16 State House Station
Augusta, Maine 04333

MaineDOT

Transportation Research Division

Technical Report 02-2

Using Foamed Asphalt as a Stabilizing Agent in Full Depth Reclamation of Route 8 in Belgrade

Interim Report – Third and Fourth Year, October 2006

Transportation Research Division

Using Foamed Asphalt as a Stabilizing Agent in Full Depth Reclamation of Route 8 in Belgrade

Introduction

Maine has a variety of soil types throughout the state. A majority of these soil types degrade rapidly and have poor stability. To eliminate the cost of supplying quality road base material from a distant source and increase the stability of existing soils, the Maine Department of Transportation (MaineDOT) has been requiring contractors to rehabilitate roads using the full depth reclamation process.

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.

In addition to using full depth reclaimed material, MaineDOT has been experimenting with adding a number of stabilizing agents to virgin or recycled base materials to increase stability. Stabilizing agents utilized include cement, emulsion and calcium chloride.

Foamed Asphalt is another stabilizing agent. This 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 shaped to grade and compacted. Traffic can operate on the stabilized base until a hot mix asphalt base and wearing surface is applied. This paper will evaluate the performance of Foamed Asphalt over a five year period.

Project Description

Federal project number STP-9197(00)X on State Route 8 between the towns of Belgrade and Smithfield was selected for Foamed Asphalt stabilization (Figure 1). This is a Highway Improvement project beginning at the intersection of State Route 11 in Belgrade and extending northerly 10.15 km (6.31 mi). This project has a high occurrence of frost deformation with rut depths of 18 mm (0.7 in) in areas and International Roughness Index values as high as 3.17 m/km (201 in/mi). Sections of the project were built to state standards and are scheduled for resurfacing only. Other sections are scheduled for Full Depth Reconstruction, Full Depth Reclamation, Full Depth Reclamation with Variable Depth Gravel, or Full Depth Reclamation with Foamed Asphalt.

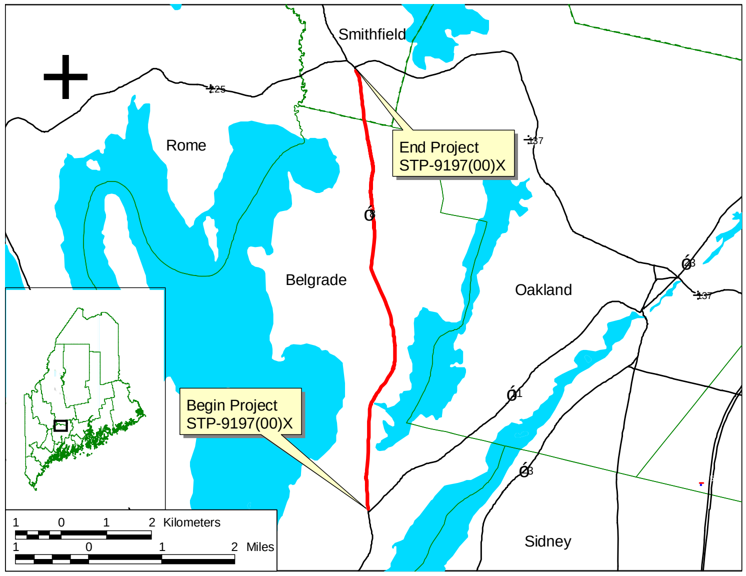


Figure 1: Project No. STP-9197(00)X Location Map

Preliminary Data Collection

A detailed overview of preliminary data collection can be reviewed in Technical Report 02-2 “Using Foamed Asphalt as a Stabilizing Agent in Full Depth Reclamation of Route 8 in Belgrade” Construction Report, February 2002.

Foamed Asphalt Mix Design

Foamed Asphalt Mix Design procedures can also be reviewed in Technical Report 02-2 “Using Foamed Asphalt as a Stabilizing Agent in Full Depth Reclamation of Route 8 in Belgrade” Construction Report, February 2002.

Construction

Construction and treatment details as well as typical cross-sections can be reviewed in Technical Report 02-2 “Using Foamed Asphalt as a Stabilizing Agent in Full Depth Reclamation of Route 8 in Belgrade” Construction Report, February 2002. Table 1 contains station limits for each treatment.

Table 1: Project Treatment by Section (not to scale)

From Station	To Station	Layer 1	Layer 2	Layer 3
1+160	1+400	SURF	SHIM	
1+400	1+490	SURF	60 B	FDR
1+490	1+640	SURF	60 B	RECON
1+640	2+680	SURF	40 B	FDRBS
2+680	2+795	SURF	SHIM	
2+795	3+460	SURF	60 B	FDRVDG
3+460	3+527	SURF	60 B	RECON
3+527	3+600	SURF	60 B	FDR
3+600	3+700	SURF	60 B	RECON
3+700	3+820	SURF	60 B	FDR
3+820	4+000	SURF	60 B	FDRVDG
4+000	4+130	SURF	60 B	FDR
4+130	4+205	SURF	60 B	RECON
4+205	4+380	SURF	60 B	FDRVDG
4+380	4+900 *	SURF	SHIM	
4+900 *	6+860	SURF	40 B	FDRBS
6+860	7+600	SURF	SHIM	
7+600	8+720	SURF	40 B	FDRBS
8+720	9+520	SURF	FDRBS	
9+520	11+280	SURF	SHIM	

SURF = 40 mm of 12.5 mm HMA Surface	RECON = Full Depth Reconstruction
SHIM = Variable Depth 9.5 mm HMA Shim	FDR = Full Depth Reclamation
40 B = 40 mm of 12.5 mm HMA Base	FDRVDG = Full Depth Reclamation w/ Variable Depth Gravel
60 B = 60 mm of 12.5 mm HMA Base	FDRBS = Full Depth Reclamation w/ Bituminous Stabilizer

* No crusher dust between stations 6+445 and 6+525

Cost Summary

Table 2 contains a Cost Summary for each treatment. As expected the Hot Mix Asphalt (HMA) Overlay has the lowest cost and Full Depth Reconstruction has the highest cost.

The Full Depth Reclamation without Stabilizer and Asphalt Stabilized Base without HMA Base are very similar in costs. Evaluation of these sections over the five-year period will determine which treatment is cost effective.

Sections treated with Full Depth Reclaimed material plus Variable Depth Gravel and Asphalt Stabilized Base with HMA Base are also similar in costs. Once again evaluation of these sections will determine which treatment is cost effective.

Table 2: Treatment Cost Summary (cost per square meter)

Treatment	40 mm HMA Surface	Shim[1]	40 mm HMA Base	60 mm HMA Base	FDR	VDG[2]	Excavation	ASCG[3]	Stabilized Subbase	Total Cost
Hot Mix Asphalt Overlay	3.42	2.93								6.35
Full Depth Reclamation	3.42			5.13	1.33					9.88
FDR with Variable Depth Gravel	3.42			5.13	1.33	5.04				14.92
Full Depth Reconstruction	3.42			5.13			5.04	8.29		21.88
Stabilized Base w/HMA Base	3.42		3.42						8.32	15.16
Stabilized Base wo/HMA Base	3.42								8.32	11.74

[1] Average depth of 35 mm
[2] Variable Depth Gravel (average depth of 360 mm)
[3] Aggregate Subbase Course Gravel (650 mm depth)

Project Evaluation

The project will be evaluated over a period of five years. Three experimental areas were demarcated for evaluation, one control and two test sections. Performance of each test section will be compared to the control section and summarized in the Experimental Test Section Analysis portion of the report. Data collection will include Falling Weight Deflectometer (FWD) measurements to monitor changes in structural integrity of each section plus roughness, rutting, and cracking to monitor surface conditions.

In addition to evaluating the control and test sections, FWD tests will be collected every 100 meters to monitor structural changes within each treatment and the Automatic Road Analyzer (ARAN) will test the entire project for rut depth and roughness. A visual evaluation of the entire project will be conducted in late winter/early spring of each year to locate areas that have frost movement. Results of these tests are summarized in the Project Analysis section of the report.

Experimental Test Section Analysis

It was important to select a Control Section that closely compares to the Foamed Asphalt treated sections.

A Control Section, located between stations 3+700 and 3+820, was constructed using full depth reclaimed material for the subbase much like the Foamed Asphalt sections only without bituminous stabilizer. Caution was taken to select an area that has no variable depth gravel added to the recycled subbase. The surface is paved with 60 mm of 12.5 mm Hot Mix Asphalt (HMA) Base and 40 mm of 12.5 mm HMA Surface.

Test Section One is located between stations 4+980 and 5+180. The reclaimed subbase is treated with Foamed Asphalt. The surface is paved with 40 mm of 12.5 mm HMA Base and 40 mm of 12.5 mm HMA Surface.

Test Section Two is located between stations 9+100 and 9+300. This section has Foamed Asphalt stabilized subbase and is surfaced with 40 mm of HMA Surface with no HMA Base.

Structural Summary

Pavement deflections were recorded on September 16, 2004 and September 6, 2005. Readings were collected at the same locations in all three sections for each year.

FWD data was processed using DARWin Pavement Design Analysis System. DARWin utilizes FWD deflections plus pavement and gravel depths to determine Subgrade Resilient Modulus, Existing Pavement Modulus, Effective Existing Pavement Structural Number, and Structural Number for Future Traffic.

The Effective Existing Pavement Structural Number (ESN) measures the structural ability of a roadway to carry traffic loads. Deflections of HMA and subbase material above subgrade are used to calculate the ESN making it a good tool to monitor roadway stability. Accurate pavement and subbase gravel depths are necessary to determine the ESN. Material layer depths from construction plans were used to assure subgrade materials were not influencing FWD deflections. Reclaimed subbase material stabilized with foamed asphalt was considered pavement in the ESN calculations. Figure 2 displays the Hi, Low, Mean, and Standard Deviation for each test section.

The Control Section has an average ESN of 97 in 2004 then increased to 98 in 2005. Although the average ESN has remained stable for the past four years the standard deviation is high indicating non-uniformity within the section.

The average ESN in Test Section One, with 80 mm (3 in) of HMA over 200 mm (8 in) of foamed asphalt, decreased from 102 in 2003 to 96 in 2004, then decreased to 95 in 2005. It’s interesting that the ESN was much higher than the Control Section during the first two years then decreased to levels below the Control Section the following two years. Although the average ESN is less than the Control Section in 2004 and 2005 the Standard Deviation is considerably less all four years, indicating that Test Section One is more uniform and in theory will distribute traffic loads more effectively over time.

Test Section Two, with 40 mm (1.5 in) of HMA over 200 mm (8 in) of foamed asphalt, ESN values remained the same at 95 for years 2003 and 2004 then decreased to 93 in 2005. Average ESN were greater than the Control Section in 2002 then decreased to levels lower than the Control Section in the following years. This section also has lower average Effective Existing Structural Numbers than Test

Section Two which is understandable due to the thinner asphalt layer. What is interesting is the low Standard Deviation for all four years indicating that structural integrity is more uniform than both sections possibly due to refined Foamed Asphalt construction methods when this section was built. This section has been and continues to show early signs of pavement failure in the way of rutting and cracking which will be summarized later in the report. Early pavement deterioration could be attributed to the thin HMA layer.

A statistical comparison of ESN using Tukey's Studentized Range (HSD) Test resulted in no significant difference between test sections.

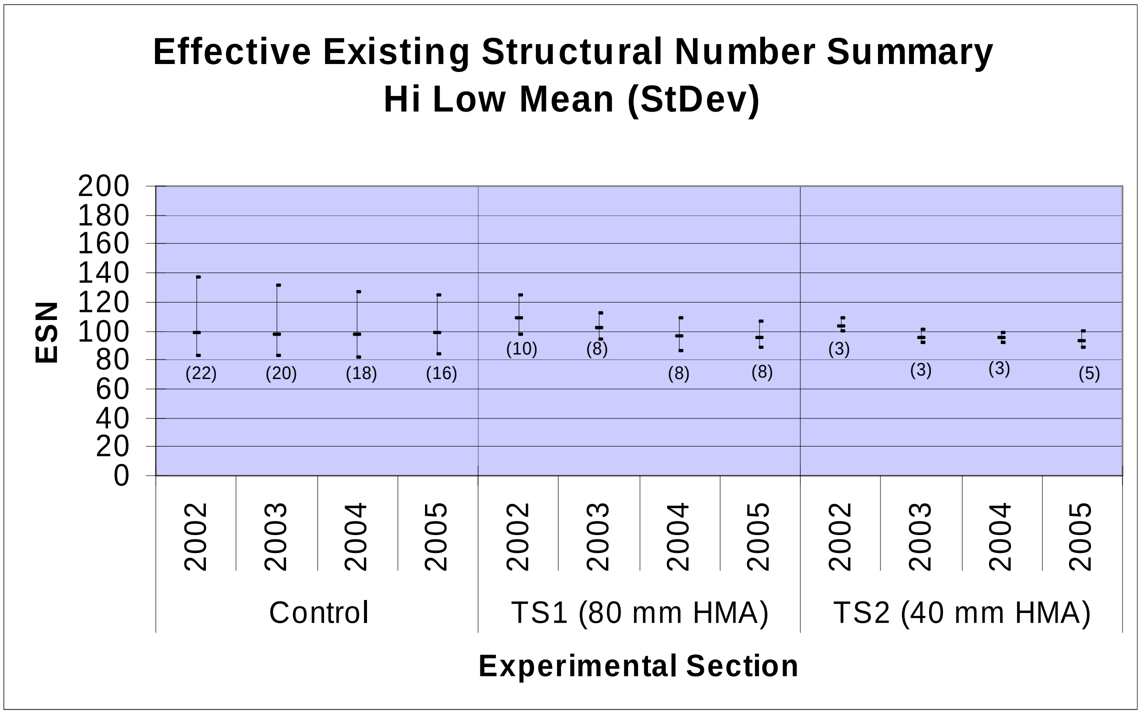
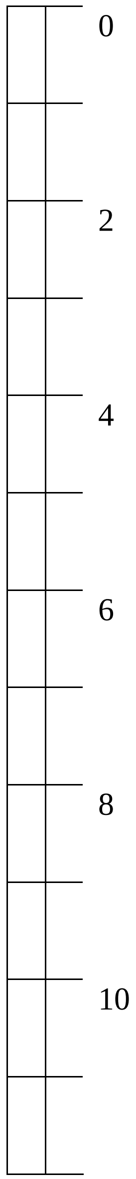


Figure 2: Effective Existing Structural Number Summary

Ride Summary

Smoothness measurements were collected on November 2, 2004 and August 23, 2005 utilizing the departments Automatic Road Analyzer (ARAN). This is an ASTM Class II profile-measuring device that is capable of accurately measuring roadway smoothness. The ARAN measures lateral profile of each wheel path every 50 mm (2 in) then averages those measurements every 20 meters (66 ft). Smoothness is displayed in International Roughness Index (IRI) units that start at zero for a road with no roughness and increases in positive increments in proportion to roughness. Figure 3 contains an IRI scale with verbal descriptions taken from ASTM Standard E 1926-98 “Computing International Roughness Index of Roads from Longitudinal Profile Measurements”.



Ride comfortable over 120 km/h. Undulation barely perceptible at 80 km/h in range 1.3 to 1.8. No depressions, potholes, or corrugations are noticeable; depressions < 2 mm/3 m. Typical high quality asphalt 1.4 to 2.3, high quality surface treatment 2.0 to 3.0.

Ride comfortable up to 100 - 120 km/h. At 80 km/h, moderately perceptible movements or large undulations may be felt. Defective surface; occasional depressions, patches or potholes (e.g. 5 - 15 mm/3m or 10 - 20 mm/5m with frequency 2 - 1 per 50 m), or many shallow potholes (e.g. on surface treatment showing extensive raveling). Surface without defects; moderate corrugations or large undulations.

Ride comfortable up to 70 - 90 km/h, strongly perceptible movements and swaying. Usually associated with defects; frequent moderate and uneven depressions or patches (e.g. 15 - 20 mm/3m or 20 - 40 mm/5m with frequency 5 - 3 per 50 m), or occasional potholes (e.g. 3 - 1 per 50 m). Surface without defects: strong undulations or corrugations.

Ride comfortable up to 50 - 60 km/h, frequent sharp movements or swaying. Associated with severe defects: frequent deep and uneven depressions and patches (e.g. 20 - 40 mm/3m or 40 - 80 mm/5m with frequency 5 - 3 per 5 m), or frequent potholes (e.g. 4 - 6 per 50 m).

Necessary to reduce velocity below 50 km/h. Many deep depressions, potholes and severe disintegration (e.g. 40 – 80 mm deep with frequency 8 – 16 per 50 m).

Figure 3: Road Roughness Scale for HMA Paved Roads

Figure 4 contains a summary of IRI values for each test section. Roughness values remain in the comfortable ride category between 1.3 and 1.8 m/km (82 – 114 in/mi) even though average IRI values have increased in all sections over the past two years.

The Control Section continues to have higher IRI values than Test Sections One and Two. Roughness increased 16 percent in 2004 and 11 percent in 2005 to an IRI of 1.65 m/km (105 in/mi) and 1.84 m/km (117 in/mi) respectively. The standard deviation is also greater than the test sections indicating a non-uniform ride which could contribute to an abnormal increase in IRI values with time.

Test Section One has consistently had the lowest average IRI. Roughness values range from a low of 1.03 m/km (65 in/mi) in 2003 to a high of 1.64 k/km (104 in/mi) in 2005. Standard deviation has also been low indicating a uniform roadway treatment.

Test Section Two has lower IRI values than the Control Section but slightly higher than Test Section One. Roughness values range from a low of 1.25 m/km (79 in/mi) in 2002 to a high of 1.76 m/km (112 in/mi) in 2005. Standard deviations are lower than the Control Section but slightly higher than Test Section Two indicating the section is not as uniform as Test Section Two. The lack of HMA base may be contributing to the increased IRI values.

A statistical comparison of IRI values using Tukey's Studentized Range (HSD) Test resulted in no significant difference between test sections.

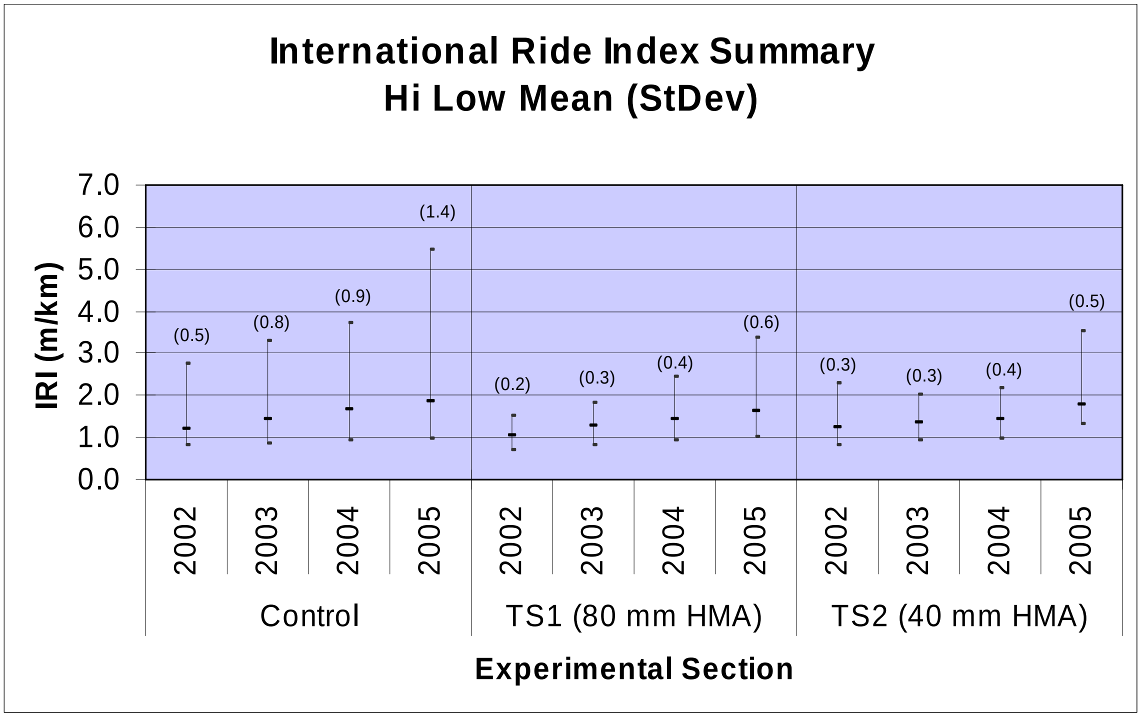


Figure 4: International Ride Index Summary

Rut Depth Summary

Rut depth measurements were collected on November 2, 2004 and August 23, 2005 utilizing the ARAN test vehicle. Rut depth measurements are collected in each wheel path every 50 mm (2 in) then averaged at 20 m (66 ft) intervals. Depths are accurate to the nearest millimeter or tenth of an inch when measuring in US Customary units. Figure 5 contains a summary of ARAN Rut Depth measurements.

Rutting is minimal after four years exposure to traffic. Average rut depths range from a low of 3.4 mm (0.13 in) in Test Section One to a high of 6.7 mm (0.26 in) in the Control Section.

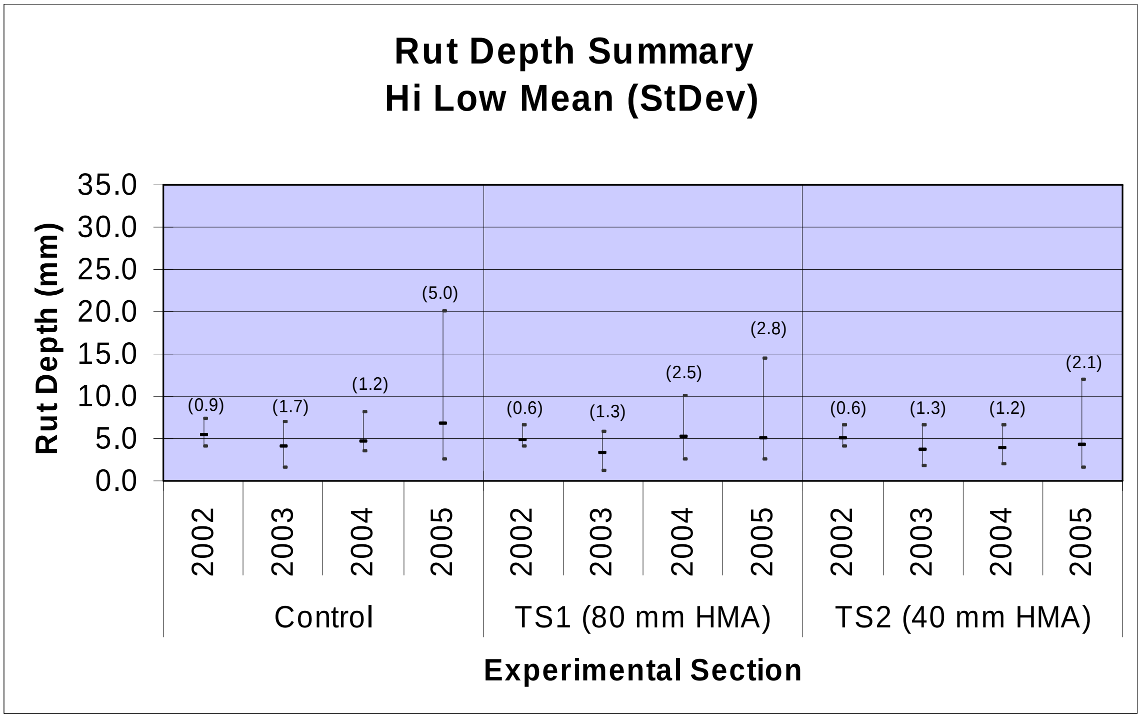


Figure 5: Rut Depth Summary

Mean rut depths in the Control Section increased 10 percent in 2004 and 49 percent in 2005 to a depth of 4.5 mm (0.18 in) and 6.7 mm (0.26 in) respectively. A cross pipe settled in the north end of the section resulting in an isolated high rut depth reading of 20 mm (0.79 in) and a high standard deviation of 5.0. Overall rutting is higher than both test sections.

Rutting in Test Section One increased 53 percent in 2004 to an average depth of 5.2 mm (0.21 in). Rutting improved 6 percent in 2005 to an average depth of 4.9 mm (0.19 in). With the exception of 2004 data, mean rut depths and standard deviations have been lower than the Control Section.

Test Section Two with, 40 mm (1.5 in) of HMA, has consistently less rutting and lower standard deviation than the Control Section and has been performing better than Test Section One for the past two years. One reason for this may be attributed to the quality of Foamed Asphalt. The contractor had no experience placing Foamed Asphalt and started on the south end of the project with guidance from the people at Wirtgen America Inc. By the time the contractor reached the north end of the project the quality of Foamed Asphalt had improved resulting in a more uniform material that may have greater stability.

A statistical comparison of 2005 Rut Depth measurements revealed no significant difference between test sections.

Visual Summary

A visual inspection was completed on September 15, 2004 and September 2, 2005. The pavement on all three sections looks very good after four years exposure to traffic. Table 3 contains a crack summary of each experimental section.

Centerline separation is displayed as a percent of the length of the section.

Transverse cracks are displayed as the number of full roadway width cracks every 100 meters (328 feet) of the experimental section; for example, if there was one full and one half roadway transverse crack in a section that was 150 meters (492 ft) in length the number per 100 meters (328 ft) would be 1. If the same number of cracks were in a section that is 200 meters (656 ft) in length the number per 100 meters (328 ft) would be 0.75.

Longitudinal cracking mainly occurs between wheel paths in a lane. This type of cracking is displayed as a percentage of the combined length of each lane.

Load cracking is displayed as a percentage of the total area of a section.

Centerline separation in the Control Section has increased from 27 percent in 2003 to 34 percent in 2004 and 38 percent in 2005. One transverse crack across one quarter of the roadway was observed in 2004. The same crack extended to three quarters across the roadway in 2005. Longitudinal cracking between wheel paths increased from 0.4 percent in 2003 to 0.6 in 2004 and 1.7 percent in 2005. There were no load cracks in 2004 and a total of 2.9 square meters (31.2 sq. ft.) of initial load cracking in 2005.

Table 3: Visual Inspection Summary

	Crack Type																													
	Centerline, % of length					Transverse, # / 100 meters					Longitudinal, % of length					Load, % of area														
																Initial					Moderate					Severe				
Section	02	03	04	05	06	02	03	04	05	06	02	03	04	05	06	02	03	04	05	06	02	03	04	05	06	02	03	04	05	06
Control		27	34	38				0.2	0.6			0.4	0.6	1.7					0.4											
TS1		10	15	18					0.6				0.2	0.6				0.1	0.1											
TS2		33	55	79			0.2	0.9	1.2			0.5	1.7	1.9			0.2	1.3	2.7											

Test Section One with 80 mm (3 in) of HMA continues to have the lowest amount of cracking. Centerline cracking increased to 15 and 18 percent in 2004 and 2005 respectively. Four transverse cracks were observed in 2005. One was halfway across the road and three were a quarter across the road. Longitudinal cracking was first observed in 2004 at a total of 0.2 percent which increased to 0.6 percent in 2005. This section has the least amount of load cracking with 0.1 percent in 2004 and 2005. The low amount of load cracking suggests that the foamed asphalt combined with 80 mm (3 in) of HMA continues to distribute traffic loads more efficiently than the Control and Test Section Two.

Test Section Two has the majority of cracking. There is more than twice as much centerline and transverse cracking. Longitudinal cracking increased dramatically from 0.5 to 1.7 percent between 2003 and 2004 then increased to 1.9 percent in 2005. Load cracking increased from 0.2 percent in 2003 to 1.3 percent in 2004 then more than doubled to 2.7 in 2005. Although FWD deflections indicate that the roadway is structurally sound the thin layer of HMA is showing signs of premature cracking which could lead to accelerated roadway failure in the future.

Project Analysis

This portion of the report will summarize Effective Structural Number, IRI, and Rut Depth measurements on each treatment within the project. A section of foamed asphalt between stations 6+445 and 6+525 has no crusher dust and is too short to effectively analyze. Data collected in this area will be included with foamed asphalt plus crusher dust. If this section shows signs of premature deformation before the end of this study, additional tests will be collected to determine if the lack of crusher dust is a contributing factor.

An inspection of the project to detect frost movement was conducted on March 25, 2005. There were many areas that had frost movement. Sections treated with surface and shim and sections with Full Depth Reclamation with HMA base and surface mix had the least amount of frost movement followed by Reconstructed and Variable Depth Gravel sections. The majority of frost areas were located in the Foamed Asphalt treated sections with and without HMA base.

Each treatment in the following figures is represented as:

C = Full Depth Reclamation
F = Foamed Asphalt
F2 = Foamed Asphalt without HMA Base
R = Full Depth Reconstruction
S = Shim
V = “C” + Variable Depth Gravel

Structural Summary

Effective Existing Structural Numbers will be utilized to monitor stability of each treatment. Figure 6 contains a summary of 2002 thru 2005 ESN data.

Average Structural Numbers in the Full Depth Reclamation treatment remained at 95 in 2004 then increased to the highest reading at 98 in 2005. This treatment has had the lowest structural readings and the greatest standard deviation of all treatments indicating that the treatment is not very consistent.

Structural stability in the Foamed Asphalt with HMA base treatment areas has decreased 6.6 percent in 2004 to an average ESN of 113 then increased to an ESN of 114 in 2005. Structural Numbers have steadily decreased for the first three years then stabilized in the fourth year. It appears that the Foamed Asphalt treatment may be stabilizing to a uniform level with time. Standard deviations for all four years are high indicating a non-uniform treatment. When reviewing Structural Numbers by stations it appears that the first portion of the project has a wide range of values. Foamed Asphalt was placed in this area first and being a new process for the contractor and the department it was also a learning process. The material behind the reclaimer had many large recycled asphalt pavement pieces in the 75 mm (3 in) plus range which does not blend with the foamed asphalt well resulting in decreased stability. As construction progressed, the contractor refined the process to produce a more uniform mix with fewer large particles resulting in structural numbers that are very uniform in the second half of the project including the Foamed Asphalt area with no HMA base. This treatment continues to have greater stability than the Full Depth Reclamation, Foamed Asphalt with no HMA base, and Shim treatments.

Foamed Asphalt with no HMA base has stabilized with an average ESN of 98 in 2004 and 2005, a decrease of 2.0 percent from 2003. Standard deviations for all four years are low signifying a uniform treatment. This was the last foamed asphalt section to be constructed indicating the contractor may have refined placement of foamed asphalt to produce a uniform subbase material. It’s apparent that the lack of HMA base has reduced structural stability as compared to areas treated with Foamed Asphalt with HMA base. This treatment has higher stability than the Full Depth Reclamation treatment but lower than the remaining treatments. The amount of load, transverse and longitudinal cracks are continuing to increase indicating a pavement layer of 40 mm (1.5 in) may be too thin to distribute traffic loads over foamed asphalt.

Average structural numbers for Full Depth Reconstruction areas decreased in 2004 then increased slightly in 2005. In 2004 structural numbers decreased 6.6 percent to an ESN of 141 then increased to one of the highest readings at 144 in 2005. Standard deviations continue to be low indicating a uniform treatment. This treatment and the Variable Depth Gravel treatment are performing very similarly.

Average structural numbers for the Shim treatment increased 3.8 percent in 2004 to 108 then increased to 109 in 2005. Cracks are continuing to reflect through the pavement which is typical of shim and surfaced roadways. This treatment has higher structural numbers than the Full Depth Reclamation and Foamed Asphalt without HMA base areas.

Variable Depth Gravel areas have greater structural numbers than the remaining treatments. Values decreased 2.6 percent in 2004 to an ESN of 148 then increased 1.3 percent in 2005 to a value of 150, the highest average ESN of all treatments. Structural numbers have consistently been higher all four years possibly due to improved drainage capabilities of the variable depth gravel.

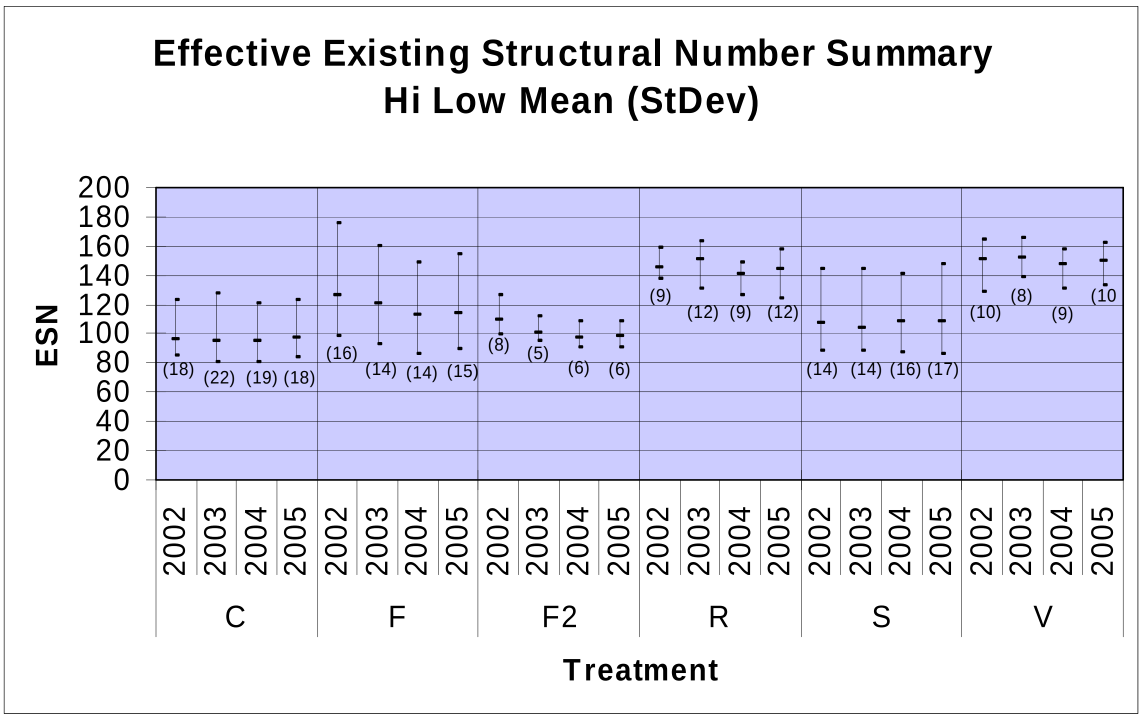


Figure 6: Effective Existing Structural Number Summary

Effective Existing Structural Numbers for 2005 were statistically compared to each other to determine if there is a significant difference between treatments. Results are displayed in Table 4.

Analysis reveals that the Variable Depth Gravel and Full Reconstructed treatments have significantly higher structural numbers than the remaining treatments.

Areas treated with Shim, Foamed Asphalt with HMA base, Foamed Asphalt without HMA Base, and Full Depth Reclamation are structurally similar.

Table 4: Statistical Comparison of Treatment Effective Existing Structural Numbers

The SAS System
The GLM Procedure

Class Level Information

Class	Levels	Values
Treatment	6	C F F2 R S V

Number of observations 101

Dependent Variable: StrNum

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	20807.44978	4161.48996	19.07	<.0001
Error	95	20728.41161	218.19381		
Corrected Total	100	41535.86139			

R-Square	Coeff Var	Root MSE	StrNum Mean
0.500951	12.80939	14.77138	115.3168

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	5	20807.44978	4161.48996	19.07	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	5	20807.44978	4161.48996	19.07	<.0001

Tukey's Studentized Range (HSD) Test for StrNum
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	95
Error Mean Square	218.1938
Critical Value of Studentized Range	4.11354

Comparisons significant at the 0.05 level are indicated by ***.

Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits			Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
V - R	5.700	-17.833	29.233		S - V	-40.594	-56.160	-25.028	***
V - F	35.857	20.739	50.975	***	S - R	-34.894	-55.555	-14.232	***
V - S	40.594	25.028	56.160	***	S - F	-4.737	-14.818	5.345	
V - F2	51.500	31.120	71.880	***	S - F2	10.906	-6.077	27.890	
V - C	51.750	26.331	77.169	***	S - C	11.156	-11.630	33.942	
R - V	-5.700	-29.233	17.833		F2 - V	-51.500	-71.880	-31.120	***
R - F	30.157	9.831	50.484	***	F2 - R	-45.800	-70.294	-21.306	***
R - S	34.894	14.232	55.555	***	F2 - F	-15.643	-32.217	0.932	
R - F2	45.800	21.306	70.294	***	F2 - S	-10.906	-27.890	6.077	
R - C	46.050	17.228	74.872	***	F2 - C	0.250	-26.061	26.561	
F - V	-35.857	-50.975	-20.739	***	C - V	-51.750	-77.169	-26.331	***
F - R	-30.157	-50.484	-9.831	***	C - R	-46.050	-74.872	-17.228	***
F - S	4.737	-5.345	14.818		C - F	-15.893	-38.375	6.590	
F - F2	15.643	-0.932	32.217		C - S	-11.156	-33.942	11.630	
F - C	15.893	-6.590	38.375		C - F2	-0.250	-26.561	26.061	

[1] C = Full Depth Reclamation, F = Foamed Asphalt, F2 = Foamed Asphalt without HMA Base, R = Full Depth Reconstruction, S = Shim, V = “C” + Variable Depth Gravel

Smoothness Summary

ARAN data was utilized to compare smoothness of each treatment from station 1+200 to 11+200. Figure 7 contains a summary of the results.

Smoothness measurements increased each year on all treatments. The average IRI ranges between a low of 1.0 to a high of 2.0 m/km (63.4 and 126.7 in/mi). Smoothness readings are typical for a project exposed to traffic for four years and based on IRI descriptions in Figure 3, the project as a whole continues to have a smooth ride.

Full Depth Reconstruction and Full Depth Reclamation have the highest IRI readings. Full Depth Reclamation increased from 1.4 m/km (88.7 in/mi) to 1.6 m/km (101.4 in/mi) in 2004 and 1.9 m/km

(120.4 in/mi) in 2005. Full Depth Reconstruction increased from 1.4 m/km (88.7 in/mi) in 2003 to 1.6 m/km (101.4 in/mi) in 2004 then increased to the highest IRI at 2.0 m/km (126.7 in/mi) in 2005.

Foamed Asphalt with HMA base areas have a smoother ride than Full Depth Reclamation, Full Depth Reconstruction, and Foamed Asphalt without HMA base areas. Average IRI increased from 1.2 m/km (76.0 in/mi) in 2003 to 1.4 m/km (88.7 in/mi) and 1.6 m/km (101.4 in/mi) in 2004 and 2005 respectively.

Foamed Asphalt without HMA base has a rougher ride than its counterpart. IRI values increased from 1.4 to 1.5 m/km (88.7 to 95.0 in/mi) between 2003 and 2004. In 2005 the average IRI increased to a value of 1.8 m/km (114.0 in/mi).

Areas treated with Shim and Variable Depth Gravel has similar smoothness results. Shim treatments have the lowest average IRI (lower IRI denotes smoother roadway) at 1.1 and 1.2 m/km (69.7 and 76.0 in/mi) for 2004 and 2005 respectively. Variable Depth Gravel has an average IRI of 1.2 (76.0 in/mi) in 2004 and 1.3 m/km (82.4 in/mi) in 2005.

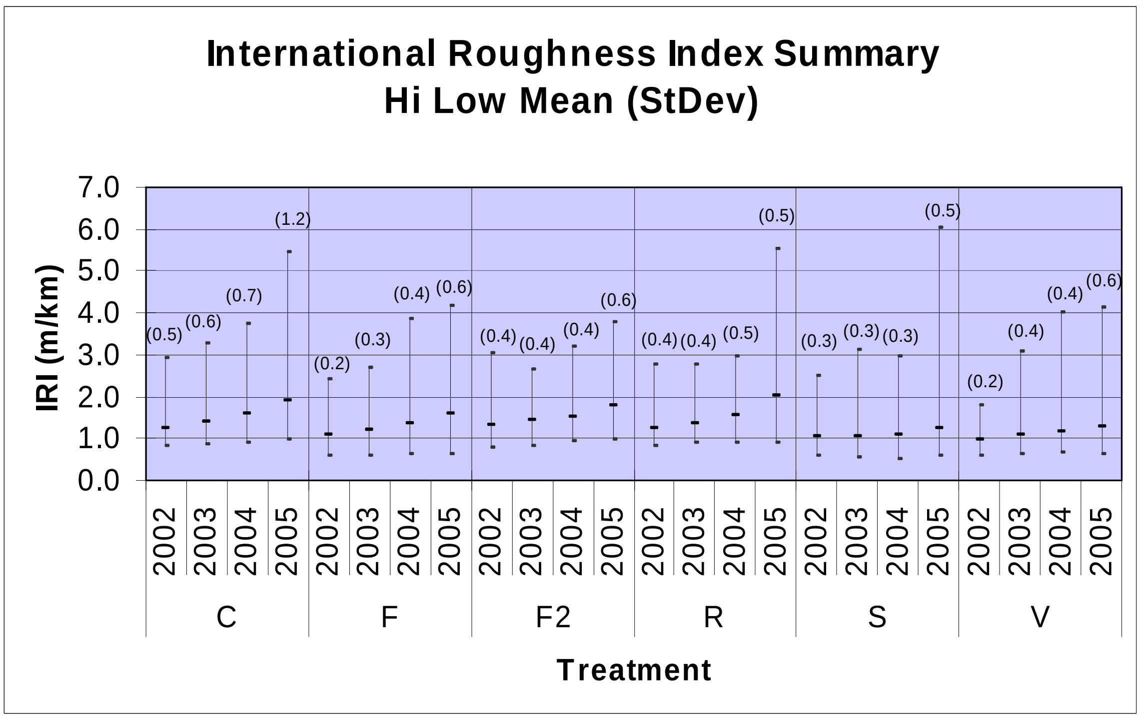


Figure 7: International Roughness Index Summary

A statistical comparison of each treatment using 2005 ARAN Ride data is displayed in Table 5. Treatments that are significantly different at the 95% confidence level are summarized below.

Variable Depth Gravel and Shim treatments are significantly smoother than the remaining treatments.

Foamed Asphalt sealed with HMA base and surface is significantly smoother than areas treated with Full Depth Reconstruction, Full Depth Reclamation, and Foamed Asphalt sealed with HMA surface only.

Full Depth Reconstruction, Full Depth Reclamation, and Foamed Asphalt with HMA surface have statistically similar IRI values and are rougher than the remaining treatments.

Rut Depth Summary

The ARAN was utilized to measure rut depths in each wheel path at 20 meter intervals from station 1+200 to 11+200. Figure 8 contains a summary of test results for each treatment.

Average Rut Depths increased in 2004 and 2005 on all treatments and range in depth from a low of 3.1 mm (0.12 in) in 2004 to a high of 7.1 mm (0.28 in) in 2005. Rutting is typical for a project of this age.

Areas treated with Shim and HMA surface continue to have the least amount of rutting with an average depth of 3.1 mm (0.12 in) in 2004 and 3.3 mm (0.13 in) in 2005. The standard deviation has also been consistently lower than the other treatments in all four years. Shim areas were selected based on pre-construction FWD results therefore it's understandable that this treatment would have less rutting due to the stable condition of the road prior to resurfacing.

Variable Depth Gravel treatments have similar rut depths as the Shim treatment with an average of 3.7 mm (0.15 in) in 2004 and 4.1 mm (0.16 in) in 2005. This could be attributed to the gravel layer above the reclaimed asphalt base increasing stability of the subbase layer.

Rut depths in the Foamed Asphalt with HMA base areas increased from 3.3 mm (0.13 in) in 2003 to 4.1 mm (0.16 in) in 2004 and 5.0 mm (0.20 in) in 2005. This treatment is performing better than the Full Depth Reclamation and Full Depth Reconstruction treatments.

Rut depths in the Foamed Asphalt without HMA base areas are very stable. Average depths increased from 3.6 mm (0.14 in) in 2003 to 3.7 mm (0.15 in) in 2004 and 4.0 mm (0.16 in) in 2005. Rutting is very good considering this area was surfaced with a total depth of 40 mm (1.6 in) of HMA. The contractor was very familiar with Foamed Asphalt by the time this area was treated resulting in a more uniform product and possibly contributing to the low average rut depth.

Full Depth Reclamation areas continue to have the greatest amount of rutting. Average depths increased from 4.2 mm (0.17 in) in 2003 to 4.8 mm (0.19 in) and 7.1 mm (0.28 in) in 2004 and 2005. Unbound reclaim base material may be contributing to the higher incidence of rutting.

Full Depth Reconstruction areas have the second greatest amount of rut depths. Average rutting increased from 3.3 mm (0.13 in) in 2003 to 5.1 mm (0.20 in) in 2004 and 6.7 mm (0.26 in) in 2005.

Table 6 contains a statistical comparison of 2005 rut depths for each treatment.

Table 5: Statistical Comparison of Treatment International Roughness Index

The SAS System
The GLM Procedure

Class Level Information

Class	Levels	Values
Treatment	6	C F F2 R S V

Number of observations 1000

Dependent Variable: IRI

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	52.9723235	10.5944647	29.65	<.0001
Error	994	355.1762509	0.3573202		
Corrected Total	999	408.1485744			

R-Square	Coeff Var	Root MSE	IRI Mean
0.129787	40.24904	0.597763	1.485160

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	5	52.97232352	10.59446470	29.65	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	5	52.97232352	10.59446470	29.65	<.0001

Tukey's Studentized Range (HSD) Test for IRI
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	994
Error Mean Square	0.35732
Critical Value of Studentized Range	4.03800

Comparisons significant at the 0.05 level are indicated by ***.

Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits			Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
R - C	0.12667	-0.25691	0.51024		F - R	-0.43999	-0.73663	-0.14336	***
R - F2	0.22142	-0.12112	0.56396		F - C	-0.31333	-0.58403	-0.04263	***
R - F	0.43999	0.14336	0.73663	***	F - F2	-0.21858	-0.42711	-0.01004	***
R - V	0.73456	0.40368	1.06544	***	F - V	0.29457	0.10581	0.48333	***
R - S	0.78073	0.48097	1.08049	***	F - S	0.34074	0.21422	0.46726	***
C - R	-0.12667	-0.51024	0.25691		V - R	-0.73456	-1.06544	-0.40368	***
C - F2	0.09475	-0.22560	0.41510		V - C	-0.60789	-0.91574	-0.30005	***
C - F	0.31333	0.04263	0.58403	***	V - F2	-0.51314	-0.76804	-0.25824	***
C - V	0.60789	0.30005	0.91574	***	V - F	-0.29457	-0.48333	-0.10581	***
C - S	0.65406	0.37994	0.92819	***	V - S	0.04617	-0.14747	0.23981	
F2 - R	-0.22142	-0.56396	0.12112		S - R	-0.78073	-1.08049	-0.48097	***
F2 - C	-0.09475	-0.41510	0.22560		S - C	-0.65406	-0.92819	-0.37994	***
F2 - F	0.21858	0.01004	0.42711	***	S - F2	-0.55931	-0.77227	-0.34636	***
F2 - V	0.51314	0.25824	0.76804	***	S - F	-0.34074	-0.46726	-0.21422	***
F2 - S	0.55931	0.34636	0.77227	***	S - V	-0.04617	-0.23981	0.14747	

[1] C = Full Depth Reclamation, F = Foamed Asphalt, F2 = Foamed Asphalt without HMA Base, R = Full Depth Reconstruction, S = Shim, V = “C” + Variable Depth Gravel

Data reveals that the Shim, Foamed Asphalt without HMA base, and Variable Depth Gravel treatments have significantly less rutting than the Full Depth Reclamation, Full Depth Reconstruction, and Foamed Asphalt with HMA base treatments.

Foamed Asphalt with HMA base has significantly less rutting than the Full Depth Reclamation and Full Depth Reconstruction sections.

Full Depth Reconstruction and Full Depth Reclamation are statistically similar in rutting.

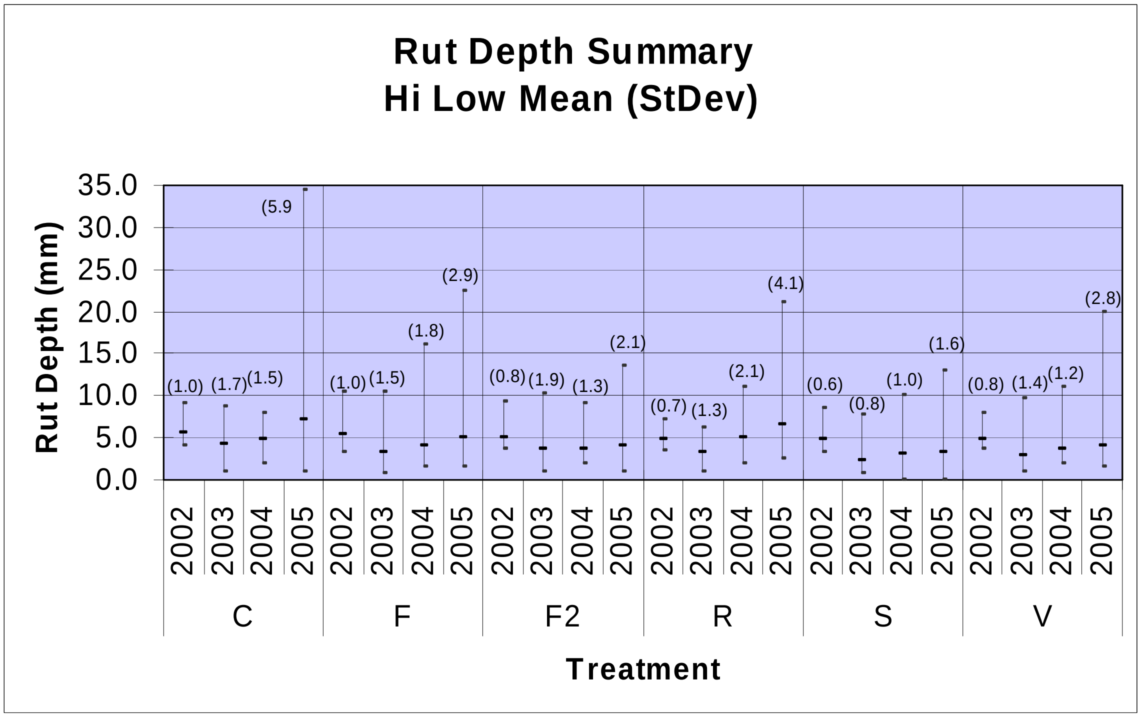


Figure 8: Treatment Rut Depth Summary

Summary

The project is performing very well after four years exposure to traffic and the environment. Statistical evaluation of the Test Section portion of the project revealed no significant difference between Effective Structural Numbers, International Ride Index values, or Rut Depths.

The obvious difference between the experimental test sections is the amount of cracking. Test Section One (Foamed Asphalt surfaced with 80 mm (3 in) of HMA) has the least amount of cracking and minimal load cracking. The Control Section, with 100 mm (4 in) of HMA, has more than twice the longitudinal cracking and four times as much initial load cracking as Test Section One indicating that a reduced layer thickness of HMA over Foamed Asphalt does postpone the formation of longitudinal and load cracking thereby extending the life expectancy of the roadway. Test Section Two, with Foamed Asphalt and 40 mm (1.75 in) of HMA, has the greatest amount of cracking in all categories indicating that 40 mm (1.75 in) of HMA over Foamed Asphalt does not effectively support traffic loads.

Table 6: Statistical Comparison of Treatment Rut Depths

The SAS System
The GLM Procedure

Class Level Information

Class	Levels	Values
Treatment	6	C F F2 R S V

Number of observations 1000

Dependent Variable: RutDepth

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1102.325573	220.465115	29.28	<.0001
Error	994	7483.268177	7.528439		
Corrected Total	999	8585.593750			

R-Square	Coeff Var	Root MSE	RutDepth Mean
0.128392	62.18244	2.743800	4.412500

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	5	1102.325573	220.465115	29.28	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	5	1102.325573	220.465115	29.28	<.0001

Tukey's Studentized Range (HSD) Test for RutDepth
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	994
Error Mean Square	7.528439
Critical Value of Studentized Range	4.03800

Comparisons significant at the 0.05 level are indicated by ***.

Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits			Treatment Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
C - R	0.4268	-1.3339	2.1874		V - C	-3.0158	-4.4289	-1.6028	***
C - F	2.0686	0.8261	3.3112	***	V - R	-2.5891	-4.1078	-1.0703	***
C - V	3.0158	1.6028	4.4289	***	V - F	-0.9472	-1.8136	-0.0808	***
C - F2	3.0670	1.5966	4.5375	***	V - F2	0.0512	-1.1188	1.2212	
C - S	3.8234	2.5652	5.0817	***	V - S	0.8076	-0.0812	1.6964	
R - C	-0.4268	-2.1874	1.3339		F2 - C	-3.0670	-4.5375	-1.5966	***
R - F	1.6419	0.2803	3.0034	***	F2 - R	-2.6403	-4.2126	-1.0680	***
R - V	2.5891	1.0703	4.1078	***	F2 - F	-0.9984	-1.9556	-0.0412	***
R - F2	2.6403	1.0680	4.2126	***	F2 - V	-0.0512	-1.2212	1.1188	
R - S	3.3966	2.0207	4.7726	***	F2 - S	0.7564	-0.2211	1.7339	
F - C	-2.0686	-3.3112	-0.8261	***	S - C	-3.8234	-5.0817	-2.5652	***
F - R	-1.6419	-3.0034	-0.2803	***	S - R	-3.3966	-4.7726	-2.0207	***
F - V	0.9472	0.0808	1.8136	***	S - F	-1.7548	-2.3355	-1.1741	***
F - F2	0.9984	0.0412	1.9556	***	S - V	-0.8076	-1.6964	0.0812	
F - S	1.7548	1.1741	2.3355	***	S - F2	-0.7564	-1.7339	0.2211	

[1] C = Full Depth Reclamation, F = Foamed Asphalt, F2 = Foamed Asphalt without HMA Base, R = Full Depth Reconstruction, S = Shim, V = "C" + Variable Depth Gravel

Analysis of each treatment within the project has shown significant differences. Observations are listed below.

- Variable Depth Gravel and Full Depth Reconstruction treatments continue to have significantly higher structural numbers than the remaining treatments.
- Both Foamed Asphalt areas have a similar structural pattern; they begin with high structural numbers then degrade for the next two years then level off. The remaining treatments have fairly uniform structural numbers or have degraded slightly. A similar pattern is observed in the experimental test section analysis.
- Shim and Variable Depth Gravel treatments continue to have significantly smoother rides than the remaining treatments.

- Foamed Asphalt with 80 mm (3 in) of HMA continues to have a significantly smoother ride than the Foamed Asphalt with 40 mm (1.5 in) of HMA, Full Depth Reclamation, and Full Depth Reconstruction.
- Areas treated with Shim, Foamed Asphalt with 40 mm (3 in) of HMA, and Variable Depth Gravel has significantly less rutting than the remaining treatments.
- Full Depth Reclamation and Full Depth Reconstruction areas have significantly more rutting then the remaining sections.

The final report will contain a life cycle cost analysis to determine which treatment is more cost effective. In addition, the Mechanistic – Empirical Pavement Design Guide and Foamed Asphalt test data from Worchester Polytechnic Institute will be used to compare predicted and actual pavement distresses.

Prepared by:
Brian Marquis
Transportation Planning Specialist
Transportation Research Division

Reviewed By:
Dale Peabody
Division Engineer
Transportation Research Division

Other Available Documents:
"Using Foamed Asphalt as a Stabilizing Agent in Full Depth Reclamation of Route 8 in Belgrade",
Construction Report # 02-2, February 2002
Interim Report - First Year, December 2003
Interim Report - Second Year, January 2005

For more information contact:
Brian Marquis
Maine Department of Transportation
P.O. Box 1208
Bangor, Maine 04402 - 1208
207-941-4067
E-mail: brian.marquis@maine.gov