Determination of Structural Layer Coefficient for Roadway Recycling Using Foamed Asphalt

Final Report

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Submitted by

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Abstract

In 2003, three Maine projects were selected for testing in order to determine the Structural Strength of Foamed Asphalt Layers. The test plan consisted of conducting FWD tests, obtaining samples, and conducting laboratory tests on samples. The test results are listed in tables one through seven. It is recommended that a rational and effective pavement investigation system be developed to identify such sections (with large aggregates) properly and in time (well before construction), such that the mix design and construction can be done with good confidence and adequate performance can be expected from pavements with foamed asphalt treated full depth reclaimed mixes.

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Introduction

Since 2001, approximately 20 different foamed asphalt mix designs have been completed and so far more than 10 foamed asphalt projects have been constructed in different parts of Maine. In 2003, three such projects built in 2002, along with the Belgrade Route 8 project, were selected for a detailed investigation.

Foamed asphalt is a stabilizing agent used with full depth reclamation. Full depth reclamation involves milling the existing bituminous pavement plus a portion of the base material. The milled material is then graded and compacted. Traffic can use the roadway until a bituminous base and wearing surface is applied.

Foamed asphalt is a mixture of air, water and hot asphalt. Cold water is introduced to hot asphalt causing the asphalt to foam and expand by more than 10 times its original volume. During this foaming action the asphalt has a reduced viscosity making it much easier to mix with aggregates. A specialized piece of equipment mills the existing bituminous pavement and base material and introduces foamed asphalt all in one process. The material is then graded and compacted. Traffic can operate on the stabilized base until a hot mix asphalt base and wearing surface is applied. Some other stabilizing agents include cement, emulsion and calcium chloride.

This report shows the detailed investigation to determine the structural strength of foamed asphalt layers.

Objective

Collect foamed asphalt and HMA samples from sites and determine relevant properties through testing. From core and beam samples determine resilent and dynamic modulus and test for fatigue using the Asphalt Pavement Analyzer and by three point bending tests. From test data determine the structural layer coefficient of foamed asphalt layers and recommend appropriate structural strength of foamed asphalt mixes to be used in Maine.

Construction

The work involved pulverizing the existing HMA surface together with approximately 50 mm of the underlying gravel to a minus 50 mm size. After initial reclaiming, the material is then graded and compacted. Some areas required additional Untreated Surface Course material to bring the cross-slope to proper grade. A Wirtgen Model WR2500 pulverizer was used to introduce foamed asphalt to the recycled asphalt pavement. A layer of Type II Portland Cement as wide as the pulverizer was placed on the roadway and the roadway was reclaimed with foamed asphalt to a depth of 150 mm. The material was compacted with a pad foot roller, shaped to cross-slope and grade, then compacted with a steel drum vibratory roller and rubber tired roller. The treated recycled asphalt pavement was surfaced with 30 mm of 9.5 mm nominal maximum aggregate size (NMAS) shim and 30 mm of 9.5 mm NMAS surface mix.

Methodology

The test plan consisted of conducting Falling Weight Deflectometer (FWD) tests, obtaining samples, and conducting laboratory tests on samples. FWD tests were carried out using a load of 40 kN, with JILS equipment. Both core full depth cylindrical and beam samples of foamed asphalt base material were obtained.

The core full depth cylindrical samples were tested for resilient modulus in indirect tensile mode (ASTM D4123). Some of the samples were conditioned (for testing moisture susceptibility) by subjecting them to repeated pulses of 207 kPa under water for 10,000 cycles, each cycle taking approximately 5 seconds.

The beam samples were used for two different tests. First, tests were conducted with the Asphalt Pavement Analyzer (APA) to compare fatigue performance with the fatigue performance of HMA. The test consisted of running loaded wheel (1.1 kN) on beams. The APA is equipped with an Automated Vertical Measurement System including a computer program to plot measurements received from transducer signals, which represent vertical movement of the beam. The computer program plots two lines to represent each beam. The solid line is an average of the vertical movement at the ends of the beam and is called the reference line. The dotted line is the deformation of the center of the beam. As the test progresses, the two lines diverge at a constant rate until the beam approaches fatigue failure. Another set of beams was tested for fatigue properties (for determination of strain versus fatigue life, transfer function) using a beam fatigue equipment (AASHTO TP8). The test consists of haversine loading a beam at third points to generate specific strain levels and acquiring data.

The structural layer coefficients of the four Maine projects were determined through the backcalculation of the falling weight deflectometer results. To see the assumptions and thought process used to determine the structural layer coefficients in more detail see appendix A.

Results

This section provides the results of visual observation and tests conducted on the foamed asphalt reclaimed materials in the three projects. Results of backcalculation from FWD data is provided for the project for which it was not possible to obtain intact cores (Route 15, Bucksport), resilient modulus data is provided for two projects for which intact cores could be obtained (Route 1, Orient and Route 2A, Machowahoc), and fatigue property data for the project from which intact beam samples were available (Route 2A, Machowahoc).

Visual Observations

Photos of typical cores obtained from the three projects are shown in Table 2. It is noted that apart from the difference in foamed asphalt content, the most obvious difference is in the particle size. It was impossible to obtain any intact core from the Route 15, Bucksport project, simply because of the presence of a significant amount of plus 50 mm diameter particles in the foamed asphalt reclaimed material. It was observed that about 100 mm of the layer just under the HMA (prior to reclaiming) consisted of penetration macadam material, and obviously the large stones did not get crushed down to minus 50 mm size during reclamation.

In the case of Route 1, Orient, a small amount of plus 50 mm particles were noted on the top part, although it was possible to obtained cores from this part. The bottom two third part (100 mm below the top 50 mm) consisted of a significant amount of plus 25 mm and a fair amount of plus 50 mm particles. The cores obtained from the top one third of the foamed asphalt reclaimed layer were quite intact and allowed testing for volumetric properties and resilient modulus.

As Table 2 shows, the cores from the Route 2A, Machowahoc project were the best. There were a few plus 50 mm particles, and for that reason and most likely also because of the higher foamed asphalt content, the material was very “uniform” and the appearance of the material was very similar to that of a HMA mix. Cores and beams could be obtained from 125 mm out of the 150 mm reclaimed layer.

Results of testing for volumetric properties and gradation

Bulk specific gravity and theoretical maximum density of the mixes from Route 1 Orient and Route 2A Machowahoc projects were determined, and air voids were calculated (Table 3). The top part of the Route 1 Orient project showed air voids of 9.4 percent, whereas the top and bottom part of the Route 2A, Machowahoc project showed air voids of 15.4 and 14.4 percent, respectively. Table 4 shows the results of sieve analysis carried out with materials (from cores) obtained from the Route 1 Orient and Route 2A Machowahoc projects. Note that the gradations do not show the plus 50 mm diameter particles – which were removed from the mixes prior to sieve analysis. Other than the significant amount of plus 50 mm particles, the gradation of the Route 1 Orient and the Route 2A, Machowahoc mixes are very similar. Note also the difference between the gradations of the top and bottom part of the Route 2A, Machowahoc material – the bottom contained a small amount of plus 25 mm particles.

Results of testing for modulus

Backcalculation of foamed asphalt layer moduli were done for the Route 15, Bucksport project, using EVERCALC (*4*) software. The resilient modulus of HMA layers (binder and surface, considered as one lift) was determined in the laboratory and used in the backcalculation. The samples from Route 1A and Route 2 were also tested for resilient modulus at 25^{o}C in the laboratory. The results are shown in Table 5. The moduli values range from 1,473 Mpa for the Route 15, Bucksport project to 3,676 MPa for the bottom layer of the Route 2A, Machowahoc project. The low value of 1,473 Mpa has been confirmed in other projects with layer characteristics similar to the Route 15 Bucksport project (*5*). The moduli values obtained for the Route 1 Orient project (average: 2,111 MPa) as well as the top part of Route 21 Machowahoc project (average: 3,326 Mpa) were found to be very close to each other, whereas the values obtained from the cores from the bottom part of the Route 2A Machowahoc project were found to be with relatively higher variability.

In order to determine the effect of moisture on the foamed asphalt mixes, two cores from the Route 1 Orient and two cores from Route 2A Machowahoc project were subjected to moisture conditioning. The conditioning was done by subjecting the cores to repeated pressure/vacuum cycles (pressure of 207 kPa) under water (maintained at 25^{o}C) for 9,999 cycles (each cycle takes approximately 6 seconds) as outlined in Reference *6*. At the end of conditioning, the cores were surface dried and tested for resilient modulus, and the post conditioning modulus was compared to the initial modulus to determine the retained modulus. As shown in Table 5, the results from the Route 1 Orient (18 percent) and Route 2A Machowahoc (top part only) (83 percent) are significantly different. The samples from Route 1 Orient were found to have cracks along the interface between the large particles and the finer matrix. The results bring out two important things: 1. A mix with a high resistance against moisture damage (such as that the Route 2A Machowahoc mix) is achievable with foamed asphalt material, and 2. The resistance against moisture damage is significantly affected by the presence of large particles (such as those with plus 50 mm diameter) – the higher the percentage the lower is the resistance. This is no surprise since foamed asphalt coats only fine particles and large stones remain mostly uncoated – resulting in areas of low cohesion in the mix.

Results of testing for fatigue properties

Beams obtained from the top portion of the Route 2A Machowahoc project were tested with the Asphalt Pavement Analyzer (ASTM Draft procedure) and with the flexural or beam fatigue equipment and procedure (AASHTO TP8).

Use of the Asphalt Pavement Analyzer: Test conducted for evaluation of fatigue properties with the APA are indicative in nature – they do not provide any data that can be used for determination of any strain versus cycles to failure (transfer function) that can be used in design. The results of APA testing are shown in Table 6. Note that the HMA beams shown (for comparison) in Table 6 are beams cut out from the Route 2A Machowahoc project. The beams consist of surface and binder layer (not separated). The HMA beams survived about 8,000 cycles whereas the foamed asphalt reclaimed material beams lasted for only 200 cycles. However, the failure mechanisms were different for the two types of materials. The HMA beams failed with bottom up cracking, whereas the foamed asphalt samples failed by raveling of material at the surface.

Use of flexural fatigue test: The results of tests conducted on beams obtained fro the Route 2A Machowahok (top only) and a 12.5 mm HMA surface course mix are shown in Table 7. From the results (showing relative low cycles of failure at 500 and 700 microstrains for the foamed asphalt reclaimed mix and high cycles of failure at 200 microstrain) it seems that at least theoretically one can use a thick foamed asphalt reclaimed layer with a non structural wearing course on top to obtain a desirable pavement life. However, practical issues such as depth of reclamation (from consideration of existing materials) and effectiveness of construction equipment in milling and adequate compaction should be taken into account, and these considerations are most likely going to dictate the thickness of foamed asphalt reclaimed layers. With the moduli and the strain versus cycles to failure data, one can now effectively use mechanistic pavement design procedures for obtaining reliable results. It must be noted that specific numbers related to structural-fatigue properties are at best to be used only as guides – the wide range of materials in the existing pavements make it absolutely necessary to conduct thorough investigation and mix design prior to reclamation. However, the results obtained in this study give confidence that given the right kind of materials and mix design, it is quite possible to obtain foamed asphalt reclaimed layers with desirable properties.

Conclusions and Recommendations

Based on the results obtained from tests on foamed asphalt reclaimed materials in this study, the following conclusions are made:

1. It is possible to obtain foamed asphalt reclaimed mixes with predominantly HMA mixes, relatively low amount of unbound granular materials and Portland cement, with moderate to high moduli values (as compared to hot mix asphalt) and adequate resistance against moisture damage.
2. The single most important factor affecting the performance of a properly designed foamed asphalt reclaimed mix/layer is the percentage of large aggregate particles, particularly plus 50 mm (in diameter) in the existing material. Presence of large particles results in low moduli values and very low resistance against moisture damage.
3. Moduli values of foamed asphalt mixes can range from 1,400 MPa to 3,500 Mpa.
4. Foamed asphalt mixes show relatively low cycles to failure at high strains (in excess of 500 microstrains), and high cycles to failure at low strains (200 microstrains).

The problem with large aggregate particles has been recognized and Maine DOT currently uses virgin aggregates (to avoid getting into layers with large aggregates as well as to increase the percentage of materials passing the 0.075 mm sieve) in projects where layers with large aggregate particles immediately below the HMA layer are suspected. The grading envelope shown in Figure 2 (*7*) can be used for making required changes in the existing material to make it suitable for foamed asphalt reclamation. Note in Figure 2 that foamed asphalt treated materials should not contain any material retained on the 50 mm sieve. The results from this study seem to confirm this. It is recommended that a rational and effective pavement investigation system be developed to identify such sections (with large aggregates) properly and in time (well before construction), such that the mix design and construction can be done with good confidence and adequate performance can be expected from pavements with foamed asphalt treated full depth reclaimed mixes.

Below are the layer coefficients for each of the four test projects. For more specific information as to how these tests results were acquired see appendix A.

Project	Age (years)	Laboratory Resilient Modulus[1]		Backcalculated Modulus		Layer Equivalence Based on Equal Strain		Layer Coefficient[2]
		MPa	ksi	MPa	ksi	BSM	ATB	
Belgrade-Rt8	>2	1243.8	180.4	999.3	144.9	1.00	0.67	0.22
Orient Cary-Rt.1	<1	2111.3	306.2	655.0	95.0	1.18	0.78	0.23
Farmington-Rt.156	<1	2453.7	355.9	1827.1	265.0	1.23	0.82	0.22
Macwahoc-Rt 2A	<1	3325.8	482.4	2505.1	363.3	1.35	0.91	0.35

1: Laboratory tests were conducted on cores taken from top part of the layer only. Intact cores could only be taken from top 100mm of the layers.
2: Determined according to procedure outlined in AASHTO Guide for Design of Pavement Structures, 1993 as done in Reference 3.

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5. Maine Department of Transportation. *Rehabilitation of Part of Route 8 with Foamed Asphalt.* 2002.
6. Buchanan, M. Shane., Vernon Moore, Rajib Mallick, Sean O'Brien and Ali Regimand. *Accelerated Moisture Susceptibility Testing of Hot mix Asphalt (HMA) Mixes*. Paper submitted for presentation and publication at the 83rd Transportation Research Board Meeting, to be held in Washington DC, January 2004.
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TABLE 1: Project Descriptions

Project	Location	Mix Design
Route 1A, Orient-Cary	The project is located in Aroostook County, on Route 1 between the towns of Orient and Cary Plantation.	PG 64-28 asphalt binder, 2.5 % , Water, 3.0 % , Portland Cement, 1.5 %
Route 2A, Macwahoc – T1R4 WELS	The project is located in Aroostook County, on Route 2A between the towns of Macwahoc and T1R4 WELS.	PG 64-28 asphalt binder, 3.0 % , Water, 3.0 % , Portland Cement, 1.5 %
Route 15, Bucksport	The project is located in Hancock County, on Route 15 in the town of Bucksport	PG 64-28 asphalt binder, 2.5 %, Water, 3.0 %, Portland Cement, 1.5 %

TABLE 2: Visual observation of foamed asphalt cores

Project	Photo	Comments
Rt 15, Bucksport		Significant amount of plus 50 mm particles; not possible to get intact cores
Rt 1, Orient	 	Fair amount of plus 50 mm particles in top part; possible to get cores from only top 50 mm out of 150 mm foamed asphalt layer; bottom layer has good amount of plus 50 mm particles
Rt 2A, Machowahoc		A few plus 50 mm particles; possible to get cores upto 125 mm out of 150 mm foamed asphalt layer

TABLE 3: Volumetric properties

Project/mix design	Layer*	Thickness, mm	Bulk Specific gravity	Theoretical Maximum Density	Air Voids (Average), %
Rt 15, Bucksport/2.5 % asphalt binder, 1.5 % cement	Top	64	NA	NA	NA
	Bottom	64	NA	NA	NA
Rt, 1, Orient/2.5 % asphalt binder, 1.5 % cement	Top	64	2.148 2.161 2.125	2.359 2.376	9.4
	Bottom	64	NA	NA	NA
Rt. 2A, Machowahoc/3.0 % asphalt binder, 1.5 % cement	Top	64	2.034 2.012 2.073	2.409 2.409	15.4
	Bottom	64	2.069 2.068 2.048		14.4

NA – not available
Foamed asphalt reclamation was done in one pass/layer; cores were separated into top and bottom parts to determine differences in properties, if any; note that only approximately 125 mm (out of 150 mm) of foamed asphalt layers could be cored out intact.

TABLE 4: Results of sieve analysis

Project	Layer	Gradation	
		Sieve Size, mm	% Passing
Rt 15, Bucksport	NA	NA	
Rt 1, Orient	Top ((Bottom not available)	37.5	
		25	
		19	100
		12.5	96
		9.5	89
		4.75	69
		2.36	54
		1.18	40
		0.6	27
		0.3	14
		0.15	7
		0.075	3.9
Rt. 2A, Machowahoc	Top	37.5	
		25	100
		19	98
		12.5	92
		9.5	87
		4.75	68
		2.36	52
		1.18	36
		0.6	24
		0.3	11
		0.15	5
		0.075	2.8
	Bottom	37.5	100
		25	96
		19	94
		12.5	91
		9.5	86
		4.75	70
		2.36	58
		1.18	41
		0.6	27
		0.3	15
		0.15	7
		0.075	3.9

NA – not available

TABLE 5: Moduli of foamed asphalt layers/materials

Project	Method of determination	Layer	Dry Modulus, MPa	Conditioned Modulus, MPa	Retained Modulus, %
Rt 15, Bucksport	FWD/Backc-alculate	NA	Average*: 1,473	NA	NA
Rt 1, Orient	Laboratory test	Top (Bottom not available)	2,039.5 2,129.5 2,165.0 Average**: 2,111	290 488 Average: 389	18
Rt 2A, Machowahoc	Laboratory test	Top	3,445.0 3,381.0 3,151.5 Average: 3,326	3,052 2,448 Average: 2,750	83
		Bottom	3961 4088 2979 Average: 3,676	NA	NA

* Average of all values (from multiple tests) from results of backcalculation showing low errors

** Average of values obtained from three samples

NA – Not available

TABLE 6: Results of fatigue tests conducted with the APA

Project	Material	Average Air Voids	Passes to failure
Rt 2A, Machowahoc	HMA	5.7	7,855 
	Foamed Asphalt	Average Voids: 15.4	221 

TABLE 7: Results of beam fatigue tests

With foamed asphalt reclaimed material from Route 2A, Machowahoc, and a typical 12.5 mm HMA

Foamed Asphalt

Strain level, microstrain	Cycles to Failure
200	2,152,710
500	32,760
500	50,510
500	11,390
700	3,330
700	3,330
700	13,360

HMA*

Strain level, microstrain	Cycles to Failure
200	2,600,000
500	400,230
700	65,240
700	76,190

* HMA beams were fabricated in the laboratory

FIGURE 1: Foamed Asphalt Project Locations

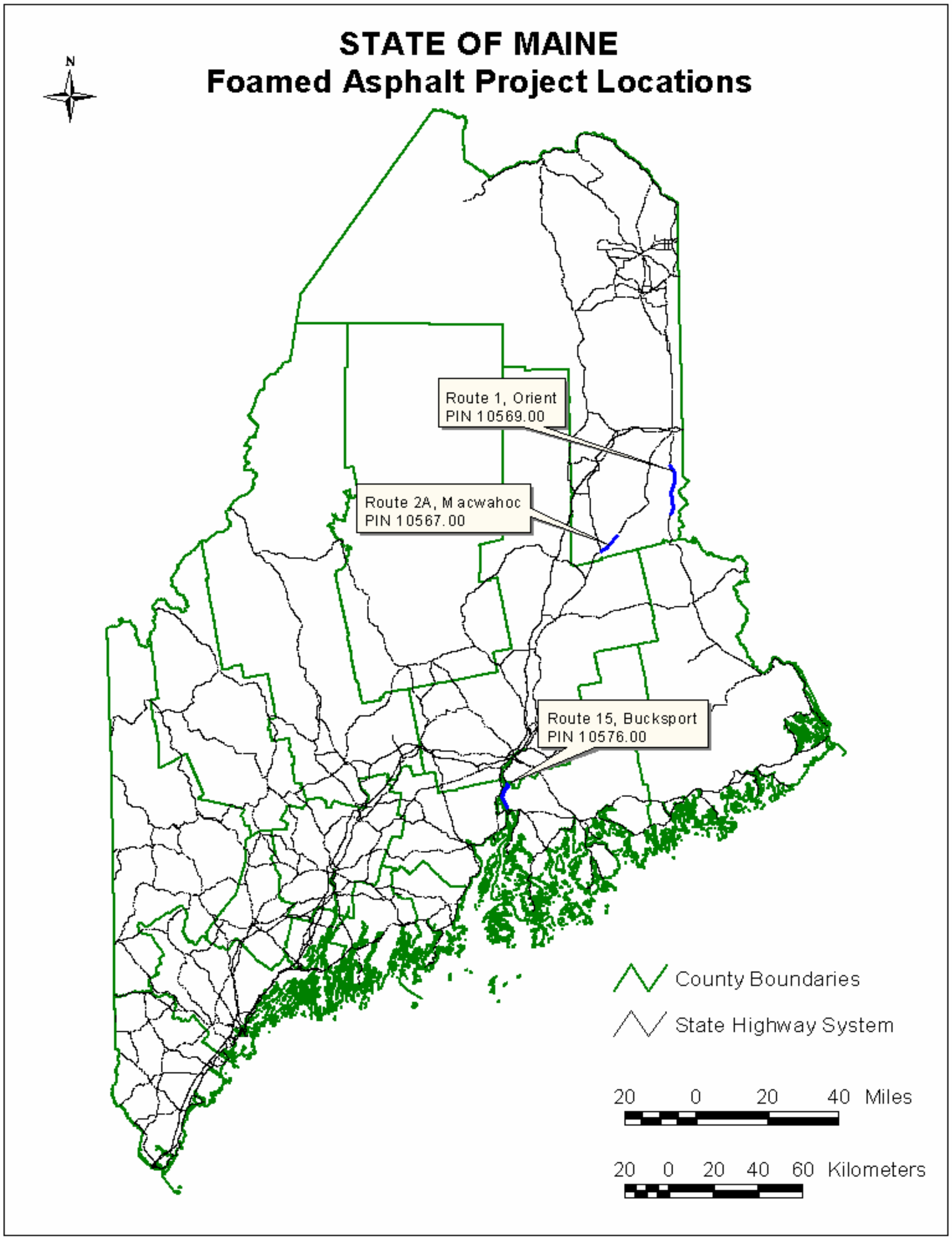
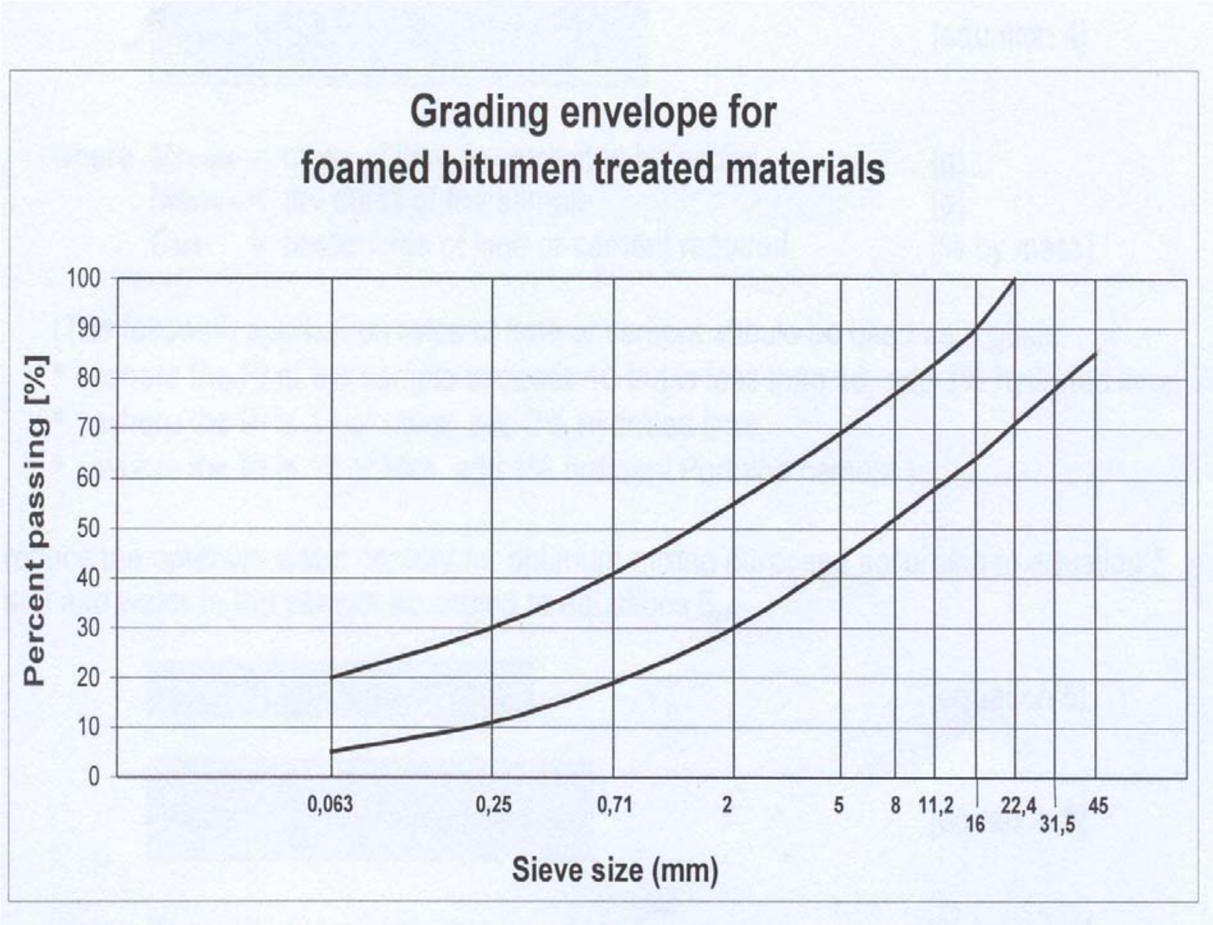


FIGURE 2: Grading envelope for foamed asphalt reclaimed materials (7)



APPENDIX A: Structural Layer Coefficient Calculations

Estimation of Structural Strength of Foamed Asphalt Layers

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Note: Abbreviations used in this report
HMA – Hot Mix Asphalt
FAM – Foamed Asphalt Concrete
BSM - Bituminous Stabilized Mixtures
ATB - Asphalt Treated Base

METHOD - I:-

Task 1
Comparison of resilient modulus (at 25 degC) of different layers of pavement structure for the 4 Maine projects with the resilient modulus of AASHTO mixes

Table 1: Resilient Modulus of Different Layers of Pavement for the ME Projects and the Standard Structure

Project	Resilient Modulus											
	Maine DOT Samples				AASHTO Guide Vol 1 (Part II, Ch 2, Table 2.7.), 1986 (1)							
	HMA (Tested)		FAM (Tested)		Bitumen Stabilized Mixtures (BSM)		Asphalt Treated Base (ATB)		Granular Subbase		Natural Subgrade Material	
	Mpa	ksi	Mpa	ksi	Mpa	ksi	Mpa	ksi	Mpa	ksi	Mpa	ksi
Belgrade-Rt 8	3377.0	489.8	1105.2	160.3	1172.1	170.0	4654.0	675.0	206.8	30.0	127.6	18.5
	2221.5	322.2	1173.5	170.2								
	3185.0	461.9	1285.5	186.4								
	2808.5	407.3	1622.0	235.3								
	2619.5	379.9	1142.5	165.7								
	2923.0	423.9	1509.5	218.9								
	2543.0	368.8	1297.5	188.2								
	3047.5	442.0	814.7	118.2								
Average	**2840.6**	**412.0**	**1243.8**	**180.4**								
Orient Cary-Rt 1	2191.5	317.9	2039.5	295.8								
	1798.0	260.8	2129.5	308.9								
	1822.5	264.3	2165.0	314.0								
Average	**1937.3**	**281.0**	**2111.3**	**306.2**								
Farmington-Rt 156	1106.0	160.4	2099.0	304.4								
	1394.5	202.3	2349.0	340.7								
	1375.5	199.5	2921.5	423.7								
	1310.5	190.1	2532.0	367.2								
	1574.0	228.3	2969.5	430.7								
	1593.0	231.0	2190.5	317.7								
	1531.5	222.1	2865.5	415.6								
	1593.0	231.0	2305.0	334.3								
Average	**1572.5**	**228.1**	**2453.7**	**355.9**								
Macwahoc-Rt 2A	1773.5	257.2	3445.0	499.7								
	1550.0	224.8	3381.0	490.4								
	1458.0	211.5	3151.5	457.1								
Average	**1593.8**	**231.2**	**3325.8**	**482.4**								

Note: HMA – Hot Mix Asphalt, FAM – Foamed Asphalt Mix

Task 2
Determine the potential of foamed asphalt as a structural base course

Step 1

- The four ME projects pavement structures were compared with a standard pavement structure based on AASHTO material properties.
- A 4-layer pavement structure was used for the comparison.
- The pavement structure consisted of a nonstructural HMA layer, foamed asphalt base layer, granular subbase, and subgrade.
- Variable thickness was assumed for the base layer of the four ME projects.

— Standard AASHTO resilient modulus for Bituminous Stabilized Mixtures (BSM) and Asphalt Treated Base (ATB), Granular Subbase were assumed for the standard pavement structure.

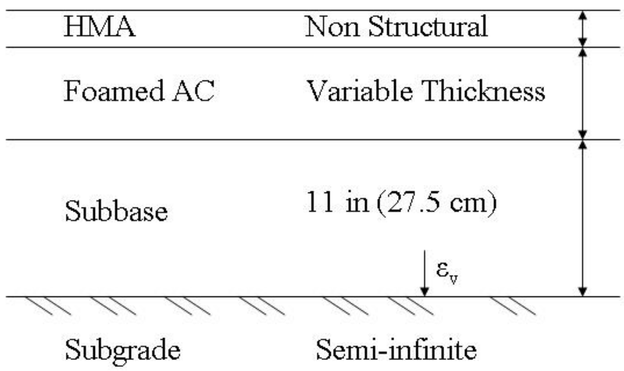

Fig 1-a Pavement Structure for Four ME Projects

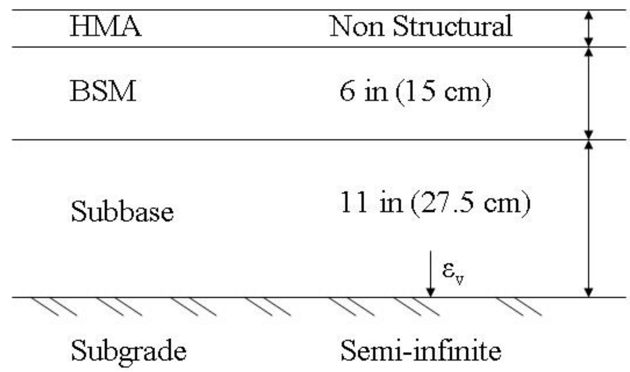

Fig 1-b Pavement Structure for Standard Structure Based on AASHTO Material Properties, BSM

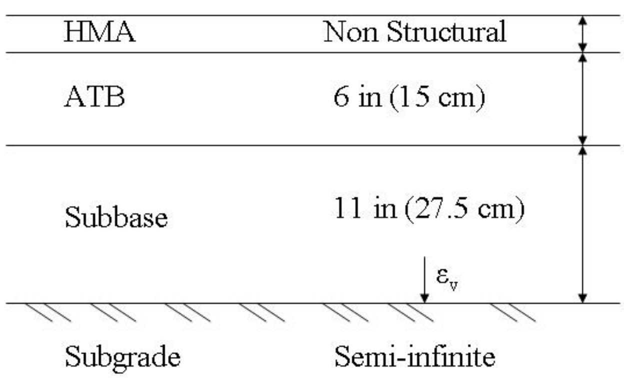

Fig 1-c Pavement Structure for Standard Structure Based on AASHTO Material Properties, ATB

Step 2
Using layered elastic analysis (WESLEA for Windows Version 3.0 software), vertical strains on top of subgrade layers for each of the structures as well as the AASHTO based structure were computed.

Table 2: Subgrade Vertical Strains

Strains (microstrain)				FAM layer thickness		Strains (microstrain)							
BSM (AASHTO) 15 cm (6 in)		ATB (AASHTO) 15 cm (6 in)				Belgrade-Rt 8		Orient Cary-Rt 1		Farmington-Rt 156		Macwahoc-Rt 2A	
Under tire	Center of dual tires	Under tire	Center of dual tires	(in)	(cm)	Under tire	Center of dual tires	Under tire	Center of dual tires	Under tire	Center of dual tires	Under tire	Center of dual tires
				2.0	5.0	641.12	655.01	616.29	640.72	608.54	636.02	591.75	625.20
				4.0	10.0	478.35	522.22	440.60	484.84	429.06	472.87	404.63	446.83
372.65	410.80	260.47	284.58	6.0	15.0	368.17	405.87	326.46	359.39	314.14	345.48	288.78	316.74
				8.0	20.0	291.72	320.48	250.75	273.86	239.03	260.54	215.47	233.84
				10.0	25.0	236.53	258.29	198.28	214.83	187.61	202.80	166.59	179.20
				12.0	30.0	195.76	212.45	160.83	173.05	151.29	162.39	132.75	141.80

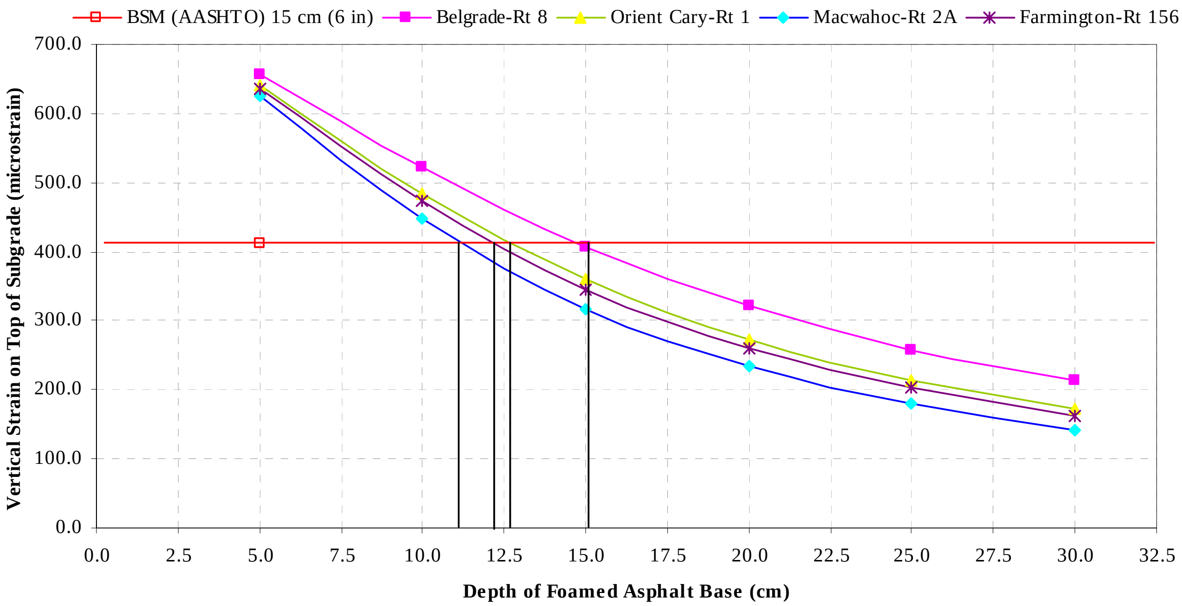

Fig 2-a Plot of Subgrade Strains - BSM Case

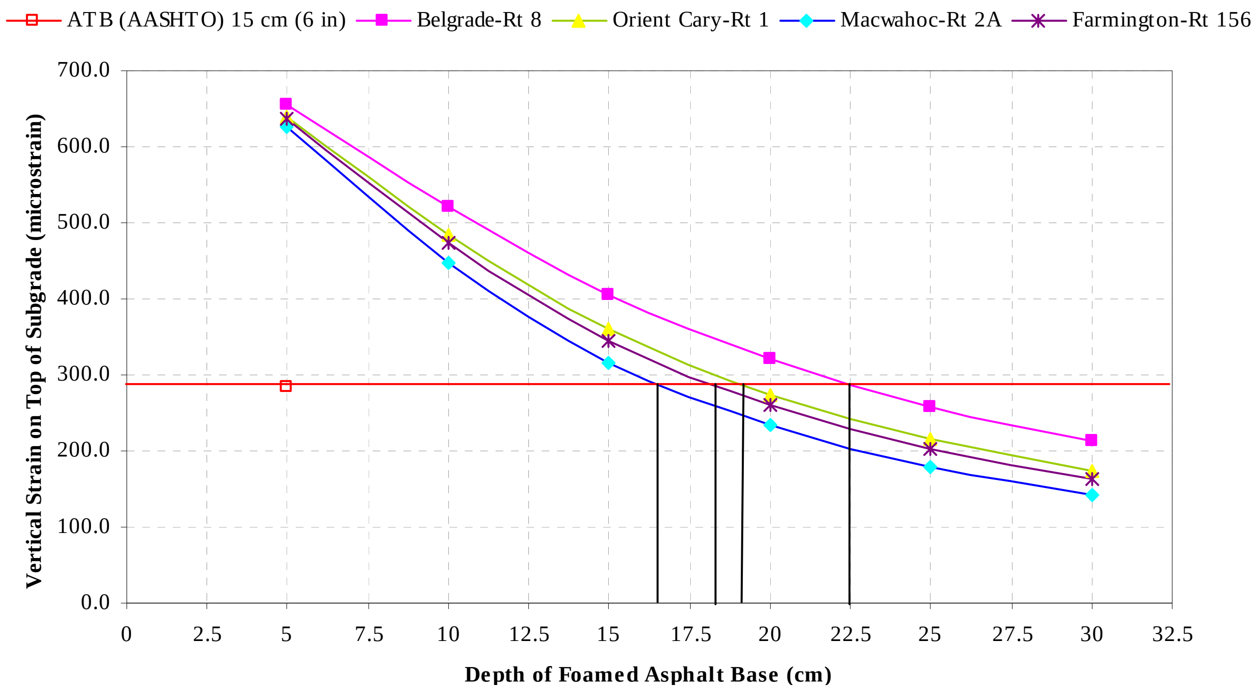

Fig 2-b Plot of Subgrade Strains - ATB Case

Step 3

Based on the computed subgrade strains, for each project, the base layer depth equivalent to the standard base layer based on AASHTO material properties were computed

Table 3-a: Equivalent Depths (Based on Subgrade Vertical Compressive Strain), compared to BSM

Project	Depth Equivalent to 6" BSM		d1/d(BSM-AASHTO)	Layer Equivalency	Average
	(cm)	(in)			
Belgrade-Rt 8	15.00	6.00	1.00	1.00	1.19
Orient Cary-Rt 1	12.75	5.10	0.85	1.18	
Farmington-Rt 156	12.19	4.88	0.81	1.23	
Macwahoc-Rt 2A	11.13	4.45	0.74	1.35	

d1 - depth of foamed asphalt base layer for various projects
d (BSM-AASHTO) - depth of AASHTO bituminous treated layer, i.e., 6 inches

Conclusions:

15.00 cm of foamed asphalt for Belgrade Rt 8 Project is equal to 15 cm of AASHTO Bituminous Stabilized Mixtures
12.75 cm of foamed asphalt for Orient Rt 1 Project is equal to 15 cm of AASHTO Bituminous Stabilized Mixtures
12.19 cm of foamed asphalt for Farmington Rt 156 Project is equal to 15 cm of AASHTO Bituminous Stabilized Mixtures
11.13 cm of foamed asphalt for Macwahoc Rt 2A Project is equal to 15 cm of AASHTO Bituminous Stabilized Mixtures

Table 3-b: Equivalent Depths (Based on Subgrade Vertical Compressive Strain), compared to ATB

Project	Depth Equivalent to 6" ATB		d1/d(ATB-AASHTO)	Layer Equivalency	Average
	(cm)	(in)			
Belgrade-Rt 8	22.50	9.00	1.50	0.67	0.79
Orient Cary-Rt 1	19.13	7.65	1.28	0.78	
Farmington-Rt 156	18.37	7.35	1.22	0.82	
Macwahoc-Rt 2A	16.56	6.62	1.10	0.91	

d1 - depth of foamed asphalt base layer for various projects
d (ATB-AASHTO) - depth of AASHTO bituminous treated layer, i.e., 6 inches

Conclusions:
22.5 cm of foamed asphalt for Belgrade Rt 8 Project is equal to 15 cm of AASHTO Asphalt Treated Base
19.13 cm of foamed asphalt for Orient Cary Rt 1 Project is equal to 15 cm of AASHTO Asphalt Treated Base
18.37 cm of foamed asphalt for Farmington Rt 156 Project is equal to 15 cm of AASHTO Asphalt Treated Base
16.56 cm of foamed asphalt for Macwahoc Rt 2A Project is equal to 15 cm of AASHTO Asphalt Treated Base

METHOD - II:-

Task 1
Determine the structural strength of the foamed asphalt base layers for the four ME projects by computing their layer coefficients.

Step 1
Plot deflection bowl

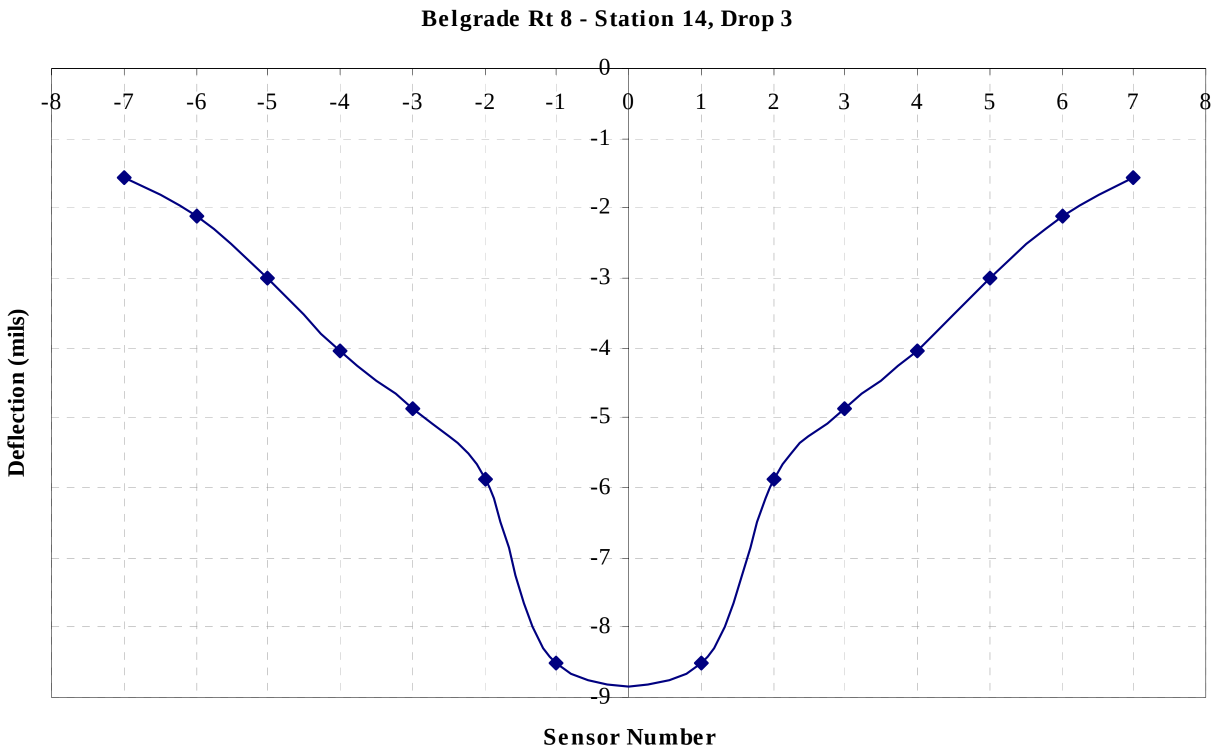

Fig 1-a Deflection Basin Based on FWD Data – Belgrade Rt 8

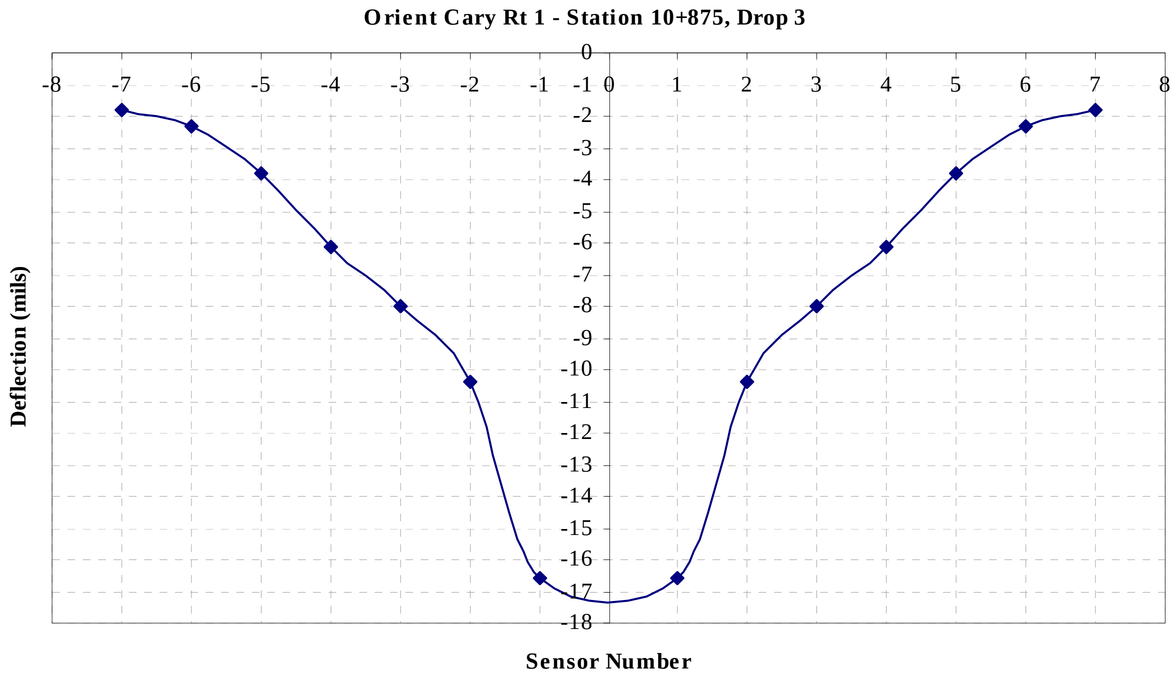

Fig 1-b Deflection Basin Based on FWD Data - Orient Rt 1

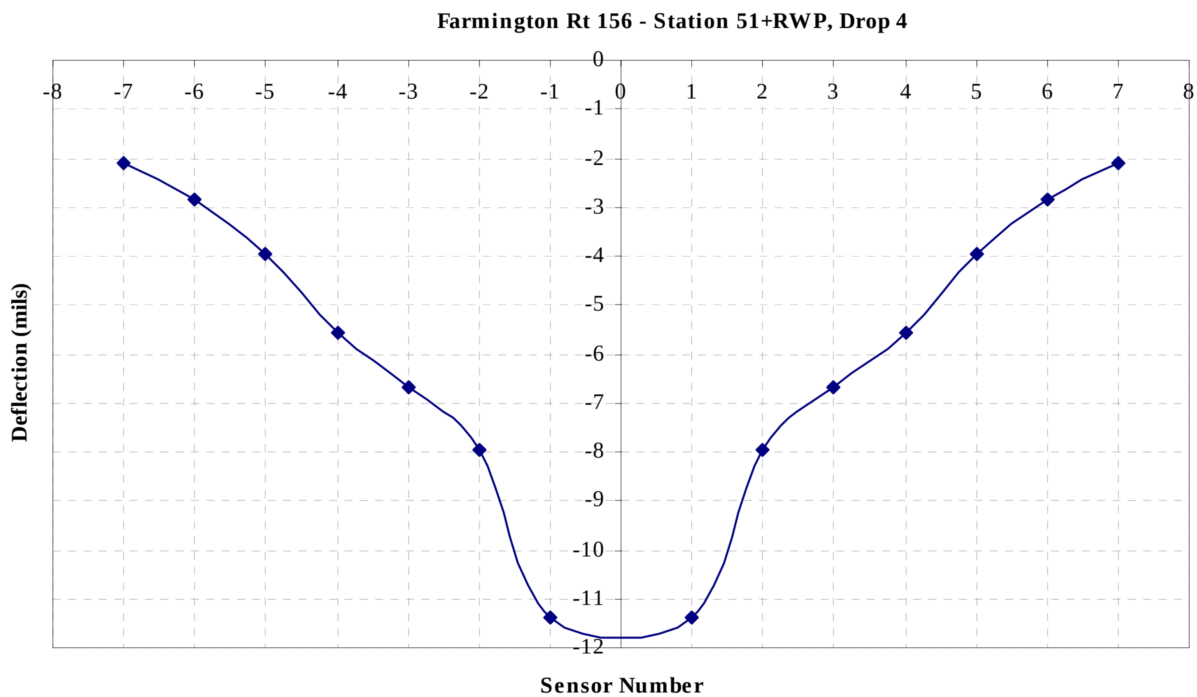

Fig 1-c Deflection Basin Based on FWD Data - Farmington Rt 156

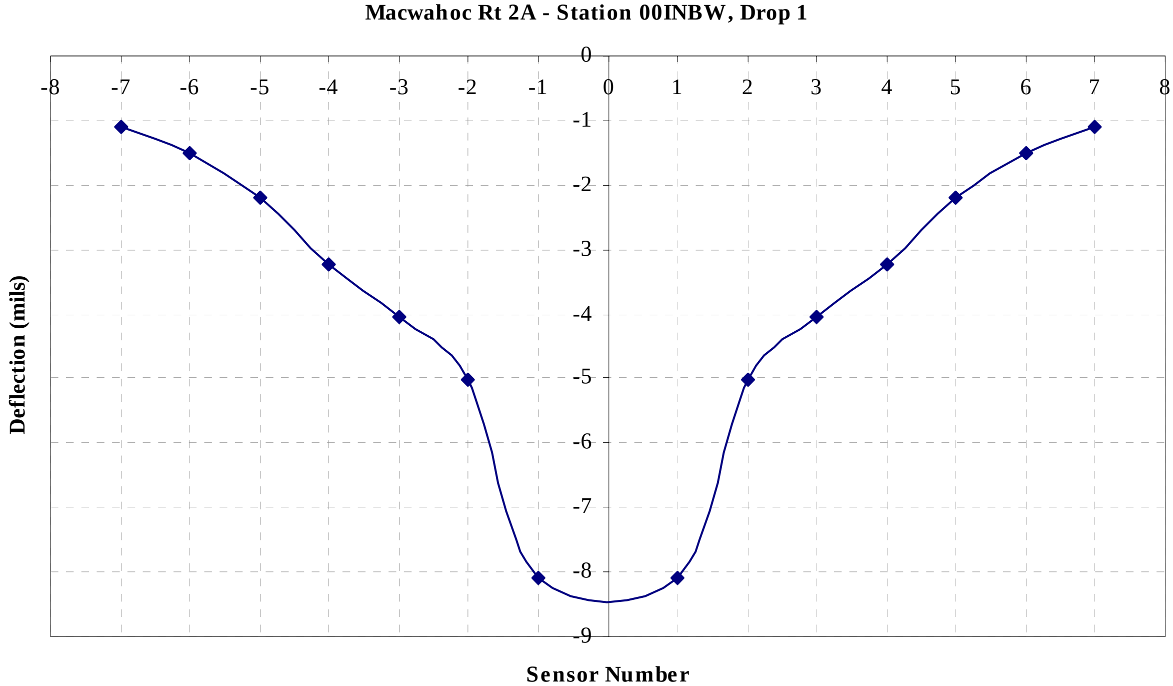

Fig 1-d Deflection Basin Based on FWD Data - Macwahoc Rt 2A

Step 2

Pick sensor with radial distance from load greater than (0.7*a_e)

"a_e" is the radius of the stress/deflection bulb at the subgrade-pavement interface

Table 1-a: FWD Sensor Distances

Sensor	1	2	3	4	5	6	7
Distance from load, in (cm)	0 (0.0)	12 (30.0)	18 (45.0)	24 (60.0)	36 (90.0)	48 (120.0)	60 (150.0)

Table 1-b: Computation of (0.7*ae)

a_e in (cm)	**0.7*a_e in (cm)**
60 (150)	42 (105)

Therefore, the sensor that falls beyond 0.7a_e is sensor 6.

Step 3
Determine Backcalculated Subgrade Resilient Modulus

Table 2: Backcalculated Subgrade Resilient Modulus

	Belgrade	Orient	Farmington	Macwahoc
P, lb	9100.0	9110.0	9030.0	8920.0
d_r, mils (in)	2.11 (0.00211)	2.35 (0.00235)	2.85 (0.00285)	1.52 (0.00152)
r, in	48.0	48.0	48.0	48.0
M_r, psi	**21564.0**	**19383.0**	**15842.1**	**29342.1**

P = applied load
d_r = deflection at a distance r from center of the load
r = distance from the center of the load
M_r = backcalculated subgrade resilient modulus

$$M_r = \frac{(0.24 * P)}{(d_r * r)}$$

Step 4
Determine Effective Modulus of Pavement Layers above Subgrade

Table 3: Effective Modulus of Pavement Layers above Subgrade

	Belgrade	Orient	Farmington	Macwahoc
d_0, mils (in)	8.52 (0.00852)	16.60 (0.01660)	11.37 (0.01137)	8.10 (0.00810)
a, in	6.0	6.0	6.0	6.0
A, sq.in.	113.1	113.1	113.1	113.1
p	80.5	80.6	79.8	78.9
D, in	32.2	22.0	28.0	22.0
E_p	**135979.0**	**67615.0**	**109165.0**	**152375.0**

Note: E_p was determined by trial and error method
d_0 = temperature corrected central deflection, in
a = load plate radius, in
A = load plate area, sq.in
p = load pressure, psi
D = total thickness of all pavement layers above subgrade, in
E_p = effective modulus of pavement layers above subgrade, psi

Ep was determined such that the following equation is satisfied:

$$d_0 = 105 * p * a * \left\{ \frac{1}{M_r * \left[1 + \left(\frac{D}{a} * \left(\frac{E_p}{M_r} \right)^{1/3} \right)^2 \right]^{0.5}} + \frac{1 - \frac{1}{1 + \left(\frac{D}{a} \right)^2}}{E_p} \right\}$$

Step 5
Determine Effective Structural Number of the Pavement

Table 4: Effective Structural Number of the Pavement

	Belgrade	Orient	Farmington	Macwahoc
SN_{eff}	7.44	4.03	6.02	5.29

SN_{eff} = effective structural number of the pavement

$$SN_{eff} = 0.0045 * D * E_p^{1/3}$$

Step 6
Determine the Structural Layer Coefficient of Foamed Asphalt Base Layers

Table 5: Structural Layer Coefficient of Foamed Asphalt Base Layer

Project		HMA	Foamed AC Base	Granular Subbase (backcalculated)
Belgrade-Rt 8	**Mr (ksi)**	412.0		51.6
	D (in)	4.0	8.0	20.3
	a	0.44		0.20
	a_2		**0.22**	
Orient Cary-Rt 1	**Mr (ksi)**	281.0		21.7
	D (in)	4.0	6.0	12.0
	a	0.35		0.10
	a_2		**0.23**	
Farmington-Rt 156	**Mr (ksi)**	228.1		46.2
	D (in)	4.0	6.0	18.0
	a	0.35		0.18
	a_2		**0.22**	
Macwahoc-Rt 2A	**Mr (ksi)**	231.2		37.3
	D (in)	4.0	6.0	12.0
	a	0.32		0.16
	a_2		**0.35**	

Note: In the backcalculation step, the range of Mr for the HMA and the foamed asphalt base were determined on the basis of the results of laboratory tests on HMA and foamed asphalt field cores.

M_r = resilient modulus of various layers
a = layer coefficients of various layers
a_2 = layer coefficient of foamed asphalt base layer
D = layer thickness, in

a_3 i.e. layer coefficient of granular subbase layer was calculated using the following formula

$$a_3 = 0.249 * \log_{10}(M_r) - 0.977$$

Mr = backcalculated modulus of granular subbase, psi

$$a_2 = \frac{SN_{eff} - a_1 D_1 - a_3 D_3}{D_2}$$

a_1, a_2, a_3 = layers coefficients of HMA, foamed asphalt base, granular subbase respectively
D_1, D_2, D_3 = layers thickness of HMA, foamed asphalt base, granular subbase respectively

Table 6: Structural Strength of Foamed Asphalt

Project	Age (years)	Laboratory Resilient Modulus[1]		Backcalculated Modulus		Layer Equivalence Based on Equal Strain		Layer Coefficient[2]
		MPa	ksi	MPa	ksi	BSM	ATB	
Belgrade-Rt 8	>2	1243.8	180.4	999.3	144.9	1.00	0.67	0.22
Orient Cary-Rt 1	<1	2111.3	306.2	655.0	95.0	1.18	0.78	0.23
Farmington-Rt 156	<1	2453.7	355.9	1827.1	265.0	1.23	0.82	0.22
Macwahoc-Rt 2A	<1	3325.8	482.4	2505.1	363.3	1.35	0.91	0.35

Note: 1. Laboratory tests were conducted on cores taken from top part of the layer only. Intact cores could only be taken from top 100 mm of the layers.
2. Determined according to procedure outlined in AASHTO Guide for Design of Pavement Structures, 1993 as done in Reference 3.

References:

1. **AASHTO Guide for Design of Pavement Structures**, 1986
2. **AASHTO Guide for Design of Pavement Structures**, 1993
3. **Romanoschi, S. A., Hossain, M., Heitzman, M., and Gisi, A. J.,** "Foamed Asphalt Stabilized Reclaimed Asphalt Pavement: A Promising Technology for Mid-Western Roads", Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa, August 2003.