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Foamed Asphalt Stabilized Base: A Case Study

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ABSTRACT

Foamed asphalt stabilized base (FASB) combines reclaimed asphalt pavement (RAP) and/or recycled concrete (RC) with a foamed asphalt binder. The pavement structural properties of FASB fall somewhere between conventional graded aggregate base (GAB) and hot mix asphalt (HMA). Therefore, the required thickness of the pavement section can be reduced, resulting in cost savings in addition to recycling benefits.

This case study was conducted on an 8 inch FASB layer constructed during May to July 2011 on MD Route 295 near Baltimore-Washington International (BWI) Airport. The primary objective of the project was to evaluate the suitability of using this material in high traffic volume pavements and to assess its fundamental engineering properties. FASB density, moisture content and hydraulic properties were evaluated in the field and its stiffness was monitored as the material dried and cured during the first week and at 4 to 6 months after placement. Field tests included nuclear moisture and density gauge readings, permeability assessment, and stiffness measurements using a lightweight deflectometer (LWD), a GeoGauge, and a falling weight deflectometer (FWD). Of particular interest was the increase in stiffness of the FASB with time during curing and the comparison of this increase with that observed in a companion GAB control section at the site. Overall, the final field cured stiffness of the FASB was found to be substantially higher than that for GAB. Recommendations on appropriate installation methodologies, weather constraints, and QC/QA methods are provided.

INTRODUCTION

FASB is a partially bound material consisting of aggregate skeleton, foamed binder, water, and air voids with distinct behavior that lies between that of HMA and GAB. To produce FASB, foamed asphalt is mixed together with aggregates, e.g. RAP and/or RC, at ambient temperature, producing a partially bound material. In the foaming process, a controlled flow of cold water and pressurized air is introduced into a hot asphalt stream in a mixing chamber and then delivered through a nozzle as asphalt foam (Csanyi, 1957; Mobil Oil Australia, 1970).

Foamed asphalt stabilization of recycled material (mostly RAP) with/without virgin aggregate has been implemented over the past decades in South Africa (e.g., Jenkins *et al.*, 2000, Asphalt Academy, 2002), Australia (Ramanujam and Jones, 2007), and Europe (Khweir, 2007), with only a recent resurgence of interest—and to a much lesser extent—in the U.S. (Fu *et al.,* 2008, and Kim *et al.,* 2009).

As compared to other recycled road base materials treatment methods, e.g., asphalt emulsion, Portland cement stabilization, etc., foamed asphalt treatment has shown significantly better performance. Ramanujam and Jones (2007) reported a direct comparison between foamed asphalt (with lime) treatment and emulsion treatment (with Portland cement) in which the foamed asphalt section showed significantly better performance in terms of handling early traffic and also superior rain resistance before applying the wearing course. Compared to recycled road base materials treated with Portland cement or other cementitious agents, foamed asphalt mixes (which may include small amounts of cement as well) have the additional benefit of improved flexibility or reduced brittleness. Jenkins *et al.* (2000) also reported that foamed asphalt and asphalt emulsion stabilized mixes have comparable strength, stiffness, and moisture susceptibility. However, the foamed asphalt strategy is often preferred because the asphalt emulsion treatment introduces extra moisture (the continuous phase in the emulsion) into the mix and requires considerably longer curing periods before the road can be opened to traffic. Muthen (1999) demonstrated that foamed asphalt treated material exhibits higher stiffness in comparison to emulsion treated material at ambient temperature and it can resist higher strains before failure.

In summary, FASB provides a potentially fast, cost-effective and environmentally friendly flexible pavement rehabilitation strategy if designed and produced effectively. FASB performance in the field is related to its fundamental engineering properties, specifically stiffness, which is not only affected by the mix design (Khosravifar *et al*., 2012) but also by the field construction, compaction, curing, and climatic conditions. The stiffness of FASB is influenced by compaction, field moisture content, applied stress states, loading rate, and temperature (Khosravifar *et al*., 2013). During this case study, the stiffness of FASB was monitored in the field over consecutive days after its placement and several months later.

FIELD CONSTRUCTION

The case under study was a lane widening on MD Route 295 near BWI Airport. The pavement design for this project consisted of an 8 inch thick HMA layer over an 8 inch thick base layer of either FASB or GAB over selected portions of the alignment. The subgrade construction included several remedial undercuts and filling with GAB along the 3600 ft construction site. The base and overlay layers were placed using a paver and were compacted using a Bomag intelligent compaction roller.

The FASB Control Strip was placed in May 2011 in one 8 inch thick lift. Around 200 tons of FASB were placed and compacted along a 200 ft strip. Curing conditions were favorable with daily average temperatures in the mid-to-upper 70ºF range and little precipitation for the entire week after placement.

The main FASB placement started on July 7, 2011, and included two segments. Because of problems maintaining target grade during placement of the single 8 inch thick lift in the Control Strip, the main FASB segments were placed in two 4 inch thick lifts. The mainline construction included:

1. Segment A: the first 4 inch layer was placed on July 7, 2011, and the second 4 inch lift was placed four days later on July 11.
2. Segment B: FASB was placed in two 4 inch lifts on a same day (July 11, 2011).

A companion GAB section was installed on July 13 in two 4 inch lifts. The project plan is shown in Figure 1.

Weather conditions for the mainline segments were mostly favorable for curing, with daily average temperatures in the low 80ºF range and no significant rain except for a local thunderstorm on site on the night of July 7 one night after the placement of the first layer of Segment A. On-site rain gauges recorded 3" rain. The FASB and GAB base layers were covered by an 8 inch HMA layer on July 18.

Figure 1. Project plan. Numbers in parentheses indicate placement dates; numbers in white squares indicate the stations.

FIELD TESTING PLAN AND TEST DEVICE SPECIFICATIONS

Construction/Immediate Post-Construction.

Control Strip The project team performed *in situ* stiffness tests using a Humboldt GeoGauge 4140 and a Zorn ZFG 3000 LWD at multiple locations every 25 to 30 ft along the 200 ft FASB Control Strip layer on May 24, 25, 26, 27, and 31. Two replicate measurements were performed at each location using the GeoGauge. For the LWD testing, 3 seating drops were first applied to assure a good contact and avoid any loose particles on the test surface before obtaining 3 replicate test measurements. Field density and moisture content were measured after the FASB compaction in accordance with AASHTO T 310 using a Troxler 3430 Nuclear Gauge for compaction QC/QA. The moisture offset factor of -2.9% to correct for hydrogen in the RAP and foamed binder was applied to the gauge readings according to Equation 1 (Troxler 3430 Surface Moisture-Density Gauge manual).

$$k = \frac{\%MC_{LAB} - \%MC_{GAUGE}}{100 + \%MC_{GAUGE}} \times 100 \qquad (1)$$

where MC_{LAB}: Moisture content measured in lab by oven drying method= 10.2 %
MC_{GAUGE}: Moisture content measured by the gauge= 13.4%

Main Construction Site. Similar to the Control Strip, GeoGauge and Zorn LWD stiffness measurements were obtained on the main construction site after placement of the FASB and on the following days at spacings of every 100 ft over the 1600 ft site.

The stiffness readings for the GAB sections were performed on the day of its placement (7/13/11) and on the following day, about every 100 ft along the 1180 ft test strip. The measurements were interrupted because of a thin leveling layer placed on top of the existing layer on 7/14 that affected the in-place curing and stiffness, making any potential subsequent measurements inconsistent. However, the potential equilibrium stiffness (explained next) of the GAB material in the field was obtained on a nearby undercut and fill section.

The equilibrium stiffness is obtained when the material is placed and dries in the field under relatively constant weather conditions until its moisture content is in equilibrium with the surrounding environment and the rate of evaporation approaches zero. This equilibrium can be reached within 7 days for uncovered coarse sand (Yanful and Choo, 1997).

Dynatest FWD measurements were attempted on the unpaved structure. However, the standard 12 inch diameter loading plate used for production testing on paved surfaces was found inappropriate for the construction QC/QA of the unpaved structures because of the relatively high induced pressures and consequent plastic deformations.

Long-Term Post-Construction. Long-term post-construction stiffness was also measured using a Dynatest FWD on the final paved structure in November 2011, 4 to 6 months after construction of the various segments and before opening the site to traffic.

MATERAL PROPERTIES

The FASB test mixture in this study consisted of a blend of 40% RAP and 60% RC mixed with 2.8% foamed asphalt at ambient temperature. The PG 64-22 binder used in the mix was foamed at a 2.2% foaming water content at 320ºF. The detailed information about the material characteristics and the mix design is provided under

“Mix Group A” in Khosravifar *et al*., 2012. Figure 2 shows the gradation of the GAB and FASB evaluated in the study. The optimum moisture content (OMC), maximum dry density (MDD), and the *in-situ* permeability (k) of the GAB and FASB are summarized in Table 1. The FASB had a lower MDD, lower percentage of fines, and a comparable permeability to GAB. This suggests that the drainage function of FASB should be comparable to that of GAB.

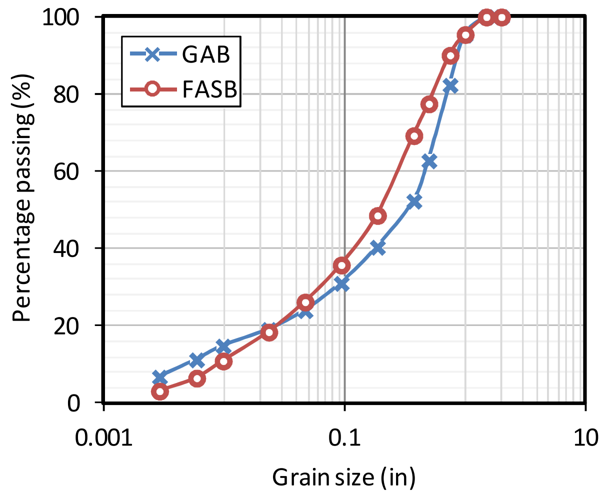

Figure 2. Gradation of the GAB and FASB base materials.

Table 1. GAB and FASB properties.

Material	Percentage passing sieve #200 (%)	Optimum moisture content (%)	Maximum Dry density (pcf)	*In-situ* Permeability (in/sec)	
	AASHTO T 27	AASHTO T 180- method D, AASHTO T 224		Borehole test	Falling head test
GAB	6.7	5.2	148.8	1.11E-03	3.98E-03
FASB	3.1	10.2	122.4	3.17E-03	1.13E-02

FIELD TEST RESULTS

Construction/Immediate Post-Construction. Nuclear moisture and density measurements were conducted on the Control Strip to assess the level of compaction. The results in Table 2 indicate satisfactory compaction throughout the FASB construction site.

The increase in *in-situ* stiffness with time was measured with the GeoGauge 4140 and Zorn ZFG 3000 LWD daily during the first week after FASB placement. The GeoGauge and Zorn LWD *in-situ* test devices are designed to measure the stiffness values within a range usually applicable to unbound material. The GeoGauge is capable of measuring stiffness values up to 80 ksi (GeoGauge User Manual), although its practical upper limit was found to be about 65 ksi. Several overload errors were observed during testing at several locations on FASB sections on the seventh day, indicating that the material had become too stiff for accurate measurement.

The Zorn LWD is capable of measuring stiffness values up to 19 ksi corresponding to deflections of 0.2 mm (Zorn ZFG 3000 LWD User Manual). Actual stiffness readings were obtained for up to 30 ksi, corresponding to a 0.13 mm deflection. Error messages were observed during testing on FASB sections at several locations beginning on the fourth day, indicating that the material had become too stiff for accurate measurement.

Table 2. Nuclear gauge measurements after FASB placement.

Test Segment	Date	Moisture content (%)	Wet density (pcf)	Dry density (pcf)	Compaction (%)
Control Strip	5/24/2011	10.9	134.1	120.8	98.7%
Segment A- 1st lift	7/7/2011	10.2	133.2	120.8	98.7%
Segment B- 2nd lift	7/11/2011	10.9	134.8	121.5	99.3%

Overall, the Zorn LWD underpredicted the stiffness of the FASB and GAB materials by a factor of 0.5 in comparison to the GeoGauge, as shown in Figure 3. Possible reasons for this systematic difference include the differences in the frequency of the applied load, the induced stress levels, and the depth of the zone of influence for each device. The GeoGauge users manual reports the depth of zone of influence to be 9 to 12 inch. The depth of the zone of influence for the LWD as determined from a finite element simulation (Khosravifar *et al.*, 2013) was determined to be about twice the diameter of the loading plate or 24 inches. The *in-situ* stiffness ($E_{in\text{-}situ\ \mathrm{Device}}$) reported by the LWD or the GeoGauge is the overall modulus for all material in its zone of influence.

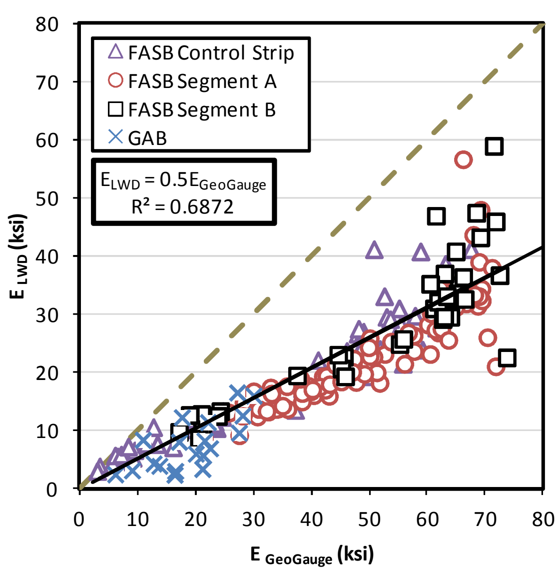

Figure 3. Correlation between the stiffness measured by the Zorn LWD and GeoGauge on different FASB and GAB sections during 7 days of monitoring.

Stiffening Process of GAB versus FASB. A conventional GAB material will gain stiffness as it dries from the compacted moisture content near the optimum to a lower long-term equilibrium moisture condition. During this process, aggregate particles are drawn closer as the moisture in the pores evaporates and suction pressures develop.

The FASB material gains a greater stiffness after placement in the field when placed under suitable climatic conditions. The moisture evaporation not only brings together the aggregates particles but also helps the foamed asphalt droplets to bond better to the aggregate particles. As the moisture disappears and the foamed asphalt bonds become stronger, the material gets stiffer. This process is defined as curing.

Precipitation can adversely affect the stiffening process. Figure 4 shows the stiffness gains as measured by the GeoGauge and Zorn LWD devices on the first 4-inch thick lift of Segment A. Trends versus time are presented both in terms of absolute stiffness and percentage stiffness change. As shown in this figure, both the GeoGauge and the Zorn LWD captured the rain-induced decrease in stiffness on the day after the FASB placement, highlighted by the circle in Figure 4b. Although stiffness subsequently rebounded during the following dry and sunny days, the net stiffness gain at 4 days after placement was relatively small. Possible explanations for this include:

- The 4-inch thick lift is too thin relative to the zone of influence of the GeoGauge and the LWD devices, and therefore the measurements are unduly affected by the underlying subgrade layer.
- Curing may have been partially but irrevocably hampered by the heavy rain on the night after the FASB was placed. As described previously, the on-site rain gauge measured 3" of rain on the night of July 7.

Figure 5 demonstrates the increase in *in-situ* stiffness over time for the GAB versus FASB sections as measured by the Zorn LWD and GeoGauge. The average initial stiffness values (E_i) measured using the Zorn LWD on the FASB sections were 11.4, 10.9, and 14.2 ksi for the Control Strip, Segment B, and Segment A-2nd lift, respectively. The corresponding initial stiffness for the GAB section was 5.6 ksi. The average initial stiffness values measured using the GeoGauge were 23.0, 21.2, 30.3, and 15.7 for the respective FASB sections and 15.7 ksi for the GAB section. The reason for a higher initial stiffness of the 2nd lift of Segment A is that the first 4 inch lift of the FASB material had already cured and stiffened for a few days before the second lift was placed and the measurements were influenced by the underlying first lift. This is also the reason for the relatively small percentage increase in $\Delta E/E_i$ for the second lift of Segment A (Figure 6); the first lift had already partially cured and increased in stiffness.

The average stiffnesses of the FASB sections after 7 days of curing and drying in the field were 35.1 ksi, and 63.8 ksi as measured by the LWD and GeoGauge, respectively (Figure 5). The corresponding stiffnesses of the GAB section were 16.1 ksi and 32.8 ksi. As shown in Figure 6a, the LWD measured a stiffness increase of 243% and 224% for Segment B and Control Strip, respectively. The corresponding trends measured using the GeoGauge are depicted in Figure 6b. The percentage increases in the stiffness of the GAB are also shown in Figure 6. The GAB stiffness increase was substantially lower than for the FASB sections (except for Segment A). This is consistent with the strengthening of the foamed asphalt bonds due to curing in addition to the partial saturation effects from drying.

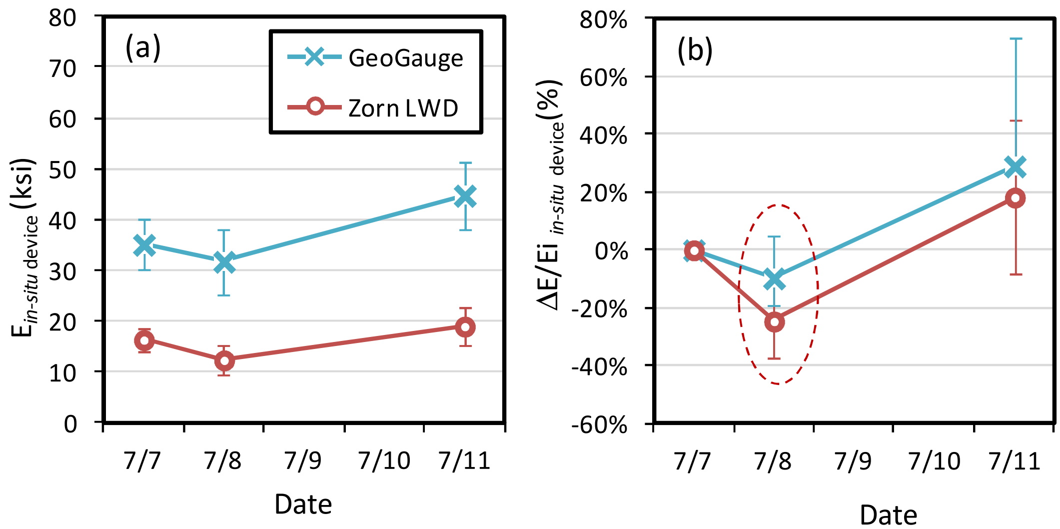

Figure 4. The average (a) stiffness, (b) percentage increase in stiffness with time as measured using the Zorn LWD and GeoGauge on Segment A- first 4 inch lift.

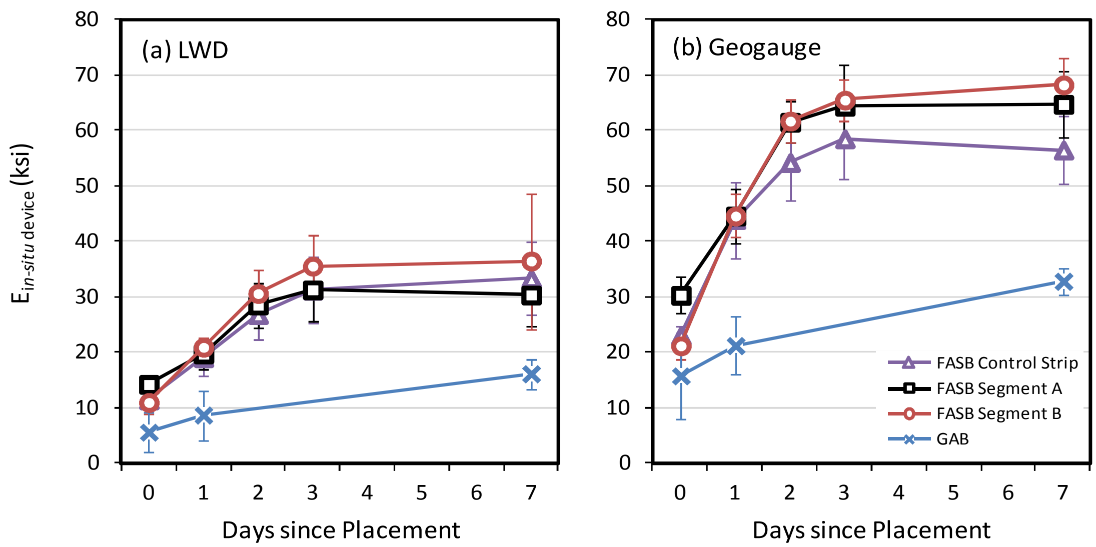

Figure 5. The average stiffness increase with time as measured using (a) Zorn LWD, and (b) GeoGauge on FASB Control Strip, Segment A- second 4 inch lift, Segment B, and the companion GAB. Error bars show one standard deviation.

Both the Zorn LWD and GeoGauge stiffness measurements exhibited higher variability as the material stiffened and the devices approached their measurement limits after 3 to 4 days of drying and curing in the field. Therefore, it is not certain that the stiffness of the FASB material had stabilized similar to what was observed in the less-stiff GAB; the curing process was likely still ongoing for the FASB. This was confirmed by falling weight deflectometer (FWD) measurements performed on the paved sections four to six months after HMA placement, as described in the next section.

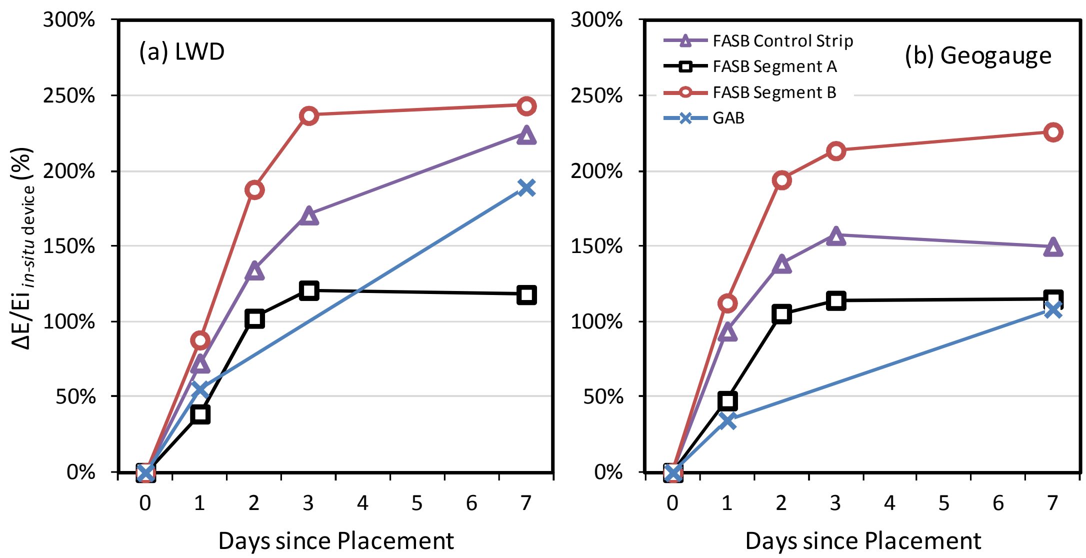

Figure 6. The average percentage increase in stiffness as measured using (a) the Zorn LWD, and (b) GeoGauge on the FASB Control Strip, Segment A, Segment B, and the companion GAB. Error bars show one standard deviation.

Long-Term Post-Construction. Long-term post-construction stiffness was also measured using a Dynatest FWD on the final paved structure in November 2011, 4 to 6 months after construction of the various segments and immediately before opening the site to traffic. Three to four measurements were obtained on each test segment. Backcalculation analysis was performed using ModTag V4.3.0 assuming the material as linear elastic; the results are plotted in Figure 7 for the HMA, base and subgrade. The RMS backcalculation errors were less than 6.9% and averaged 3.9%, indicating a good fit. The backcalculated average subgrade modulus was 41.6 ksi and relatively uniform, although slightly stiffer under Segment B. The moduli of the FASB sections were significantly higher than those for the GAB section.

The stiffness of the GAB measured using the FWD was in the same range as the ultimate stiffness measured by GeoGauge and Zorn LWD. The FWD results showed that the FASB became significantly stiffer than the final GeoGauge and LWD values seven days after placement. The long-term stiffness of the GAB backcalculated from the FWD results was about 24 ksi. The corresponding long-term stiffness of the field-cured FASB was about 295 ksi, 12.3 times that of the GAB. Placement of the HMA layer may have improved the curing of the underlying FASB by applying additional heat and enhancing moisture evaporation.

The lower stiffness GAB layer appears also to have reduced the modulus of HMA layer. It is usually more difficult to achieve the same HMA compaction over a softer underlying layer than over a stiffer layer.

Within the FASB sections, Segment A had the lowest moduli, which could be due to the four day delay in placing the second 4 inch lift. This is important from a construction point of view. Breaking the installation of FASB layers into two separate days affected the final stiffness of the material even with rewetting of the surface before placement of the second lift.

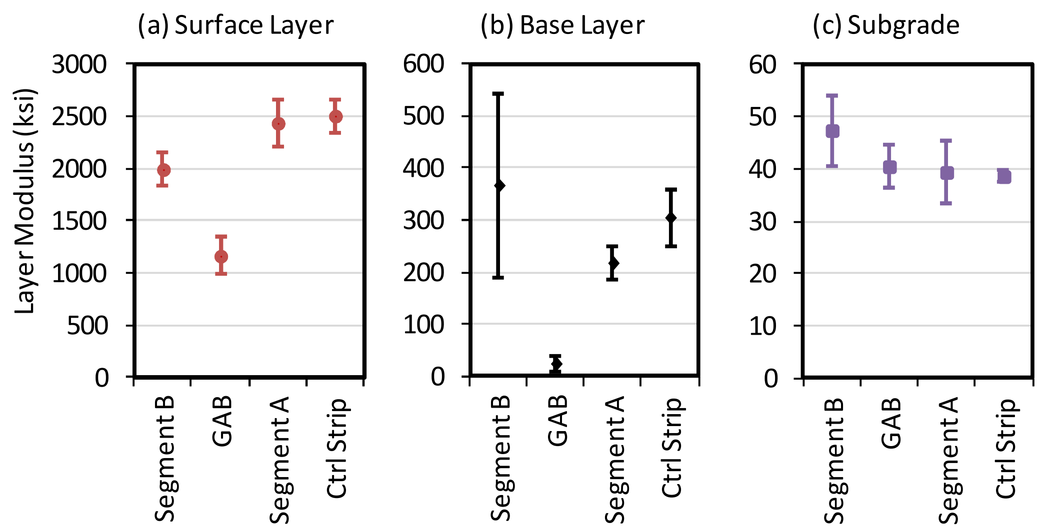

Figure 7. Backcalculated moduli for the (a) HMA layer, (b) base layer, and (c) subgrade. Error bars indicate one standard deviation.

CONCLUSIONS

The main conclusions from the construction/immediate post-construction and long term post-construction testing in this field study are as follows:

- The test sections were properly compacted and showed a satisfactory, uniform compaction as indicated by Nuclear Gauge moisture and density measurements.
- The Zorn LWD and GeoGauge devices gave significantly different values for the *in-situ* stiffness, with the Zorn LWD systematically reporting values approximately 0.5 times those from the GeoGauge at the same locations. The reasons for these differences include different load levels, loading rates, depth of zones of influence, analysis assumptions, and other factors. Given these issues, neither of the devices can be considered to give the "true" in place stiffness. The more useful measures are the percentage increase in stiffness with time and the relative stiffness of the FASB versus conventional GAB.
- Curing of the FASB in the Control Strip and mainline Segment B placement produced stiffness increases of 188 to 234% within one week after placement as measured by GeoGauge and Zorn LWD respectively. The stiffness increases measured using the Zorn LWD tended to be slightly higher than those measured using the GeoGauge.
- Comparing the Control Strip placed in May 2011 and the mainline placement in July 2011, the influence of weather on FASB curing is clear. The Control Strip placed in May 2011 under generally favorable curing conditions (no rain, average daily temperatures in mid-70^{o}F range) increased in stiffness by 150% (224%) over a one-week period as measured by the GeoGauge (Zorn LWD), reaching average values 7 days after placement of 56.5 ksi and 33.3 ksi as measured by the GeoGauge and Zorn LWD, respectively. The mainline segments placed in July 2011 under ideal curing conditions (average daily temperatures in the low-80^{o}F range, no rain except for one brief but intense thunderstorm) exhibited greater increases stiffness, reaching average values 7 days after placement of 67.0 ksi and

34.2 ksi as measured by the GeoGauge and Zorn LWD, respectively. The thunderstorm on the night after placement of the first lift of Segment A caused a pronounced decrease in in-place stiffness of the FASB, but this mostly rebounded during the subsequent warm and dry days.

- The initial stiffness of the FASB sections (excluding Segment A) was on average 1.4 (GeoGauge) to 2 (Zorn LWD) times the equivalent GAB sections. The gain in stiffness after one week of drying and curing of the FASB sections was also greater than after one week of drying of the GAB; the FASB sections (excluding Segment A) increased in stiffness by a factor of 2.9 (GeoGauge) to 3.3 (Zorn LWD) while the GAB increased by a factor of 2.1 (GeoGauge) to 2.9 (Zorn LWD).
- FWD backcalculated moduli of the FASB layers averaged 295 ksi, which is significantly higher than for the GAB layer. Placement of the HMA layer may have improved the curing of the underlying FASB by applying additional heat and enhancing moisture evaporation.
- Within the FASB sections, Segment A showed the lowest moduli, which could be due to the 4 day delay in placing the second 4 inch lift for this segment. This is important from the construction point of view. Breaking the installation of FASB layers into two separate days affects the final stiffness of the material even with wetting the surface before placement of the second lift.
- Laboratory and field permeability tests found that the permeability of FASB is comparable to and in some cases slightly higher than that of GAB. This suggests that the drainage function of FASB should be comparable to that of GAB.

This field study clearly supports the suitability of FASB material for high volume pavement applications if designed and installed properly and cured under favorable climatic condition. The final in place stiffness of this flexible, partially bound material is substantially higher than unbound GAB. Therefore, its proper use can reduce the required thickness of pavement sections, resulting in cost savings in addition to recycling benefits.

Stiffness-based in place QA/QC devices are a necessity for tracking the gain in stiffness during field curing. The LWD and GeoGauge stiffness devices were both able to track the stiffness increase with time, at least until the material gets too stiff and beyond the limits of the devices. The combination of initial stiffness values, rate of stiffening, and the final stiffness measurements can be used as a guide in QC/QA of FASB material. Nuclear moisture and density gauge can effectively be used to monitor the post-construction compaction level and the field moisture content but cannot capture the stiffening of FASB during curing. Moisture corrections on the gauge are required to obtain reliable measurements.

FWD measurements, at least when done using the 12 inch diameter loading plate, is not suitable for construction/immediate post construction QC/QA on the unpaved sections as it induces excessive stress levels and plastic deformations. FWD measurements on the paved sections are appropriate for backcalculating the stiffness of the cured FASB and other layers.

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