Station	Depth (in.)	In-place Density (Nuclear Gauge) @ In-Place Moisture %	Apparent Gravity (166.9 pcf @ 5.8% Moisture)	Maximum Dry Density (137.1 pcf @ 5.8% Moisture)
			% Compaction Achieved	
280+50	6.5	144.4 @ 2.0	86.5	105.3
286+50	6.0	142.9 @ 2.4	85.6	104.2
296+50	5.5	143.2 @ 2.3	85.8	104.4
303+50	6.0	143.1 @ 2.3	85.8	104.4
313+50	6.0	143.0 @ 2.3	85.7	104.3
		$\bar{x}$	85.9	104.5

1 in. = 25. 4 mm

Hot Mix Asphaltic Concrete Construction

The entire IP concept is based on a design that relies on deep supporting layers to reduce the stresses in the base and surfacing layers (*1*). This allows for the use of a relatively thin asphaltic concrete pavement surface ranging from ¾ in. to 2 in. (18 mm – 50 mm) or a Surface Treatment application which has been successfully used in South Africa. The purpose of this layer is mostly to protect the crushed stone layer from water penetration, and since these layers are prone to aging and fatigue cracking under both traffic loading and environmental conditions, it is important to note that this layer is not considered to have any structural value. Life-cycle costing should therefore include preventative maintenance costs such as occasional crack sealing (*1*).

On the LBP, the asphaltic concrete layers consisted of 2 in./220 lb./yd.^{2} (51 mm/119 kg/m^2) of 19 mm Superpave topped with 1.5 in./165 lb./yd.^{2} (38 mm/89 kg/m^2) of polymer-modified 12.5 mm Superpave as a surface course. Both the 19 mm and 12.5 mm Superpave mixes were placed using a wedge lock paver. A total of 1390.64 tons (1261.31 Mg), including 1084.02 tons (983.21 Mg) of 19 mm and 306.62 tons (278.10 Mg) of 12.5 mm, were placed, followed by testing with a nuclear gauge to determine density and extraction of in-situ cores to test for specific gravity and air voids. All quality acceptance testing at the plant during production and field verification testing met the requirements of Section 828 (Hot Mix Asphalt Concrete Mixtures) of the GDOT Standard Specifications.

Post-Construction Performance Data

Since its completion in 2009, the LBP has been structurally evaluated. Between August 20, 2008, and May 14, 2009, FWD testing was conducted along the length of the newly constructed roadway to assess the strength of the newly placed pavement layers. Based on the deflection data gathered for the target load of 9 kips (4050 kg), the new pavement structure evaluated as a whole was determined to be in excellent condition with an average normalized deflection of 8.54 mils at Sensor One (9000 lbf/4050 kg), as shown in Table 7.

TABLE 7 Normalized Deflections: LaGrange Bypass Project

		Deflections (mils):				
Sta. (ft.)	**Comments**	**R1**	**R2**	**R3**	**R4**	**R7**
0	None	9.6	6.04	4.14	2.71	0.91
108		10.27	6.26	4.21	2.88	1.21
201		9.7	6.22	4.46	3.09	1.45
406		10.34	6.76	5.05	3.85	1.51
610		9.79	6.03	4.21	2.84	1.28
902		10.61	7.15	5.21	3.66	1.5
1110		10.27	6.08	4.16	2.96	1.47
1206		9.47	6.72	5.08	3.72	1.22
1500		10.97	7.71	5.86	4.48	1.67
1610		10.66	6.54	4.53	3.23	1.63
1800		12.98	8.99	6.75	4.95	1.77
2108		13.05	9.22	6.77	4.81	1.56
2109		9.41	5.62	3.9	2.88	1.47
2500		11.22	7.22	4.87	3.2	0.85
2610		9.7	5.89	4.06	2.9	0.83
2901		9.85	6.2	4.25	2.81	0.81
3000		11.83	7	4.5	3.08	0.96
3021		10.92	6.76	4.33	2.9	1.02
3050	Area milled following previous testing; Consists of GAB, 25mm SP, 19mm SP, and 12.5mm Superpave	3.85	2.97	2.77	2.6	0.95
3075		3.29	2.39	2.18	2.02	1.01
3100		2.89	2.22	2.05	1.93	0.94
3110		3.76	2.7	2.4	2.17	0.9
3125		3.26	2.33	2.16	1.99	0.96
3135		4.92	3.53	3.15	2.83	1.1
3160		6.41	5.44	4.95	4.29	1.23
3185		3.11	2.54	2.44	2.28	1.14
Mean		8.54	5.64	4.17	3.12	1.21
Std. Dev.		3.32	2.04	1.3	0.83	0.3

1 mil = 0.0254 mm

Normalized deflections at Sensor One for each layer tested at each drop location are shown in Figure 6.

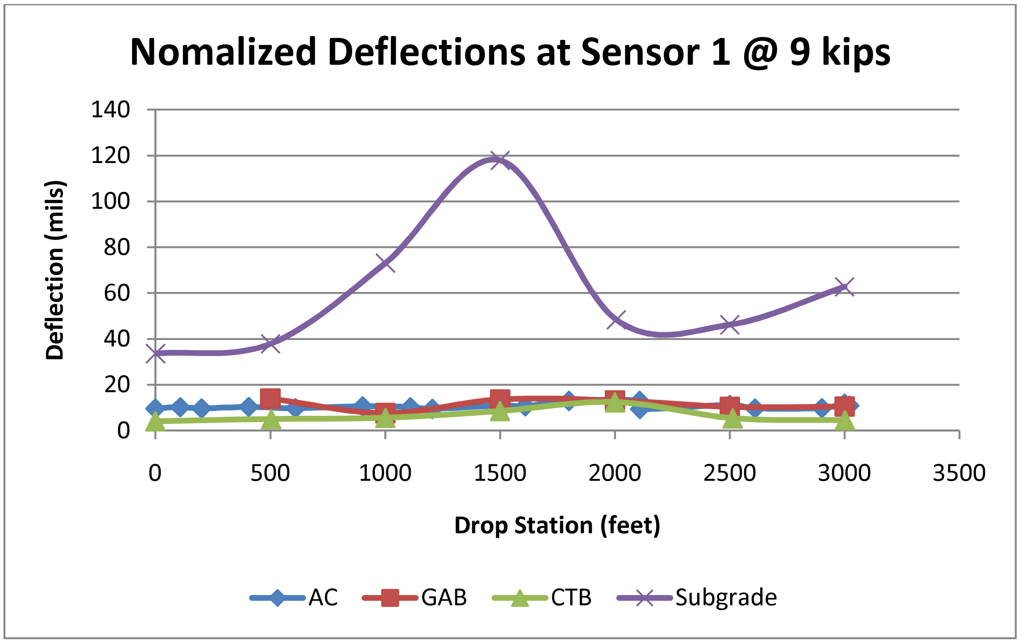


FIGURE 6 Normalized Deflections at Sensor 1 (9000 lbf/4050 kg): Pavement Layers for LaGrange Bypass Project.

Also, the Remaining Pavement Life (RL) in years was determined through the use of the analysis program MODULUS. MODULUS separates the RL into two types, RUT (the effect that rutting has on the pavement life) and CRK (the effect that cracking has on the pavement life). Throughout the length of the project, the remaining pavement life for both cracking and rutting is over 10 years (*7*).

CONCLUSIONS

Overall, the Morgan County and LaGrange Bypass projects were both successful in that all construction processes were completed without any major complications. Construction went smoothly, no additional equipment was needed for construction, and all specification requirements were met. Since the LBP is only Phase I of the Bypass and traffic will be limited until Phase II can be completed, it will be several years before performance data can be collected and a long-range assessment can be made. Based on 10 years of superior performance, however, with the MCP and IP's proven effectiveness in South Africa under high traffic conditions and harsh weather conditions, it is certain that this cost-effective construction process will be used on future GDOT projects.

REFERENCES

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