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Maine Department of Transportation

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 - Second Year, January 2005

Transportation Research Division

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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 (MDOT) 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, MDOT 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. 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 either Full Depth Reconstruction, Full Depth Reclamation with Variable Depth Gravel or Full Depth Reclamation with Foamed Asphalt.

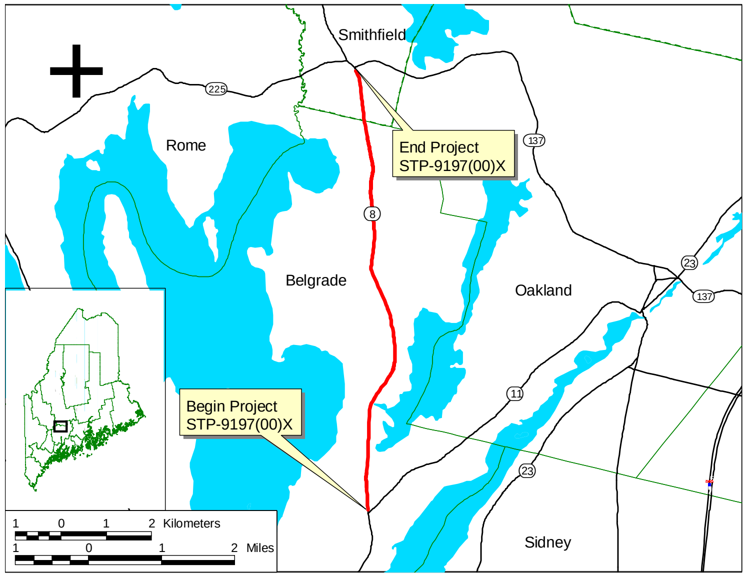


Figure 1: Project No. STP-9197(00)X Location Map

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)

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
SHIM = Variable Depth 9.5 mm HMA Shim
40 B = 40 mm of 12.5 mm HMA Base
60 B = 60 mm of 12.5 mm HMA Base
RECON = Full Depth Reconstruction
FDR = Full Depth Reclamation
FDRVDG = Full Depth Reclamation w/ Variable Depth Gravel
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	CIPR	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 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 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.

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.

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.

Test Section Structural Summary

Pavement deflections were recorded on August 19, 2003. 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.

Structural numbers in all three test sections have decreased since 2002. The Control Section has an average ESN of 97, a decrease of 1 percent from last year. Although the average ESN has remained stable the standard deviation is high indicating non-uniformity within the section.

Test Section One with 80 mm (3 in) of HMA over 200 mm (8 in) of foamed asphalt continues to have the highest ESN at 102, a decrease of 6.4 percent.

Test Section Two has the lowest ESN at 95, a 7.8 percent decrease. This section was surfaced with 40 mm (1.5 in) of HMA and has been showing early signs of pavement failure in the way of rutting and cracking which will be summarized later in the report.

2003 Effective Structural Numbers were statistically analyzed utilizing Tukey's multiple comparison tests. Analysis results are summarized in Table 3 and reveal no significant difference between test sections at a 95 percent confidence level.

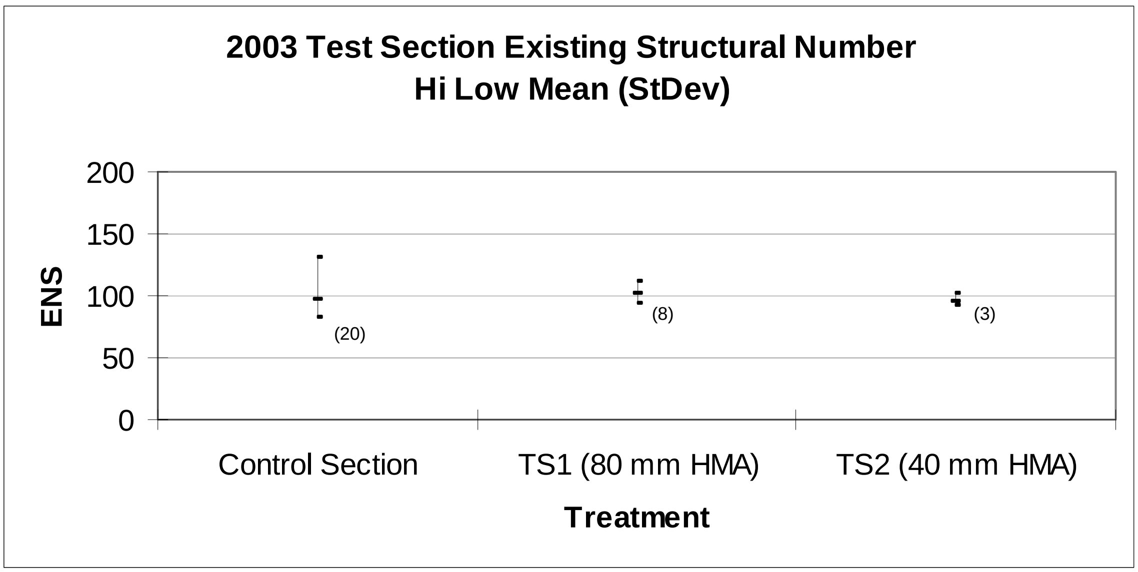


Figure 2: Summary of Test Section Effective Existing Structural Numbers

Table 3: Statistical Comparison of Test Section Effective Structural Numbers

The SAS System
The GLM Procedure

Class Level Information

Class	Levels	Values
Section	3	Control TS1 TS2

Number of observations 16

Dependent Variable: ESN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	125.866667	62.933333	0.43	0.6613
Error	13	1916.133333	147.394872		
Corrected Total	15	2042.000000			

R-Square	Coeff Var	Root MSE	ESN Mean
0.061639	12.38840	12.14063	98.00000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Section	2	125.8666667	62.9333333	0.43	0.6613

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Section	2	125.8666667	62.9333333	0.43	0.6613

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

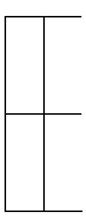
Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	147.3949
Critical Value of Studentized Range	3.73414

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

Section Comparison	Difference Between Means	Simultaneous 95% Confidence Limits	
TS1 - Control	4.800	-15.474	25.074
TS1 - TS2	6.667	-12.745	26.078
Control - TS1	-4.800	-25.074	15.474
Control - TS2	1.867	-17.545	21.278
TS2 - TS1	-6.667	-26.078	12.745
TS2 - Control	-1.867	-21.278	17.545

Test Section Ride Summary

Smoothness measurements were collected on September 17, 2003 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”.



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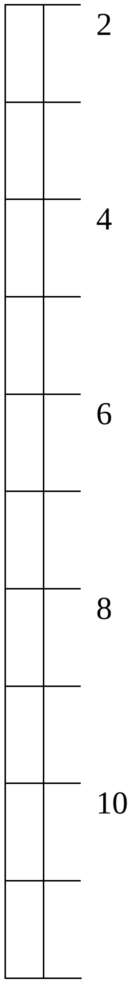
Ride comfortable over 120 km/h. Undulation barely perceptible at 80 km/h in range 1.3 to 1.8. No depressions, potholes, or corrugations are noticeable; depressions < 2 mm/3 m. Typical high quality asphalt 1.4 to 2.3, high quality surface treatment 2.0 to 3.0.



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 2003 IRI values. Roughness values remain in the smooth category between 1.02 – 1.57 m/km (65 – 99 in/mi) even though average IRI values have increased in all sections over the past year.

The Control Section has the highest average IRI at 1.42 m/km (90 in/mi), an increase of 16.4 percent. The standard deviation is also high indicating a non-uniform ride.

Test Section One has the lowest average IRI at 1.29 m/km (81.7 in/mi) and the highest increase at 25.2 percent. This section is more uniform with a standard deviation of 0.29.

Test Section Two has an average IRI of 1.36 m/km (86.2 in/mi) and the lowest increase at 9.0 percent. The standard deviation is low indicating a uniform ride.

Table 4 contains a statistical comparison of 2003 IRI values. 2003 analysis reveals no significant difference between sections.

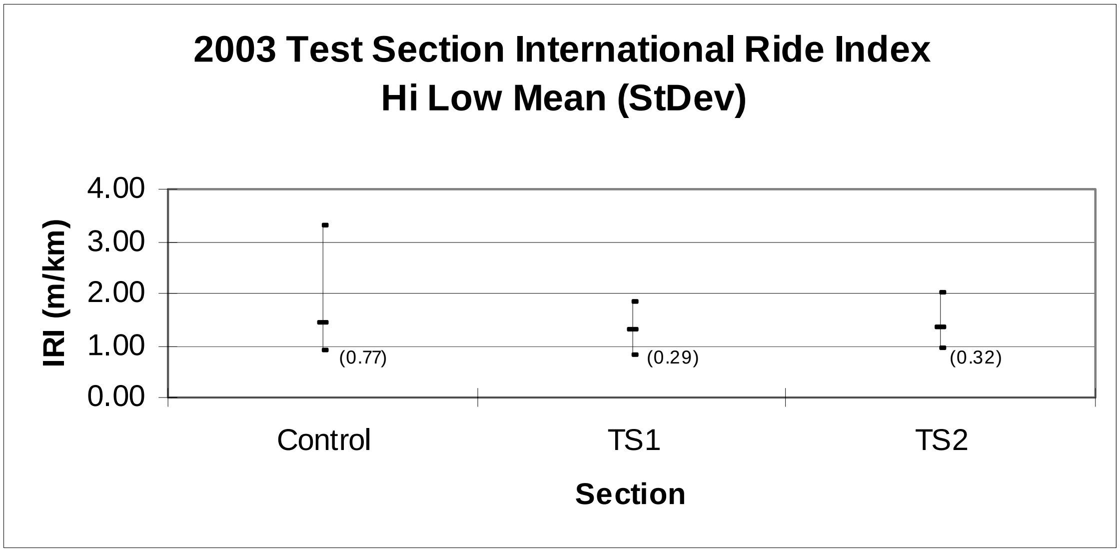


Figure 4: Summary of Test Section International Ride Index Measurements

Table 4: Statistical Comparison of Test Section International Ride Index Measurements

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                              The SAS System
                             The GLM Procedure

                          Class Level Information
                    Class        Levels    Values
                    Section           3    Control TS1 TS2

                        Number of observations    52
Dependent Variable: IRI
                                             Sum of
      Source                  DF           Squares     Mean Square    F Value    Pr > F
      Model                    2        0.12245077      0.06122538       0.30    0.7423
      Error                   49       10.00615500      0.20420724
      Corrected Total         51       10.12860577

                 R-Square     Coeff Var      Root MSE      IRI Mean
                 0.012090      33.56440      0.451893      1.346346

      Source                  DF         Type I SS     Mean Square    F Value    Pr > F
      Section                  2        0.12245077      0.06122538       0.30    0.7423

      Source                  DF       Type III SS     Mean Square    F Value    Pr > F
      Section                  2        0.12245077      0.06122538       0.30    0.7423

                   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                     49
                   Error Mean Square                      0.204207
                   Critical Value of Studentized Range     3.41805

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

                                     Difference       Simultaneous
                  Section               Between      95% Confidence
                 Comparison               Means          Limits
              Control - TS2              0.0650    -0.3338  0.4638
              Control - TS1              0.1265    -0.2723  0.5253
              TS2     - Control         -0.0650    -0.4638  0.3338
              TS2     - TS1              0.0615    -0.2839  0.4069
              TS1     - Control         -0.1265    -0.5253  0.2723
              TS1     - TS2             -0.0615    -0.4069  0.2839
```

Test Section Rut Depth Summary

Rut depth measurements were collected on September 17, 2003 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.

Test results for 2003 are between 25 and 31 percent lower than 2002. This could be attributed to plow wear at centerline and edge of pavement and/or vehicle wander within wheel paths smoothing out roadway profiles. Rutting is minimal but typical of a project exposed to traffic for two years. Both foamed asphalt test sections continue to have less rutting than the Control Section.

The Control Section continues to have the greatest amount of rutting at 4.10 mm (0.16 in).

Test Section One has the least amount of rutting at 3.36 mm (0.13 in).

Test Section Two is slightly higher at 3.63 mm (0.14 in).

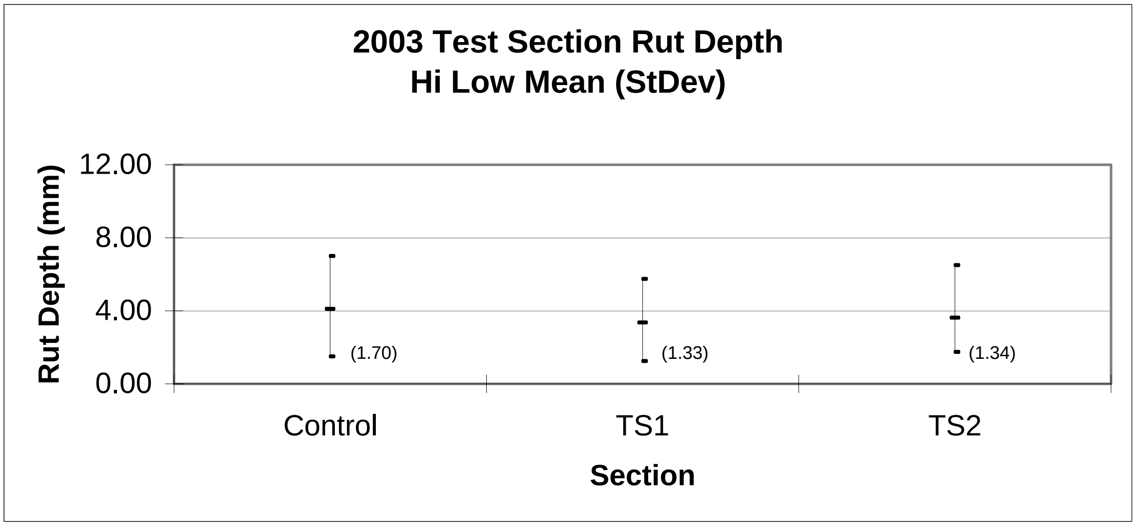

Figure 5: Summary of Test Section Rut Depth Measurements

A statistical comparison of 2003 Rut Depth measurements is displayed in Table 5. Comparisons reveal no significant difference between test sections.

Table 5: Statistical Comparison of Test Section Rut Depth Measurements

The SAS System
The GLM Procedure

Class Level Information

Class	Levels	Values
Section	3	Control TS1 TS2

Number of observations 52

Dependent Variable: RutDepth

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	4.1285256	2.0642628	1.02	0.3691
Error	49	99.4291667	2.0291667		
Corrected Total	51	103.5576923			

R-Square	Coeff Var	Root MSE	RutDepth Mean
0.039867	39.19227	1.424488	3.634615

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Section	2	4.12852564	2.06426282	1.02	0.3691

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Section	2	4.12852564	2.06426282	1.02	0.3691

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	49
Error Mean Square	2.029167
Critical Value of Studentized Range	3.41805

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

Section Comparison	Difference Between Means	Simultaneous 95% Confidence Limits	
Control - TS2	0.4792	-0.7780	1.7363
Control - TS1	0.7417	-0.5155	1.9988
TS2 - Control	-0.4792	-1.7363	0.7780
TS2 - TS1	0.2625	-0.8262	1.3512
TS1 - Control	-0.7417	-1.9988	0.5155
TS1 - TS2	-0.2625	-1.3512	0.8262

Test Section Visual Summary

A visual inspection was completed on September 30, 2003. After two years exposure to traffic, all three sections have one or more types of cracking.

The Control Section has a total of 33 m (108 ft) of centerline separation as depicted in Photo 1 and a longitudinal crack one meter (three feet) in length. No additional cracks were observed

Test Section One has the least amount of cracking with a total of 21 m (69 ft) of centerline separation that can be seen in Photo 2 with no transverse, load, or longitudinal cracking.

Test Section Two has the majority of cracking with a total of 67 m (220 ft) of centerline separation, two transverse cracks beginning to form at stations 9+163 and 9+246, a total of 3 m² (3.6 ft²) of initial load cracking, and 2 m (6.6 ft) of longitudinal cracking. The amount of cracking in Test Section Two suggests that 40 mm (1.5 in) of HMA surface over foamed asphalt is not sufficient to properly distribute traffic loads. Photo 3 displays one of the transverse cracks.

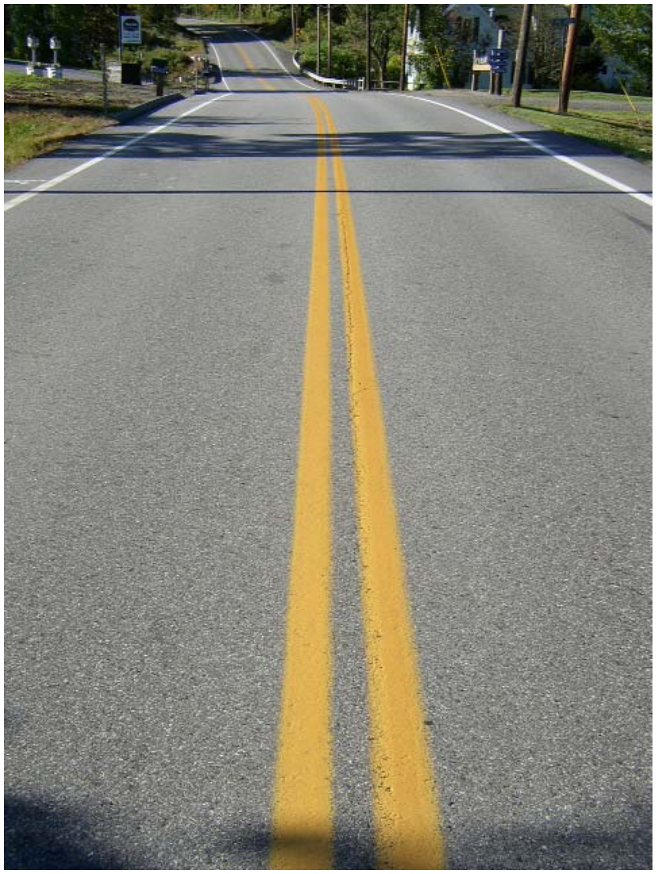

Photo 1: Control Section Centerline Cracking

Photo 2: Test Section One Centerline Cracking

Photo 3: Test Section Two Transverse Crack

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 to late in the spring. An inspection will be attempted in 2004.

Project Structural Summary

Effective Existing Structural Numbers, calculated from FWD data collected on August 19, 2003, will be utilized to monitor stability of each treatment. Figure 6 contains a summary of 2003 ESN data.

The Full Depth Reclamation treatment continues to have the lowest average structural number at 95, a decrease of 2.1 percent from last year and the smallest decrease of all treatments, and a high standard deviation indicating this treatment is not uniform throughout the project. Although 95 is lower than the remaining treatments it is considerably higher than the pre-construction project average of 77.

Foamed Asphalt with HMA base has an average structural number of 121, a 4.5 percent decrease, and a standard deviation of 14 suggesting non-uniformity. The average structural number is 17 percent higher than the foamed asphalt treatment with no HMA base. Only two treatments have higher structural numbers, Full Reconstruction and Variable Depth Gravel.

Foamed Asphalt with no HMA base has an average ESN of 100, a decrease of 8.4 percent and the greatest decrease of all treatments. The standard deviation is 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. Structural numbers are very similar to areas treated with Shim and surface. Load, transverse and longitudinal cracks are beginning to develop 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 Reconstruction and Variable Depth Gravel treatments have increased this year. Full Reconstruction has an ESN of 151, an increase of 3.6 percent, and Variable Depth Gravel increased 1.3 percent to 152. The increase may be attributed to improved soil drainage capabilities of the subbase soils.

Average ESN for the Shim treatment decreased 2.9 percent to 104. Cracks are beginning to reflect through the pavement which is typical of shim and surfaced roadways.

Effective Existing Structural Numbers were statistically compared to each other to determine if there is a significant difference between treatments. Results are displayed in Table 6.

The Variable Depth Gravel and Full Reconstructed treatments have significantly higher structural numbers than all other treatments.

Foamed Asphalt with HMA base has significantly higher structural numbers than the Shim, Foamed Asphalt without HMA base, and Full Depth Reclamation treatments.

The Shim, Foamed Asphalt without HMA Base, and Full Depth Reclamation areas are structurally similar.

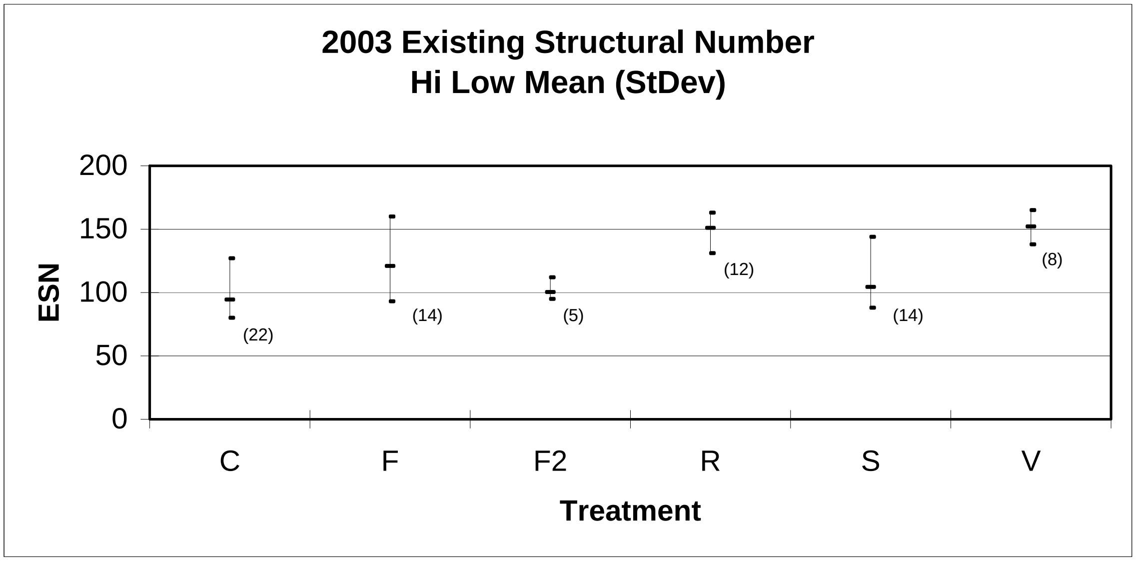

Figure 6: Summary of Treatment Effective Existing Structural Numbers

Table 6: Statistical Comparison of Treatment Effective Existing Structural Numbers

The SAS System
The GLM Procedure

Class Level Information

Class	Levels	Values[1]
Treatment	6	C F F2 R S V

Number of observations 101

Dependent Variable: ESN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	28099.84208	5619.96842	30.41	<.0001
Error	95	17558.09851	184.82209		
Corrected Total	100	45657.94059			

R-Square	Coeff Var	Root MSE	ESN Mean
0.615443	11.55895	13.59493	117.6139

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	5	28099.84208	5619.96842	30.41	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	5	28099.84208	5619.96842	30.41	<.0001

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

Alpha	0.05
Error Degrees of Freedom	95
Error Mean Square	184.8221
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	1.200	-20.459	22.859		S - V	-47.794	-62.120	-33.468	***
V - F	31.248	17.334	45.162	***	S - R	-46.594	-65.610	-27.578	***
V - S	47.794	33.468	62.120	***	S - F	-16.546	-25.825	-7.267	***
V - F2	51.825	33.068	70.582	***	S - F2	4.031	-11.600	19.662	
V - C	57.700	34.306	81.094	***	S - C	9.906	-11.065	30.877	
R - V	-1.200	-22.859	20.459		F2 - V	-51.825	-70.582	-33.068	***
R - F	30.048	11.340	48.755	***	F2 - R	-50.625	-73.168	-28.082	***
R - S	46.594	27.578	65.610	***	F2 - F	-20.577	-35.832	-5.323	***
R - F2	50.625	28.082	73.168	***	F2 - S	-4.031	-19.662	11.600	
R - C	56.500	29.973	83.027	***	F2 - C	5.875	-18.340	30.090	
F - V	-31.248	-45.162	-17.334	***	C - V	-57.700	-81.094	-34.306	***
F - R	-30.048	-48.755	-11.340	***	C - R	-56.500	-83.027	-29.973	***
F - S	16.546	7.267	25.825	***	C - F	-26.452	-47.144	-5.760	***
F - F2	20.577	5.323	35.832	***	C - S	-9.906	-30.877	11.065	
F - C	26.452	5.760	47.144	***	C - F2	-5.875	-30.090	18.340	

[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

Project Ride 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.

The average IRI for all sections ranges between a low of 1.03 and high of 1.43 m/km (65.3 and 90.6 in/mi). Smoothness readings are typical for a two year old project.

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 1.03 m/km (65.3 in/mi), the same reading as last years average. Variable Depth Gravel has an average IRI of 1.08 m/km (68.4 in/mi), an increase of 11 percent.

Sections treated with Foamed Asphalt that were sealed with HMA base and surface has the third lowest average IRI at 1.20 m/km (76.0 in/mi), an increase of 12 percent. This treatment has a much smoother ride than the Foamed Asphalt without HMA base which has the highest average IRI of 1.43 m/km (90.6 in/mi) an increase of 8 percent. It appears that the HMA base reduces the formation of ruts.

The Full Depth Reconstruction and Full Depth Reclamation treatments have similar ride averages at 1.37 and 1.40 m/km respectively, an increase of 8 and 12 percent. These two treatments also have the highest standard deviation indicating a non uniform subbase.

Based on IRI descriptions in Figure 3, the project as a whole continues to have a smooth ride after one year's exposure to traffic.

A statistical comparison of each treatment using ARAN Ride data is displayed in Table **7**. Treatments that are significantly different at the 95% confidence level are summarized below.

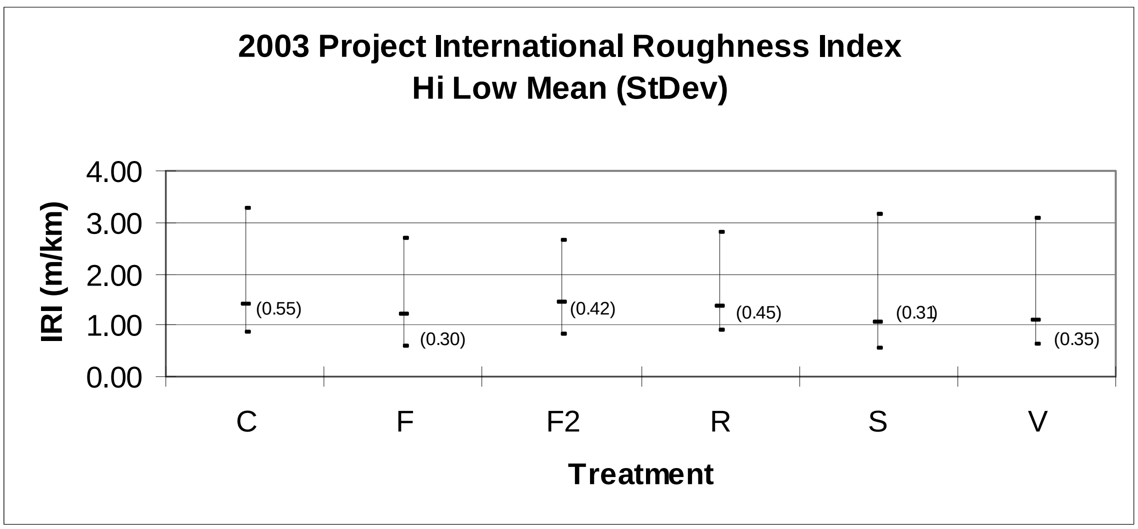

Figure 7: Treatment International Roughness Index Summary

Table 7: Statistical Comparison of Treatment International Roughness Index

```
                              The SAS System
                             The GLM Procedure

                          Class Level Information
                  Class         Levels    Values¹
                  Treatment          6    C F F2 R S V

                     Number of observations    1000
Dependent Variable: IRI
                                           Sum of
      Source                   DF         Squares     Mean Square    F Value    Pr > F
      Model                     5      16.3820962       3.2764192      28.28    <.0001
      Error                   994     115.1463013       0.1158413
      Corrected Total         999     131.5283975

                R-Square     Coeff Var      Root MSE      IRI Mean
```

0.124552	29.17618	0.340355	1.166550

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Section	5	16.38209619	3.27641924	28.28	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Section	5	16.38209619	3.27641924	28.28	<.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	0.115841
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		
F2 - C	0.03040	-0.15200	0.21280		F - F2	-0.23203	-0.35077	-0.11330	***
F2 - R	0.05979	-0.13525	0.25483		F - C	-0.20164	-0.35577	-0.04750	***
F2 - F	0.23203	0.11330	0.35077	***	F - R	-0.17224	-0.34114	-0.00334	***
F2 - V	0.35023	0.20510	0.49537	***	F - V	0.11820	0.01072	0.22568	***
F2 - S	0.39651	0.27526	0.51777	***	F - S	0.16448	0.09245	0.23652	***
C - F2	-0.03040	-0.21280	0.15200		V - F2	-0.35023	-0.49537	-0.20510	***
C - R	0.02939	-0.18901	0.24779		V - C	-0.31984	-0.49512	-0.14455	***
C - F	0.20164	0.04750	0.35577	***	V - R	-0.29044	-0.47884	-0.10205	***
C - V	0.31984	0.14455	0.49512	***	V - F	-0.11820	-0.22568	-0.01072	***
C - S	0.36612	0.21004	0.52220	***	V - S	0.04628	-0.06397	0.15654	
R - F2	-0.05979	-0.25483	0.13525		S - F2	-0.39651	-0.51777	-0.27526	***
R - C	-0.02939	-0.24779	0.18901		S - C	-0.36612	-0.52220	-0.21004	***
R - F	0.17224	0.00334	0.34114	***	S - R	-0.33672	-0.50740	-0.16604	***
R - V	0.29044	0.10205	0.47884	***	S - F	-0.16448	-0.23652	-0.09245	***
R - S	0.33672	0.16604	0.50740	***	S - V	-0.04628	-0.15654	0.06397	

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 the Full Depth Reconstruction, Full Depth Reclamation, and Foamed Asphalt sealed with HMA surface treatments.

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

Project 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 for each treatment are lower than last year’s readings and range in depth from a low of 2.25 mm (0.09 in) to a high of 4.21 mm (0.17 in). Rutting is typical for a project of this age.

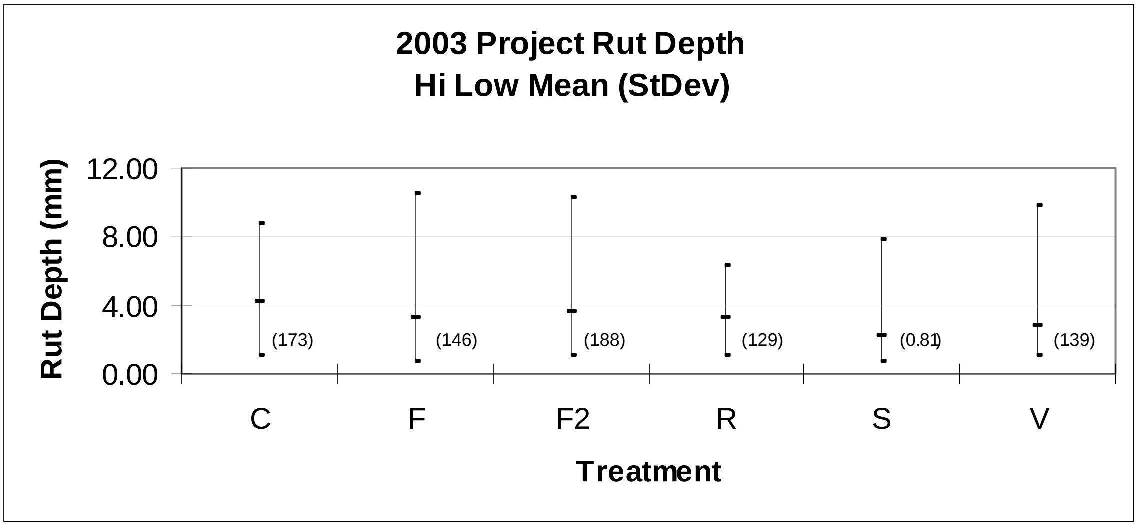

Figure 8: Treatment Rut Depth Summary

Areas treated with Shim and HMA surface has the least amount of rutting with an average depth of 2.25 mm (0.09 in). Areas selected for Shim treatment were based on Recommended Pavement Thicknesses calculated from preliminary FWD data. If the recommended pavement thickness was less than 100 mm (4 in) the area would be shimmed and surfaced with an average depth of 75 mm (3 in) of HMA. It's understandable that this treatment would have less rutting than the remaining treatments due to the stable condition of the road.

Variable Depth Gravel treatments have similar rut depths at an average of 2.81 mm (0.11 in). This could be attributed to the gravel layer above the reclaimed asphalt base increasing stability of the subbase layer.

Foamed Asphalt with HMA base and Full Depth Reconstruction treatments have similar average rut depths at 3.28 and 3.30 mm (0.129 and 0.130 in) respectively. Foamed Asphalt is performing slightly better even with an 80 mm (3 in) HMA layer (20 mm (0.75 in) less than Full Depth Reconstruction).

Foamed Asphalt without HMA base has the second highest average rut depth at of 3.63 mm (0.14 in). Rut depths are not bad considering these areas were surfaced with a total depth 40 mm (1.6 in) of HMA.

Full Depth Reclamation areas have the most severe average rut depth at 4.21 mm (0.17 in). This treatment has 100 mm (4 in) of HMA over unbound reclaim material. Traffic may be shifting and rotating particles in the unbound reclaim material contributing to increase rutting.

Table 8 contains a statistical comparison of rut depths for each treatment.

Data reveals that the Shim treatment has significantly less rutting than the remaining treatments.

Variable Depth Gravel sections have significantly less rutting than both Foamed Asphalt treatments and Full Depth Reclamation. It's interesting that this treatment isn't significantly different than the Full Depth Reconstruction treatment, which has a higher average rut depth than the Foamed Asphalt with HMA base treatment, possibly due to the lower standard deviation of 1.29 as compared to 1.46 for the Foamed Asphalt with HMA base.

Both Foamed Asphalt treatments and Full Depth Reconstruction have significantly less rutting than the Full Depth Reclamation treatment.

Table 8: Statistical Comparison of Treatment Rut Depths

The SAS System
The GLM Procedure

Class Level Information

Class	Levels	Values
Section	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	316.449466	63.289893	35.97	<.0001
Error	994	1748.994284	1.759552		
Corrected Total	999	2065.443750			

R-Square	Coeff Var	Root MSE	RutDepth Mean
0.153211	44.70028	1.326481	2.967500

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	5	316.4494655	63.2898931	35.97	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	5	316.4494655	63.2898931	35.97	<.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	1.759552
Critical Value of Studentized Range	4.03800

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

Section Comparison	Difference Between Means	Simultaneous 95% Confidence Limits			Section Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
C - F2	0.57585	-0.13502	1.28673		F - C	-0.93049	-1.53120	-0.32979	***
C - R	0.91162	0.06044	1.76279	***	F - F2	-0.35464	-0.81739	0.10810	
C - F	0.93049	0.32979	1.53120	***	F - R	-0.01888	-0.67713	0.63937	
C - V	1.39650	0.71337	2.07963	***	F - V	0.46601	0.04713	0.88488	***
C - S	1.95716	1.34886	2.56546	***	F - S	1.02667	0.74591	1.30742	***
F2 - C	-0.57585	-1.28673	0.13502		V - C	-1.39650	-2.07963	-0.71337	***
F2 - R	0.33576	-0.42436	1.09589		V - F2	-0.82065	-1.38629	-0.25501	***
F2 - F	0.35464	-0.10810	0.81739		V - R	-0.48489	-1.21913	0.24936	
F2 - V	0.82065	0.25501	1.38629	***	V - F	-0.46601	-0.88488	-0.04713	***
F2 - S	1.38131	0.90874	1.85387	***	V - S	0.56066	0.13096	0.99036	***
R - C	-0.91162	-1.76279	-0.06044	***	S - C	-1.95716	-2.56546	-1.34886	***
R - F2	-0.33576	-1.09589	0.42436		S - F2	-1.38131	-1.85387	-0.90874	***
R - F	0.01888	-0.63937	0.67713		S - R	-1.04554	-1.71074	-0.38035	***
R - V	0.48489	-0.24936	1.21913		S - F	-1.02667	-1.30742	-0.74591	***
R - S	1.04554	0.38035	1.71074	***	S - V	-0.56066	-0.99036	-0.13096	***

Summary

The project is performing very well after two years exposure to traffic and the environment. 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 sections is the amount of cracking. Test Section One (Foamed Asphalt surfaced with 80 mm (3 in) of HMA) and the Control Section have similar amounts of cracking. Test Section Two (Foamed Asphalt surfaced with 40 mm (1.5 in) of HMA) has centerline, transverse, longitudinal, and load cracking. Effective Structural Numbers are similar for all three sections indicating that a HMA surface layer of 40 mm (1.5 in) may be too thin to effectively distribute traffic loads over Foamed Asphalt resulting in premature cracking.

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

- Variable Depth Gravel and Full Depth Reconstruction treatments have significantly higher structural numbers than the remaining treatments.
- Foamed Asphalt surfaced with 80 mm (3 in) of HMA is structurally higher than the Shim, Full Depth Rehabilitation, and Foamed Asphalt with 40 mm (1.5 in) HMA surface.
- Shim and Variable Depth Gravel treatments have significantly smoother rides than the remaining treatments.
- Foamed Asphalt with 80 mm (3 in) of HMA has a smoother ride than the Foamed Asphalt with 40 mm (1.5 in) of HMA, Full Depth Rehabilitation, and Full Depth Reconstruction.
- Areas treated with Shim have significantly less rutting than the remaining treatments.
- Variable Depth Gravel sections have significantly less rutting than the Full Depth Rehabilitation and both Foamed Asphalt treatments.
- Foamed Asphalt with 80 mm (3 in) of HMA has less rutting than the Full Depth Rehabilitation treatment.
- Full Depth Reconstruction has less rutting than the Foamed Asphalt with 40 mm (1.5 in) HMA and Full Depth Rehabilitation treatments.

Future test results and life cycle cost analysis will determine which treatments are more cost effective.

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Additional Documentation:
“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