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MaineDOT

Transportation Research Division

Technical Report 02-2

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

Final Report - March, 2009

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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 (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 unbound 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 evaluates the performance of a Foamed Asphalt project 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.

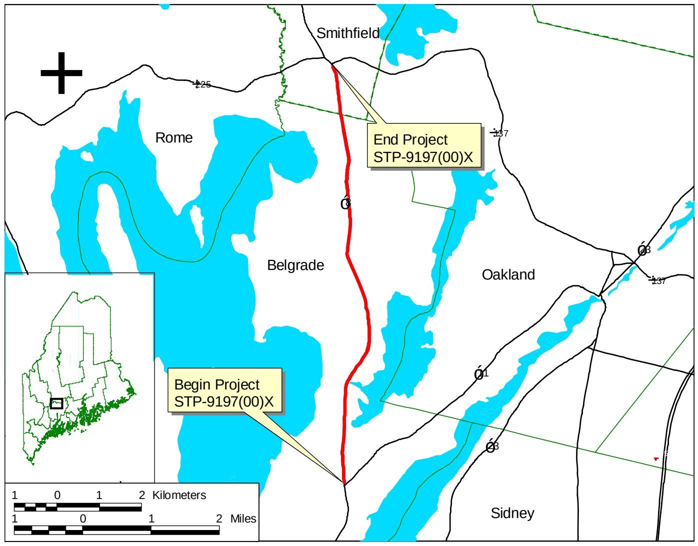


Figure 1: Project No. STP-9197(00)X Location Map

Preliminary Data Collection

A detailed overview of preliminary data collection can be reviewed in MaineDOT 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)

Station (from)	Station (to)	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
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 (foamed asphalt)

* 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 (foamed asphalt) and Asphalt Stabilized (foamed asphalt) Base without HMA Base are very similar in costs. Evaluation of these sections over the five-year period will help determine which treatment is more 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 was evaluated over a period of five years. Three experimental areas were established for evaluation, one control and two test sections. Performance of each test section were compared to the control section and summarized in the Experimental Test Section Analysis portion of the report. Data collection included Falling Weight Deflectometer (FWD) measurements to monitor changes in structural integrity of each section and Automatic Road Analyzer (ARAN) tests to monitor surface conditions such as roughness and rutting plus a visual inspection to monitor pavement cracking.

In addition to evaluating the control and test sections, FWD tests were collected every 100 meters to monitor structural changes within each treatment and the ARAN tested the entire project for rut depth and roughness. 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 Reclamation without the foamed asphalt. Caution was taken to select an area that has no Variable Depth Gravel added to the recycled base. The surface was 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 200 mm reclaimed base was treated with foamed asphalt. The surface was 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 200 mm foamed asphalt stabilized base and was surfaced with 40 mm of HMA Surface with no HMA Base layer.

Structural Summary

Pavement deflections were recorded on September 28, 2006. Annual deflections were collected at the same locations in all three sections.

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. A high ESN indicates greater structural capability. 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 base 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 decreased in all three test sections this year.

The Control Section average ESN is 92 in 2006 a decrease of 6 percent. This is the first year the ESN has decreased significantly. The preceding four year ESN values have been 98 or 97 indicating the structural condition has been very stable. Although the ESN is high the Standard Deviation is also high indicating the section is not very uniform.

The average ESN in Test Section One, with 80 mm (3 in) of HMA over 200 mm (8 in) of foamed asphalt, decreased from 95 in 2005 to 85 in 2006 a change of 10.5 percent. ESN values have been steadily decreasing each year with the most dramatic decrease occurring in 2006. The standard deviation is small indicating structural integrity is very uniform and that in theory Test Section One will distribute traffic loads more effectively over time than the Control Section.

Test Section Two has 40 mm (1.5 in) of HMA over 200 mm (8 in) of foamed asphalt. The average ESN has decreased 11.8 percent in 2006 to a value of 82. Structural numbers have been consistently lower than Test Section One values mainly due to the reduced amount of HMA. As mentioned in the last report the low Standard Deviation for all five years indicates that structural integrity is more uniform than both sections possibly due to refined Foamed Asphalt construction methods when this section was built.

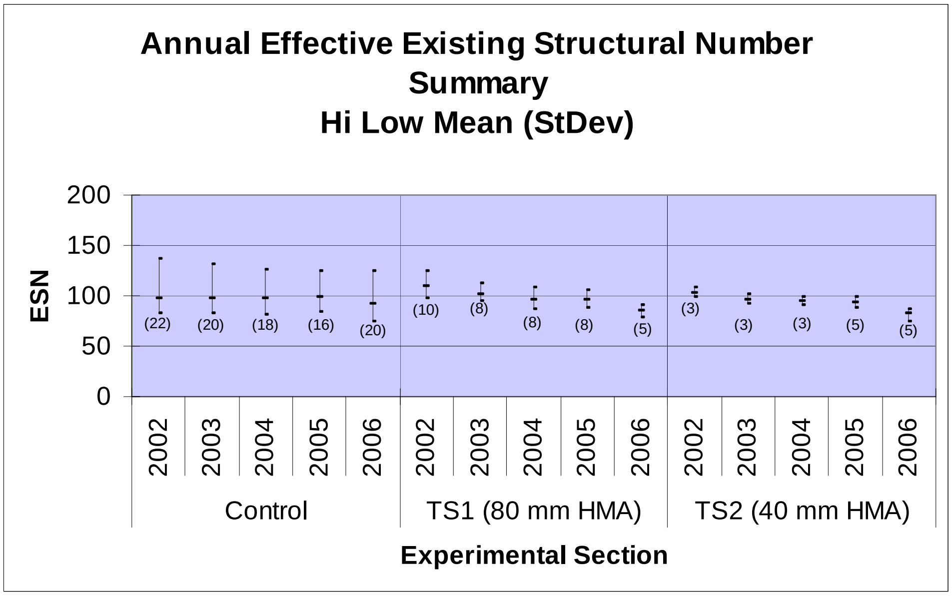


Figure 2: Effective Existing Structural Number Summary

ESN test values for 2006 were compared to determine if there is a significant difference between sections. Single Factor ANOVA data analysis reveals that the P-value is greater than the significance level (0.05) so we can accept the null hypothesis and assume that there is no significant difference between sections. Test results are displayed in Table 3.

Table 3: Analysis of 2006 ESN using ANOVA: Single Factor

Experimental Section 2006 Effective Existing Structural Number Analysis
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Control	5	461	92.2	384.7
TS1	5	424	84.8	24.7
TS2	6	491	81.83333	28.96667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	303.5667	2	151.7833	1.107017	0.35978532	3.805567
Within Groups	1782.433	13	137.1103			
Total	2086	15				

Ride Summary

Smoothness measurements were collected on September 9, 2006 utilizing the Departments ARAN test vehicle. 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 calculates an average of 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 for varying degrees of roughness taken from ASTM Standard E 1926-98 “Computing International Roughness Index of Roads from Longitudinal Profile Measurements”.

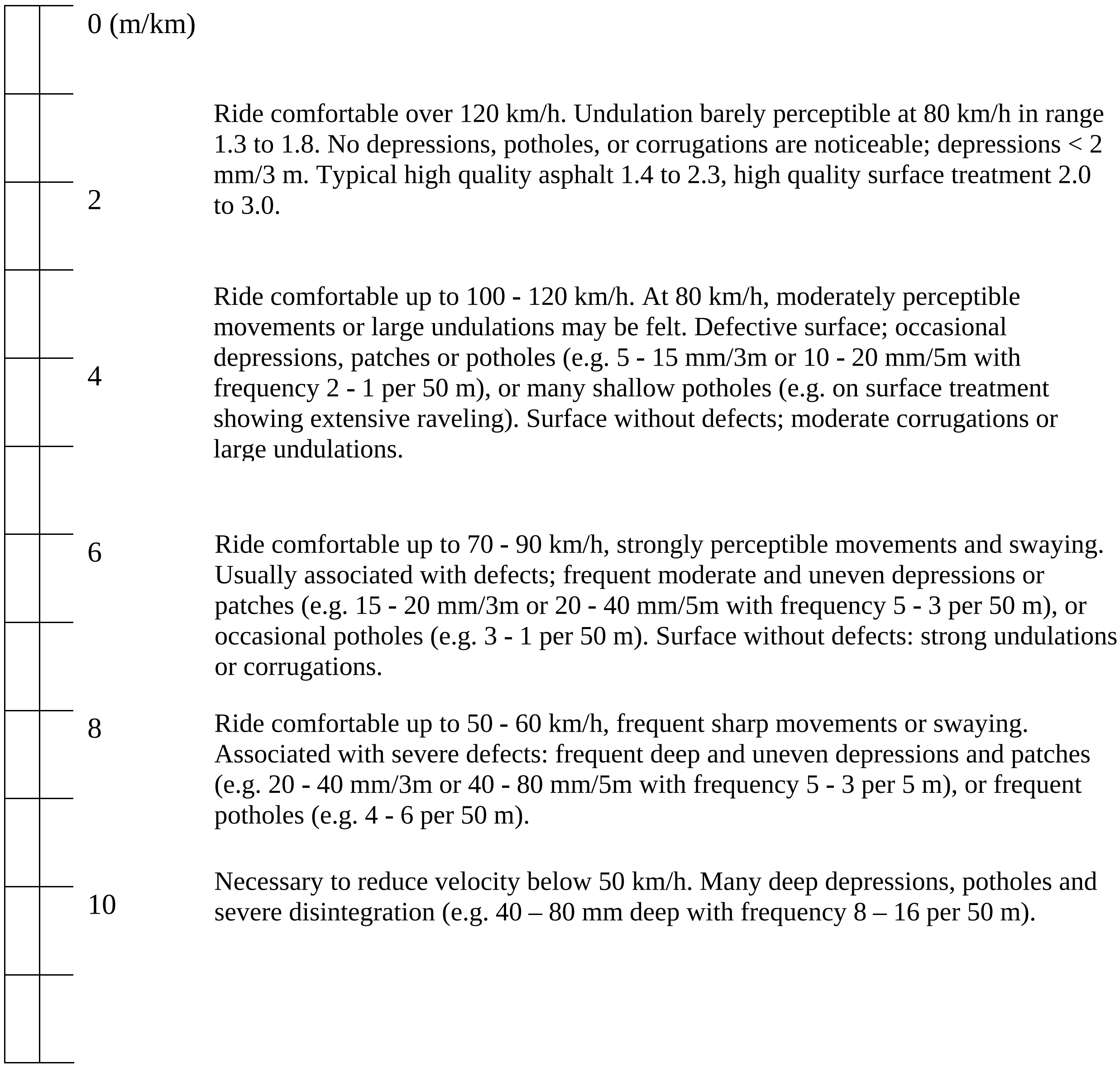


Figure 3: Road Roughness Scale for HMA Paved Roads

Figure 4 contains a summary of IRI values for each test section. Average IRI values range between 1.63 and 2.36 m/km (103 – 150 in/mi) which is considered a High Quality Surface Treatment.

The Control Section continues to have higher IRI values than Test Sections One and Two. Values increased 28 percent in 2006 to an average of 2.36 m/km (150 in/mi) which are 45 percent higher than Test Section One and 12 percent higher than Test Section Two. The standard deviation is more than twice the standard deviation of both Test Sections indicating a non-uniform ride which could contribute to an abnormal increase in IRI values with time.

Test Section One, with 80 mm of HMA, has a slightly lower average IRI than last year at 1.63 m/km (103 in/mi). 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. The standard deviation improved from 0.6 in 2005 to 0.5 in 2006 indicating a uniform roadway treatment that is less susceptible to distortion.

Test Section Two has a lower average IRI value than the Control Section but is 29 percent 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 2.11 m/km (134 in/mi) in 2006. Standard deviations are lower than the Control Section but higher than Test Section One indicating the section is not as uniform as Test Section One. The lack of HMA base may be contributing to increased IRI values.

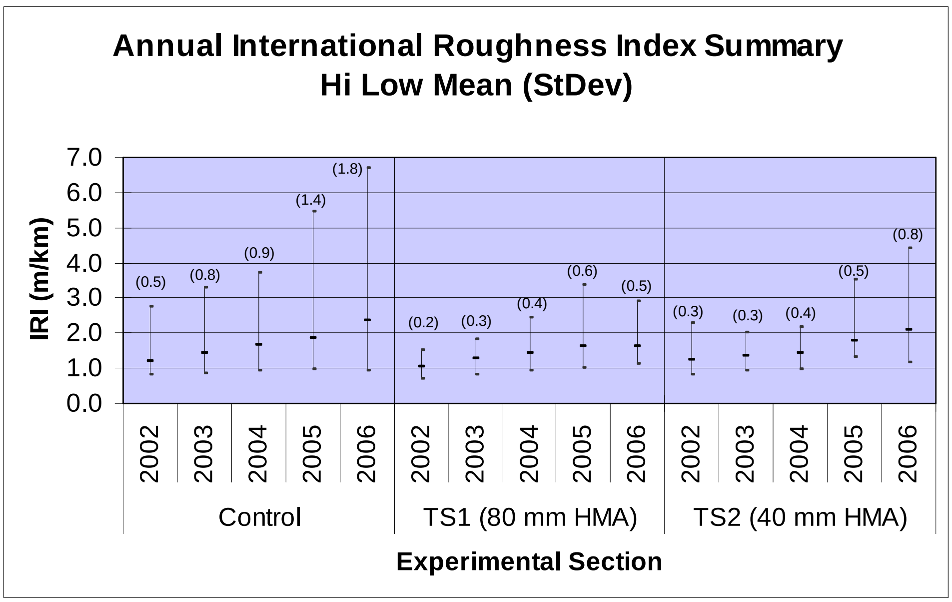


Figure 4: International Ride Index Summary

Table 4 contains a numerical output of ANOVA: Single factor test results. The P-value is greater than the significance level (0.05) indicating that there is no significant difference between sections.

Table 4: Statistical Analysis of 2006 IRI Measurements

IRI Data Analysis
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Control	12	28.26	2.355	3.173718
TS1	20	32.51	1.6255	0.204279
TS2	20	42.14	2.107	0.652938

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.523437	2	2.261718	2.164619	0.125647	3.186585
Within Groups	51.19802	49	1.044857			
Total	55.72145	51				

Rut Depth Summary

Rut Depth measurements were collected on September 9, 2006 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. Readings 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 in 2006 has increased on all three Experimental Sections while the standard deviation has decreased.

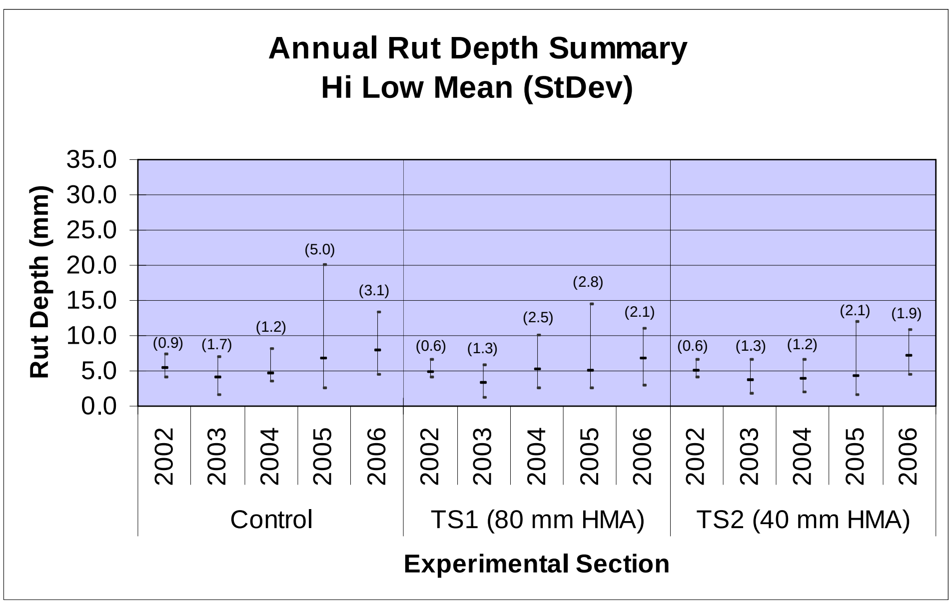


Figure 5: Rut Depth Summary

Mean Rut Depth in the Control Section remains the highest at 7.8 mm (0.31 in) an increase of 16 percent and the lowest increase of the Experimental Sections. The standard deviation decreased 32 percent but remains the highest at 3.1 mm (0.12 in). This is due in part to a cross pipe that has settled resulting in an isolated high reading of 13.3 mm (0.52 in).

Rutting in Test Section One increased nearly 39 percent in 2006 to an average depth of 6.8 mm (0.27 in) which is the lowest average of the Experimental Sections. The standard deviation decreased 25 percent to a value of 2.1 mm (0.08 in). With the exception of 2004 data, mean Rut Depths and standard deviations have continued to be 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 in 2004 and 2005. The average Rut Depth increased 67 percent to a depth of 7.2 mm (0.28 in) and the standard deviation is the lowest at 1.9 mm (0.07 in). One reason for the improved performance may be attributed to the quality of Foamed Asphalt. The contractor began placing Foamed Asphalt on the south end of the project with guidance from Wirtgen America Inc. By the time they reached the area of Test Section Two the contractor had more experience and the product looked more uniform and consistent.

ANOVA: Single Factor test results are displayed in Table 5. Analysis of 2006 Rut Depth data revealed no significant difference between test sections.

Table 5: Analysis of 2006 Rut Depth Measurements using ANOVA: Single Factor

Rut Depth Data Analysis
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
C	12	94.15	7.845833	9.738627
TS1	20	135.8	6.79	4.411189
TS2	20	143.14	7.157	3.602601

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8.37118641	2	4.185593	0.790688	0.459233	3.186585
Within Groups	259.386912	49	5.29361			
Total	267.758098	51				

Visual Summary

A visual inspection was completed on September 28, 2006. The pavement on all three sections looks very good after four years exposure to traffic. Table 6 contains a crack summary of each experimental section.

Centerline separation is displayed as a percent of section length.

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.

Table 6: Visual Inspection Summary

	Crack Type														
	Centerline, % of Length					Transverse, # / 100 meters					Longitudinal, % of Length				
Year	02	03	04	05	06	02	03	04	05	06	02	03	04	05	06
Control		27	34	38	44			0.2	0.6	0.6		0.4	0.6	1.7	1.3
TS1		10	15	18	21				0.6	0.8			0.2	0.6	1.5
TS2		33	55	79	94		0.2	0.9	1.2	1.2		0.5	1.7	1.9	5.2

	Load Cracking, Percent of Area														
Type	Initial					Moderate					Severe				
Year	02	03	04	05	06	02	03	04	05	06	02	03	04	05	06
Control				0.4	1.7										
TS1			0.1	0.1	1.6					0.4					
TS2		0.2	1.3	2.7	4.9					0.8					0.08

Centerline separation in the Control Section has increased from 38 percent in 2005 to 44 percent in 2006. The number of transverse cracks has not changed from last year with one crack extending across three quarters of the roadway. This section continues to have the least amount of transverse cracking. A portion of longitudinal cracking has migrated into the wheel path and is now considered initial load cracking. This resulted in a decrease from 1.7 percent to 1.3 percent of the section. The amount of initial load cracking increased from 0.4 percent to 1.7 percent, the smallest increase of the three sections. No moderate or severe load cracking was observed. The section looks very good with the exception of deep ruts where a skewed cross pipe has settled.

Test Section One with 80 mm (3 in) of HMA has slightly more cracking than the Control Section but considerably less than Test Section Two. Although centerline separation has increased from 18 to 21 percent it continues to be the lowest amount of all sections. The number of transverse cracks has increased from 0.6 to 0.8 which is slightly more than the Control Section and about a third less than Test Section Two. The amount of longitudinal cracking more than doubled to 1.5 percent. This is slightly more than the Control Section but considerably less than Test Section Two. Initial load cracking increased from 0.1 to 1.6 and there was 0.4 percent of moderate load cracking as well. This section has slightly more load cracking than the Control Section but much less than Test Section Two. This may be an indication of poor construction. As mentioned earlier, Foamed Asphalt was placed on this section first with an inexperienced crew and the quality of product was not as good.

Test Section Two continues to have the majority of cracking. Centerline cracking increased from 79 to 94 percent of the project while transverse cracking remained the same. Longitudinal cracking increased dramatically from 1.9 to 5.2 percent. Initial load cracking nearly doubled to 4.9 percent and there was 0.8 percent of moderate and 0.08 percent of severe load cracking. The amount of load and longitudinal cracking may be attributed to the thin layer of HMA. 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.

Treatments in the following figures are 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

Frost movement

A frost movement survey was not completed in 2006. The following inspection statement is from the 3rd and 4th Interim Report which was inspected in 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’.

Treatment areas were selected based on pre-construction FWD deflections and pavement condition. The majority of areas selected for Shim and Full Depth Reclamation had deteriorated pavement with a structurally sound base and good drainage and had little frost movement. Areas selected for Reconstruction had super elevated curves or needed realignment and drainage. Areas selected for Variable Depth Gravel and Foamed Asphalt had lower structural numbers and more frost movement. The Reconstructed and Variable Depth Gravel sections have less frost movement after construction due to additional gravel base and HMA.

Structural Summary

Effective Existing Structural Numbers will be utilized to monitor stability of each treatment. Figure 6 contains a summary of 2002 thru 2006 ESN data. Mean structural numbers have decreased in all sections.

Average Full Depth Reclamation Structural Numbers have decreased from 98 to 91 which is the second lowest average.

Foamed Asphalt without HMA base has the lowest average at 85. This treatment has consistently had the lowest structural readings with high standard deviation indicating the treatment is not very consistent.

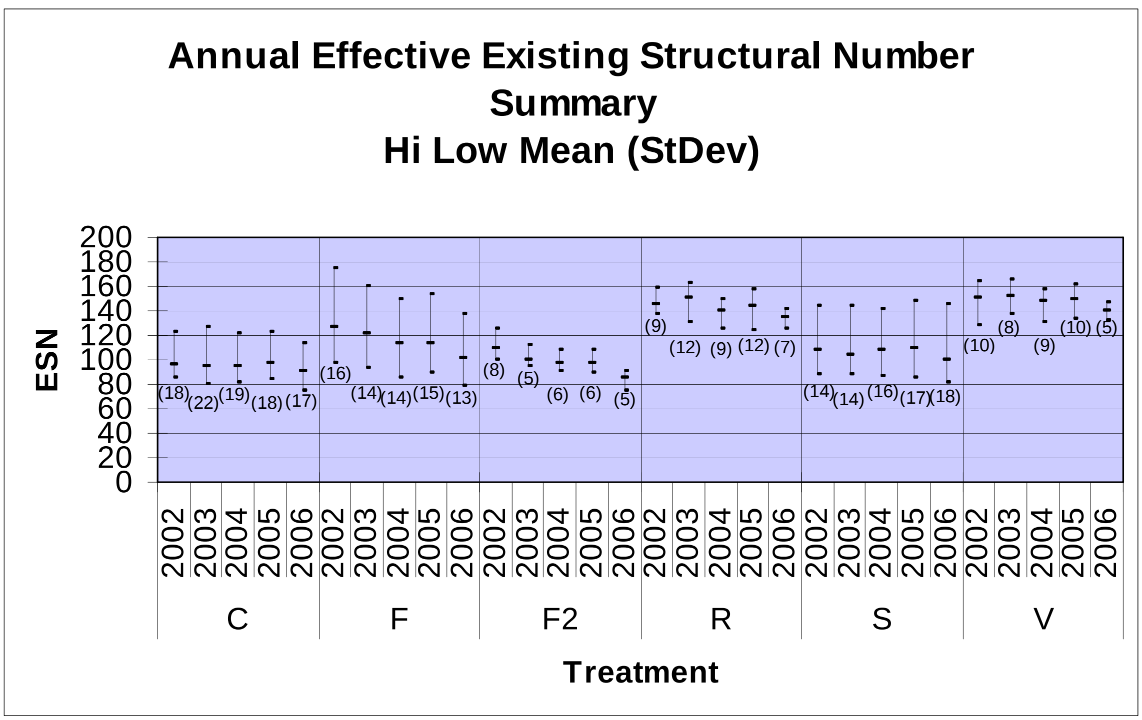
Structural stability in the Foamed Asphalt with HMA base treatment has decreased 11.4 percent to an ESN of 101 with high standard deviations. Structural Numbers have steadily decreased for the first three years then stabilized in the fourth year and decreased again in the fifth year. When reviewing Structural

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 particles in the 75 mm (3 in) plus range which does not blend well with foamed asphalt 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 uniformity than the Full Depth Reclamation, Foamed Asphalt with HMA base, and Shim treatments.

Foamed Asphalt without HMA base has the lowest average ESN at 85, a 13.3 percent decrease. The standard deviation continues to be low at 5 indicating a uniform material but structurally the section continues to degrade. As mentioned earlier the contractor had refined construction procedures when this section was built producing a more uniform Foamed Asphalt material. Reduced HMA thickness appears to be contributing to low ESN values. 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.

Figure 6: Effective Existing Structural Number Summary

Average structural numbers for Full Depth Reconstruction decreased 6.2 percent to a value of 135 which



is the second highest average. Structural numbers have been following a pattern of increasing then decreasing each year resulting in a gradual decline in stability. The rate of decline is about half the rate of Foamed Asphalt. Standard deviations continue to be low indicating a uniform treatment. This treatment and the Variable Depth Gravel treatment have similar structural results.

Structural numbers for the Shim treatment decreased 7.3 percent to an average of 101. Deflections have been very consistent which is understandable due to the relatively sound structural condition of these areas prior to resurfacing. Cracks are continuing to reflect through the pavement which is typical of shim and surfaced roadways. This treatment continues to have higher structural numbers than the Full Depth Reclamation and Foamed Asphalt without HMA base areas.

Variable Depth Gravel areas are outperforming all the treatments. Average values decreased 6.7 percent to an ESN of 140. Structural numbers have been consistently higher all five years possibly due to improved drainage capabilities of the variable depth gravel.

Effective Existing Structural Numbers for 2006 were statistically compared to each other to determine if there is a significant difference between treatments. Results are displayed in Table 7.

Table 7: Analysis of 2006 Effective Existing Structural Numbers using ANOVA: Single Factor

Effective Existing Structural Number Analysis
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
C	4	363	90.75	278.25
F	42	4250	101.1905	179.2311
F2	8	678	84.75	26.5
R	5	675	135	51.5
S	32	3218	100.5625	316.8992
V	10	1401	140.1	29.21111

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	22148.54	5	4429.708	22.55029	7.5853E-15	2.310223
Within Groups	18661.5	95	196.4369			
Total	40810.04	100				

Analysis reveals that the P-value is lower than the significance level (0.05) which means that there is a significant difference between treatments.

Figure 7 contains a Box and Whisker Plot of each treatment to determine which treatment is significantly different. Variable Depth Gravel and Full Depth Reconstructed treatments have significantly higher structural numbers than the remaining treatments and the range of data is not as variable indicating that subbase gravel has substantially increased roadway stability.

Shim sections have a wide range of ESN values which is understandable due to the wide range of pre-construction deflections. Resurfacing with HMA enhances more than increases structural integrity of the existing roadway. Data results show that Shim treatment is significantly different than the Foamed Asphalt without HMA Base treatment.

Foamed Asphalt treatment also has a wide range of ESN values. This is primarily due to construction techniques mentioned earlier. The mean value is greater than the mean values of the Shim, Full Depth Reclamation, and Foamed Asphalt without HMA Base treatments but structurally this treatment is significantly better than the Foamed Asphalt without HMA Base treatment.

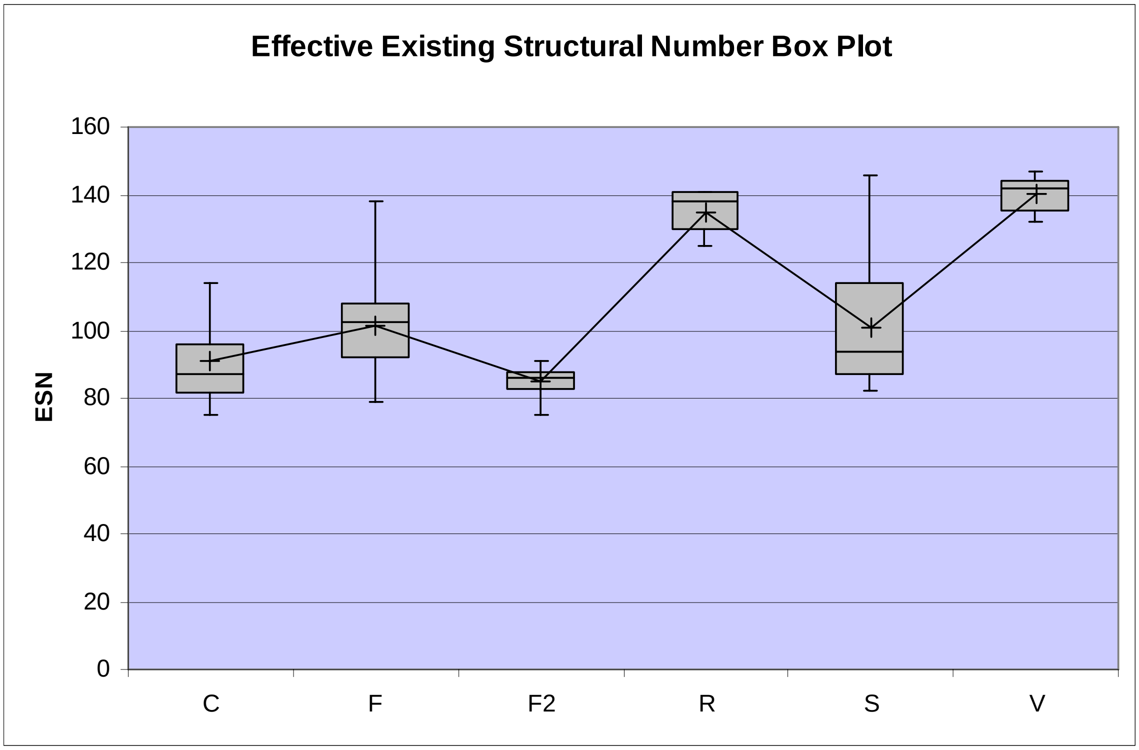


Figure 7: Box and Whisker Plot of 2006 ESN Test Results: Cross Marks the Average; Horizontal Line in Box = Median; Box Reaches = 25th and 75th Quartile; Vertical Lines = Range of data

Foamed Asphalt without HMA Base has a smaller range of data indicating the treatment is more uniform. The 40 mm (1.5 in) reduction in HMA thickness has decreased the structural capacity of the treatment resulting in the lowest mean ESN value. HMA thickness was reduced as a cost cutting measure.

Smoothness Summary

ARAN data was utilized to compare smoothness of each treatment from station 1+200 to 11+200. Figure 8 contains a summary of the results.

Smoothness measurements increased or remained the same on all treatments. The average IRI ranges between a low of 1.3 to a high of 2.1 m/km (85.4 to 133.1 in/mi). Smoothness readings are typical for a project exposed to traffic for five years and based on IRI descriptions in Figure 3, the project as a whole continues to be in the high quality surface treatment range.

Full Depth Reclamation, Full Depth Reconstruction, and Foamed Asphalt without HMA base have the greatest average IRI readings. Full Depth Reclamation increased 10.5 percent to the highest mean IRI at 2.1 m/km (133.1 in/mi). Full Depth Reconstruction remained the same at 2.0 m/km (126.7 in/mi) and Foamed Asphalt without HMA base increased from 1.8 to 2.0 m/km (114.0 to 126.7 in/mi), an increase of 11.1 percent.

Areas treated with Shim and Variable Depth Gravel has the lowest average IRI values. Shim treatments have the lowest average IRI at 1.3 m/km (82.4 in/mi) an increase of 8 percent. Variable Depth Gravel also increased 8 percent to an average IRI of 1.4 m/km (88.7 in/mi)

Areas treated with Foamed Asphalt with HMA base have smoother IRI readings than Full Depth Reclamation, Full Depth Reconstruction, and Foamed Asphalt without HMA base areas. Average IRI increased from 1.6 m/km (101.4 in/mi) to 1.7 m/km (107.7 in/mi) an increase of 6 percent.

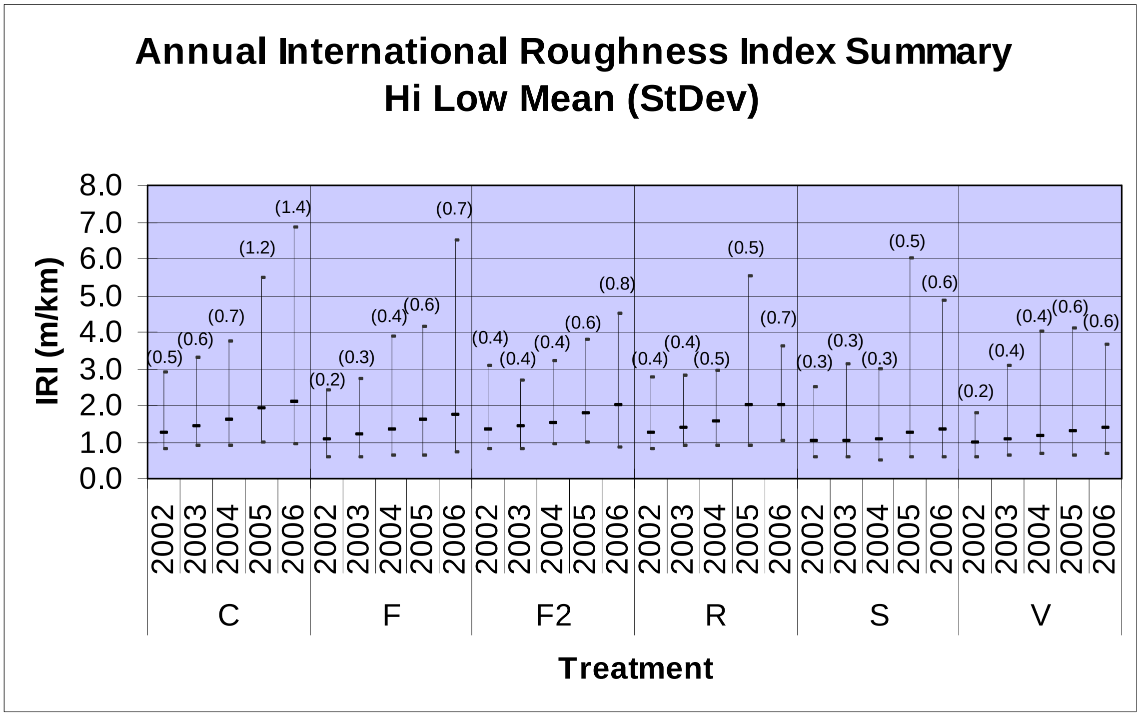


Figure 8: International Roughness Index Summary

A statistical comparison of each treatment using 2006 ARAN Ride data is displayed in Table 8. A low P-value indicates there is a significant difference between treatments.

To isolate which treatments are different a box plot of each treatment is displayed in Figure 9. Treatments that are significantly different at the 95% confidence level are summarized below.

Variable Depth Gravel and Shim treatments continue to be 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.

Table 8: Analysis of 2006 International Roughness Index using ANOVA: Single Factor

IRI Analysis
Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
C	44	92.87	2.1106818	1.83447627
F	411	710.36	1.7283698	0.46858343
F2	80	159.64	1.9955	0.58142506
R	36	72.42	2.0116667	0.43320286
S	326	437.9	1.3432515	0.35517463
V	102	141.11	1.3834314	0.34245247

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	62.883117	5	12.576623	25.9037073	1.23E-24	2.223118
Within Groups	482.11582	993	0.4855144			
Total	544.99894	998				

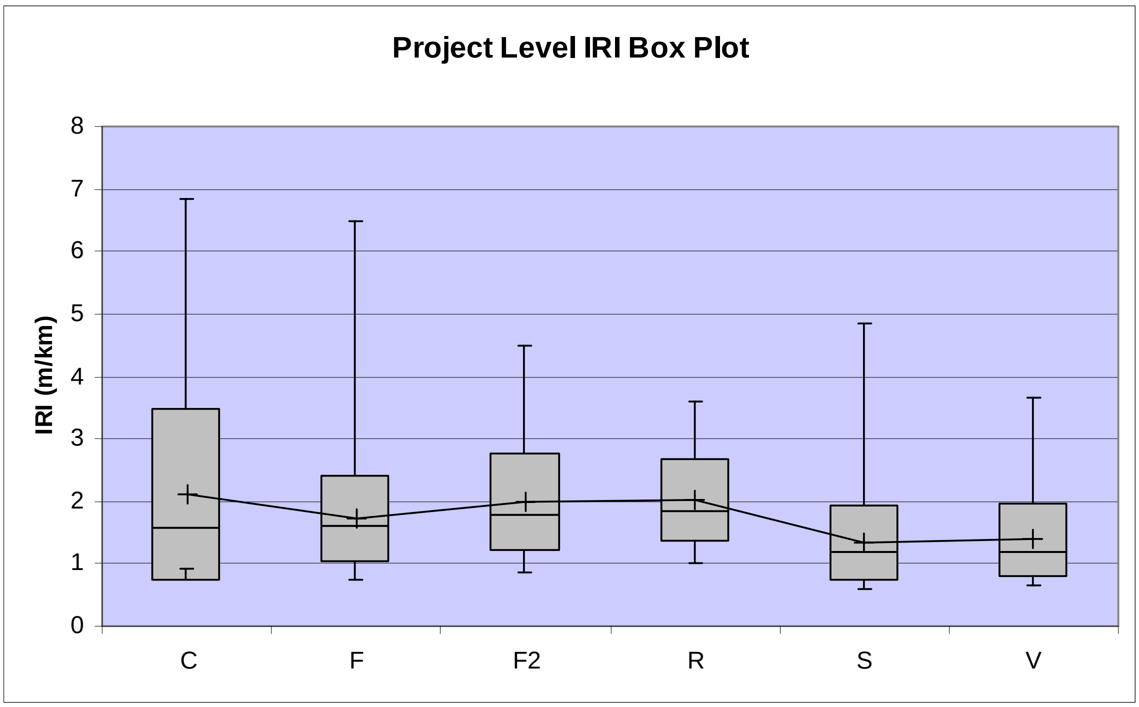


Figure 9: Graphical 2006 IRI Test Results: Cross Marks the Average; Horizontal Line in Box = Median; Box Reaches = 25th and 75th Quartile; Vertical Lines = Range of data

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 10 contains a summary of test results for each treatment.

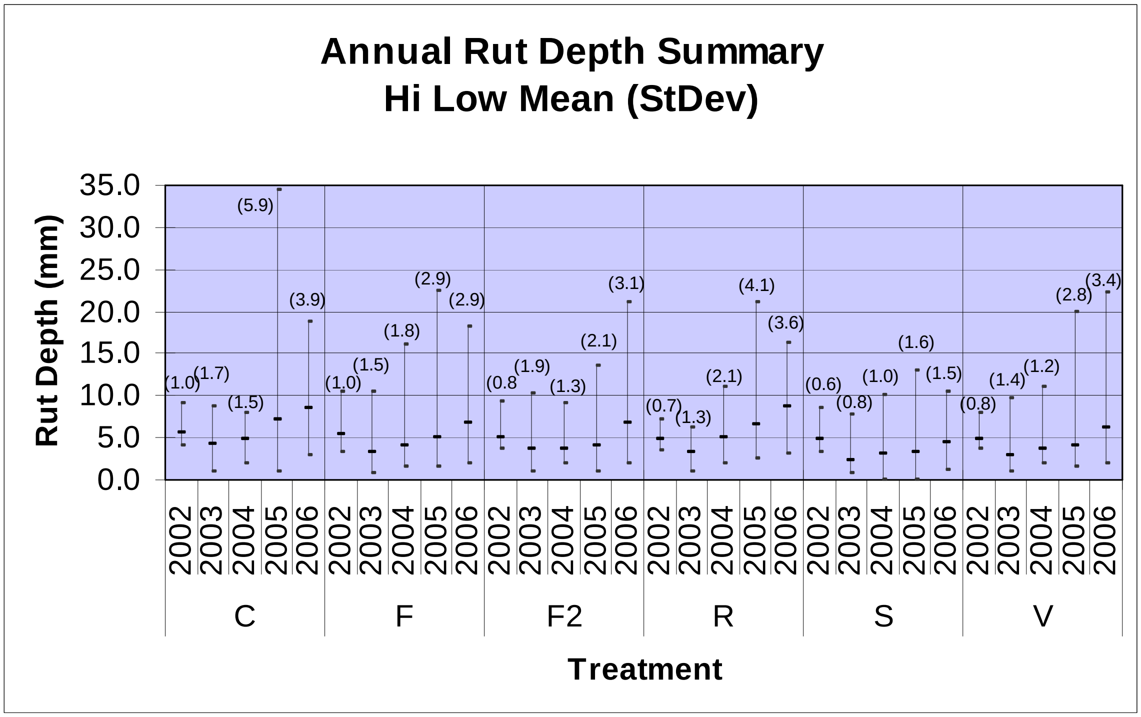


Figure 10: Rut Depth Summary

Average Rut Depths increased on all treatments and range in depth from a low of 4.5 mm (0.18 in) to a high of 8.6 mm (0.34 in). Rutting is typical in all treatments 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 4.5 mm (0.18 in). The standard deviation has also been consistently lower than the other treatments. 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 hade similar Rut Depths as the Shim treatment up until this year when the average increased 48.7 percent from 4.1 to 6.1 mm (0.16 to 0.24 in). Rutting is now similar to both Foamed Asphalt treatments.

Average Rut Depth in the Foamed Asphalt with HMA base areas increased from 5.0 mm (0.20 in) to 6.8 mm (0.27 in), an increase of 36 percent. This treatment has been rutting at a slower rate than the Full Depth Reclamation and Full Depth Reconstruction treatments.

Rut Depths in the Foamed Asphalt without HMA base areas have been very stable with little change in depth with the exception of this year. The average Rut Depth increased from 4.0 mm (0.16 in) to 6.7 mm (0.26 in) an increase of 68 percent. It appears the reduced HMA thickness is beginning to show signs of wear. Rutting is similar to the Foamed Asphalt with HMA base treatment and is still performing better than the Full Depth Reclamation and Full Depth Reconstruction treatments.

Full Depth Reclamation and Full Depth Reconstruction treatments continue to have the greatest amount of rutting. Average Rut Depth is 8.5 and 8.6 mm (0.33 and 0.34 in) respectively, an increase of 20 and 28 percent.

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 9 contains a statistical comparison of 2006 rut depths.

Table 9: Analysis of 2006 Rut Depth using ANOVA: Single Factor

Rut Depth Analysis
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
C	44	374.31	8.5070455	15.1017655
F	411	2799.8	6.8121655	8.08335749
F2	80	537.82	6.72275	9.68578222
R	36	310.35	8.6208333	13.0026079
S	326	1477.5	4.5322086	2.31714157
V	102	626.65	6.1436275	11.5425738

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1523.6051	5	304.72102	42.6018749	7.82E-40	2.223118
Within Groups	7102.6915	993	7.1527609			
Total	8626.2966	998				

A low P-value indicates there is a significant difference between treatments. A box plot of rut depth data is presented in Figure 9 to determine which treatment is different.

Shim treatments have less rutting and the data range is smaller indicating more uniformity. This treatment is significantly different or has significantly less rutting than the remaining treatments.

Variable Depth Gravel and both Foamed Asphalt treatments are statistically similar. Box reaches are small indicating data is distributed more uniformly. These three treatments are significantly different than the Full Depth Reclamation and Full Depth Reconstruction treatments.

Full Depth Reclamation and Full Depth Reconstruction treatments have similar results. They have the greatest average Rut Depth and the largest box reach indicating a greater spread of data. The median is low on the Full Depth Reclamation treatment indicating there are more high Rut Depth readings. The median value for Full Depth Reconstruction is near the middle of the box reaches indicating a more uniform data distribution and a more stable treatment.

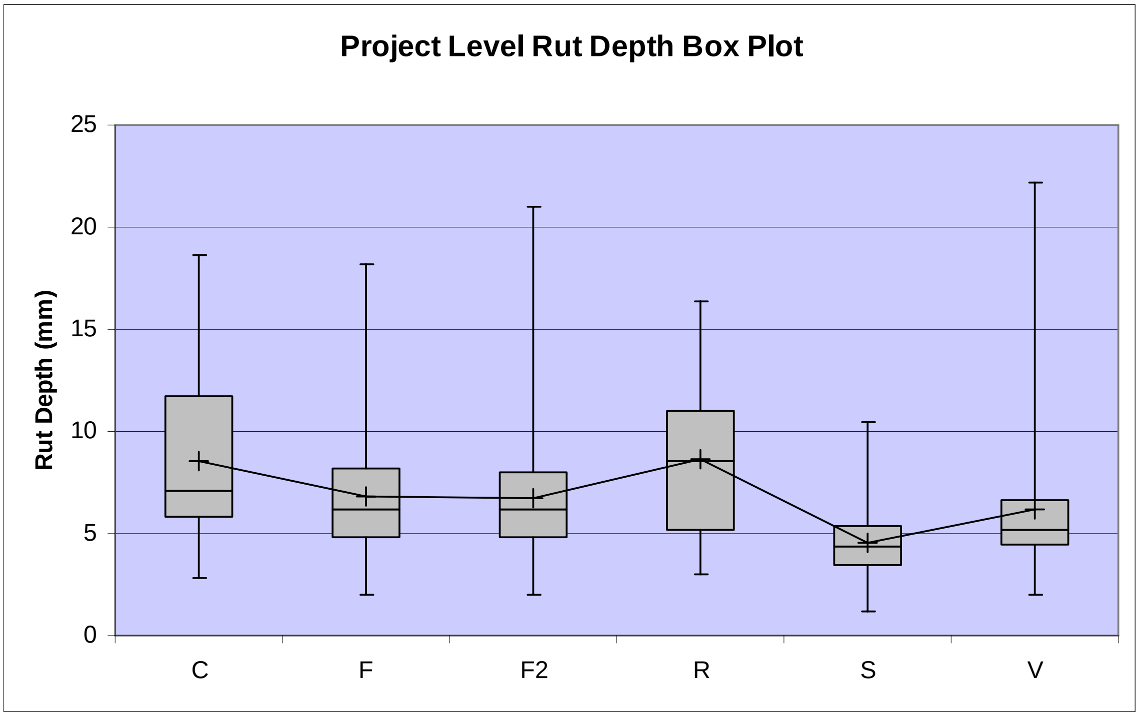


Figure 11: Graphical 2006 Rut Depth Test Results: Cross Marks the Average; Horizontal Line in Box = Median; Box Reaches = 25th and 75th Quartile; Vertical Lines = Range of data

Summary

The project is performing very well after five years exposure to traffic and the environment. Control and Experimental Test Section results for Effective Structural Numbers, International Ride Index, and Rut Depth have not revealed an analytically significant advantage but average test results are slightly better for Test Section One.

Test Section One with Foamed Asphalt and a total of 80 mm of HMA had the least amount of cracking for the first four years then transverse, longitudinal, and load cracking increased to about the same level as the Control Section on the fifth year. It's likely that over time the Control Section will deteriorate at a higher rate than Test Section One. Construction costs for Foamed Asphalt with 80 mm of HMA are 53 percent greater than Full Depth Reclamation but that cost may be inflated due to contractor inexperience. Future applications of Foamed Asphalt should bring the cost down and make the procedure more cost effective.

Test Section Two with a total of 40 mm of HMA has had the greatest amount of cracking throughout the test evaluation period. A thin layer of HMA over Foamed Asphalt was suggested to reduce overall cost of the procedure. Test results reveal that Foamed Asphalt does not effectively support a 40 mm layer of HMA.

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 and drop sharply on the fifth year. 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 have significantly less rutting than the remaining treatments
- Foamed Asphalt with and without HMA base and Variable Depth Gravel treatments has significantly less rutting than the Full Depth Reclamation and Full Depth Reconstruction.
- Full Depth Reclamation and Full Depth Reconstruction areas have significantly more rutting then the remaining sections.

On a project level analysis the Foamed Asphalt with HMA base has improved stability, ride, and rutting when compared to Full Depth Reclamation and Foamed Asphalt without HMA base.

The use of Foamed Asphalt is recommended as an alternative to Full Depth Reclamation to extent roadway life. Construction procedures are very efficient which reduces impact on traffic control. Foamed Asphalt application costs are high for this study but the cost is expected to diminish as the contractor becomes more familiar with construction procedures.

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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
Interim Report – Third and Fourth Year, October 2006

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