New Hampshire DOT

Research

Polyurethane Foam for Roadway Stabilization
NH Route 129, Loudon, NH

Final Report

Prepared by New Hampshire Department of Transportation
Bureau of Materials and Research in cooperation with the
U.S. Department of Transportation, Federal Highway Administration

Technical Report Documentation Page

1. Report No.	2. Gov. Accession No.	3. Recipient's Catalog No.
FHWA-NH-RD-15680H		

4. Title and Subtitle	5. Report Date
Polyurethane Foam for Roadway Stabilization NH Route 129, Loudon, NH	December 12, 2016
	6. Performing Organization Code
7. Author(s) Denis Boisvert, P.E.	8. Performing Organization Report No.
9. Performing Organization Name and Address New Hampshire Department of Transportation Bureau of Materials and Research Box 483, 5 Hazen Drive Concord, New Hampshire 03302-0483	10. Work Unit No. (TRAIS) 11. Contract or Grant No. 15680H, A001(220)
12. Sponsoring Agency Name and Address New Hampshire Department of Transportation Bureau of Materials and Research Box 483, 5 Hazen Drive Concord, New Hampshire 03302-0483	13. Type of Report and Period Covered FINAL REPORT 14. Sponsoring Agency Code

15. Supplementary Notes

In cooperation with the U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION

16. Abstract

This report summarizes the evaluation of the performance of polyurethane foam as a method of roadway stabilization for a rural roadway experiencing substantial frost heaving.

NHDOT is responsible for many roads which have evolved from gravel roadways and were not constructed with a full aggregate layer. These “unconstructed” roads often experience significant to severe frost heaving due to poor soil conditions and/or inadequate drainage.

Segments of NH Route 129 received polyurethane injection in 2011 and 2013. Observations of the roadway indicated rutted conditions begin to return after several years, meaning that the soil displacements continue to occur in the spring as the frost leaves the soil.

The goal of the treatment was to improve stability to the point where the roadway could be considered as a candidate for pavement preservation treatments. The failure to meet that goal means that the cost benefits of the resulting improvements are not adequate to implement this research.

	18. Distribution Statement
	No Restrictions. This document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia, 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	22	

Evaluation of Corrosion and Corrosion Control on Interstate 89 Bridges #30 and # 31

Prepared by:
CD Engineering
640 Pleasant Point Road
Cushing, ME 04563

Prepared for:
New Hampshire Department of Transportation
Bureau of Materials and Research
Concord, NH

DISCLAIMER

Report No. FHWA-NH-RD-15680H

<u>EVALUATION REPORT, OCTOBER 2011 TO JUNE 2014</u>
POLYURETHANE FOAM
FOR ROADWAY STABILIZATION
NH ROUTE 129, LOUDON, NH

Prepared By:
Denis M. Boisvert, P.E.
Chief of Materials Technology

NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
BUREAU OF MATERIALS & RESEARCH
P.O. Box 483
Concord, NH 03302-0483
Phone (603) 271-3151
Fax (603) 271-8700
E-mail: dboisvert@dot.state.nh.us

December 12, 2016

Table of Contents

EXECUTIVE SUMMARY

Discussions with a soil stabilization contractor inspired a concept for an alternative to full roadway reconstruction and significant drainage construction to improve the performance of subbase and subgrade materials within informally constructed roads. Uretek USA partnered with NHDOT to reduce winter frost heaving and improve the weakening effects of spring thaw conditions of a roadway by injecting expanding polymer foam into these materials. The goal was to displace water from the soil located in the frost zone, to occupy the void space with foam to limit future absorption, and to create a skeletal system to help support traffic loads during the spring thaw season. Two installation variants were executed in an attempt to improve the subbase nearest the pavement.

While the overall magnitude of the frost heaves was reduced, their differential nature was not eliminated. The contractor was reluctant to inject the foam at a shallow depth for fear that the uncontrolled expansion of the foam would damage the pavement surface. This resulted in an inability to reliably treat the upper regions of the subbase to stabilize the material during spring conditions. Observations indicate that rutted conditions begin to return after several years, meaning that the near-surface subbase and pavement displacements continue to occur in the spring. The goal of the treatment was to improve stability to the point where the roadway could be considered as a candidate for pavement preservation treatments. The failure to meet that goal means that the cost benefits of the resulting improvements are not adequate to implement this research.

INTRODUCTION

The New Hampshire Department of Transportation is responsible for many miles of roadway that are unofficially classified as “unconstructed”, meaning that they were not formally constructed following modern design methods and materials. These roadways evolved from gravel roads during the early days of automotive travel, without the benefit of full depth construction using well drained soils, or the installation of underdrains. These “unconstructed” roadways are prone to severe frost heaving in winter and victim to rutting and other load damage in spring due to the excess water in the base and subbase materials. The expense to reconstruct these roads is prohibitive. However, maintenance costs are also high, because these roads must generally be repaved on about a six-year cycle to restore the driving surface.

The purpose of this project was to evaluate the effectiveness of injectable polyurethane foam (such as that used for subsurface soil stabilization and reinforcement applications) as a means of stabilizing unconstructed roadway base materials against differential frost heaving. The expanding polymer foam was expected to drive water out from the pore space where it expanded, and create a skeletal support system to reduce settlement and displacement of the base and subbase materials.

The original Work Scope had a single Phase of work. The limited benefits of this work showed promise, and a second phase was later executed in a nearby location. The following narrative describes the completed work, the collected data, and evaluation of the results.

TEST SITE SELECTION

The selected test site was located at the intersection of the unpaved Captain French Road and NH Route 129 in Loudon, NH. The site is located 7.0 miles north of the intersection of NH Routes 106 and 129, and 1.5 miles south of the intersection of NH Routes 129 and 107.

Project Location

Project Layout

This site was identified by Highway Maintenance District 3 as a section of roadway exhibiting severe frost heaving. Severe ruts up to four inches in depth form in the wheel paths during the winter months. The asphaltic roadway surface was uneven and cracked, with poor drainage. These conditions create extremely poor winter driving conditions, which dissipate with the return of warmer temperatures. The cyclic behavior deforms and deteriorates the pavement and driving conditions, and requires repaved about every six years to restore the surface. The selected test site was in a wooded area with a moderate cross slope. A brook parallels the roadway about 50 feet to the west, and crosses the roadway by culvert both north and south of the test site.

Existing Conditions – Deep ruts during frost heave season

Borings taken in March 2011, to collected subsurface information across the roadway at the edges, wheelpaths, and the centerline at control and test locations. Test area conditions consisted of 0.5 to 1.1 feet of hot mix asphalt (HMA) pavement, over fine and medium silty sand to a depth of 3.0 to 4.0 feet deep, over sandy, silty glacial till. Groundwater was observed between 0.5 and 1.1 feet below the surface. The control area had 0.4 to 0.7 feet of HMA pavement, over fine and medium silty sand to a depth of 1.3 to 2.0 feet, over sandy, silty glacial till. Groundwater observations in this area ranged between 0.5 and .8 feet below the surface.

Sample gradation information from the borings was sent to Uretek USA, the company who would perform the foam injection, for use in determining the best manner (e.g. injection spacing and depth) of constructing the test site. Uretek completed the installation prior to resurfacing work on NH 129, planned for that year. This allowed the holes at the injection sites to be covered. The test section included a suitable transition zone to minimize the potential for abrupt changes in heaving at the ends of the test section.

FACILITY INSTALLATION

An arbitrary stationing of the roadway was laid out at the site for reference purposes. Beginning at a drainage culvert south of the test area, stationing ran northerly from Station 0+00 to 8+35, comprising the test area (Station 3+90 to 4+90) and the control area (Station 7+55 to 8+35).

The overall treatment area of 100 LF in length included:

- A 50 LF full treatment area, consisting of rows of three injection points wide per lane located longitudinally every four feet. Polymer was injected at depths of 48 inches and 24 inches.
- A 25 LF transition area at each end of the full treatment zone. Polymer was injected only at 24 inches deep at the same layout in these locations.

A HMA leveling course (grader shim) had been placed to fill the heavily rutted wheel paths of this roadway prior to the polymer injection. The leveling course is the standard preparation for a scheduled maintenance overlay project. Placement of the overlay had been delayed to allow for the polymer injection to be completed first.

Red paint indicates 4-foot polymer injection grid on HMA shimmed surface
Foreground is the southerly transition zone
Workers standing in the full treatment area

Polymer injection was performed on September 21 and 22, 2011. Work began on the northbound lane, with the injection of 1,240 pounds of polymer. The second day of work injected 1,380 pounds of polymer in the southbound lane.

Injection of two-part polymer formulation
1-mm vertical pavement movement measured by laser level

Procedure

The installation crew used electric hammer drills equipped with 4-foot long auger bits to drill two holes at each injection location to the respective design depths for injection. A half-inch diameter steel tube with an end cap was then inserted into each hole. An injector gun (patented by Uretek USA) was then placed at the top of each of the deeper steel tubes to inject the two-part polyurethane foam formulation. Injection continued until the local pavement surface raised one millimeter. A laser level measured the pavement movement. The polymer expanded into the voids in the soil and displaced pore water until it cured into a solid in 20 to 30 seconds. Once the deeper injection points were completed, foam was then injected into the shallow points until the pavement again rose by one millimeter. When completed, excess polymer expanding from the injection points was removed and the tubing was driven below the pavement surface.

Left: 4-ft. auger bits and hammer drills prepare holes for injection.
Right: Steel pipes are inserted to direct polymer to the bottom of the holes.

The northbound injections on Sept. 21 were uneventful. However, many of the southbound injections on Sept. 22 resulted in water squirting up from adjacent prepared holes. This may have been due to the elimination of the treated northbound subbase materials as a drainage path. The water was sometimes clear and sometimes dark brown and muddy. In some cases the water streamed as high as 10 inches above the pavement, or pulsed intermittently. Although flowing water could not be seen, the gravel area within the shoulder at the intersection of Captain French Road was observed to glisten from the excess moisture moving laterally through the material.

Southbound lane injection forced groundwater to shoot from prepared holes.

Phase I First Winter - February 2012

Measurements

A NHDOT survey party collected baseline elevation data to monitor the general heave characteristics of the test area compared to the control area. Survey nails were installed in the new HMA pavement surface of the northbound lane from Stations 3+70 to 5+10 inclusively at 10-foot intervals and from Stations 7+55 to 8+35 inclusively at 20-foot intervals. Nails were located in the left and right (outer) wheel paths and at the roadway centerline. Baseline elevation measurements were made at the nails on November 4, 2011 with the intent to capture the maximum overall heave at the end of February or early March and the post-springtime “relaxed” condition in June. Subsequent measurements were collected February 27 and June 21, 2012; March 1 and July 3, 2013.

Worcester Polytecnic Institute (WPI) provided their falling weight deflectometer (FWD) to measure the dynamic modulus of the roadway. Baseline measurements were collected in the northbound lane on November 2, 2011. Measurements were made at 10-foot intervals in the treated area and 20-foot intervals in the control area. Comparative data was also collected when the roadbed was fully thawed in late March/April to capture the weakest soil conditions, and again during the summer to measure when soils had regained strength.

The NHDOT Pavement Management Section ride quality van was commissioned to measure ride deterioration as a result of the frost action. Baseline International Ride Index (IRI) measurements were collected on November 2, 2011. Subsequent measurements would follow the elevation survey data collection intervals to capture maximum heave conditions and the “relaxed” summer conditions.

OBSERVATIONS

Initial Observations, Data and Evaluation

Unfortunately, the winter of 2011-12 was mild, with unusually little snow and below-average temperatures for November through March. Elevation survey data was collected on February 24 and June 21, 2012. In spite of the mild conditions, there was still a significant comparison of the treated and control areas. Elevation data showed that the fully treated area reduced heaving by 60% when compared with the control area in the first winter.

	November	December	January	February	March
16-yr Avg. Temp. (F)*	39.9	28.8	20.9	22.8	32.2
2011-2012	+3.7	+4.2	+4.1	+6.3	+8.6
2012-2013	-1.4	+2.8	+1.9	+2.1	+1.3

*Weather station located near Route 107 and Elm St. in Laconia.

The second winter of observation (2012-13) experienced normal temperatures and snowfall, but resulted in a very brief frost heave season, leaving little opportunity for comparison of the most extreme and differential heaving period. Elevation data indicated a 41% reduction in heaving when compared with the control area.

Heaving in the treated transition areas was reduced by 67% in the first winter and 46% in the second. These values are similar to the values of the fully treated area, indicating that the deepest injections (48 inches, located only in the full treatment area) provided no heaving reduction benefit. Pavement elevations measured in the summers of 2012 and 2013 indicated that the surface had essentially returned to its baseline elevation. Visual observations of the surface show a subtle, but improved pavement condition in the treated area, indicated by fewer cracks.

International Ride Index (IRI) measurements were recorded in both directions within the left and right wheel paths. IRI increases as surface roughness increases. Observed northbound values were consistently higher than southbound values, which is consistent with the visual conditions of the pavement. Comparisons of November (baseline) and March measurements indicate an average IRI increase 270% for 2011/12, and 170% for 2012/13 in the test area. The control area IRI increased by 340% and 310% for the same periods. As with heaving data, IRI values improve again during the summer months, but incremental surface deformation causes the values to increase over time.

Falling Weight Deflectometer (FWD) measurements indicated weakened soil conditions in the spring of 2013. It is possible that the "shallow" 24-inch injection depth leaves most of the subbase materials untreated. Even if the polymer acts as a barrier to capillary action from the subgrade soils, groundwater entering the roadbed (perhaps at the upgradient brook crossing) may still be saturating the subbase as it moves longitudinally through the roadway. The final FWD data could not be gathered until October 30, 2013. Clear trends in this data were difficult to evaluate due to the pavement deformation and highly cracked conditions of the mid-lane measurement points.

Conditions 1 year after installation: Northbound (left), Southbound (right). Note that inadequate pavement thickness at center of lanes provided marginal structure.

Phase II

The improved heaving performance described above was encouraging. Uretek USA proposed to treat a second test area (Phase II) with a focus on treating the subbase nearer to the surface. Injection was completed on November 20, 2013, followed by new elevation and ride baselines on November 26 and in early December. The Phase II treatment area was included in the final Phase I FWD measurements for baseline purposes. The same control area was utilized.

Phase II injections were located from Station 6+55 to Station 7+55 inclusively. Two-level injections on a four-foot grid were again implemented; this time at 24 inches and 15 inches deep. Polymer was again injected until a pavement rise of 1 mm was indicated by laser level. Occasionally, foam broke out through the shoulder, indicating that it sometimes expanded to the pavement surface. The shallower depth allowed for the steel piping to be easily withdrawn to perform the shallow injection. Both injection depths were completed in the same drill hole. The piping was fully withdrawn after the shallow injection. Frost heaving measured during the 2013-14 winter season indicated a 31.7% reduction when compared to the control area.

Expanding foam breaking through shoulder adjacent to injection points

IRI measurements were collected for this phase. A new set of baseline measurements were recorded in November 2013 to nullify the effects of previous movement on the control and test areas during the previous two winters. Northbound IRI values were more consistent with the southbound values than for Phase I comparisons between northbound and southbound. Comparisons of November 2013 and March 2014 measurements indicate IRI increased 240% on average over the base values for the control area, compared to an average of 103% for the test area.

A comparison of rutting data for the 2013/14 season generally indicates that the two treated areas rutted between 20 and 30 percent less than the control area. However, several negative rutting measurements indicate that rut formation due to freezing is an erratic process that would make accurate measurements unlikely. The most that should be drawn from this data is a general reduction in rutting.

EVALUATIONS

The performance of the foam injection was primarily evaluated based upon:

- Visual observations
- Observations from the Patrol Section that maintains this section of roadway
- Technical data gathered from the ride quality van
- Surface elevations.

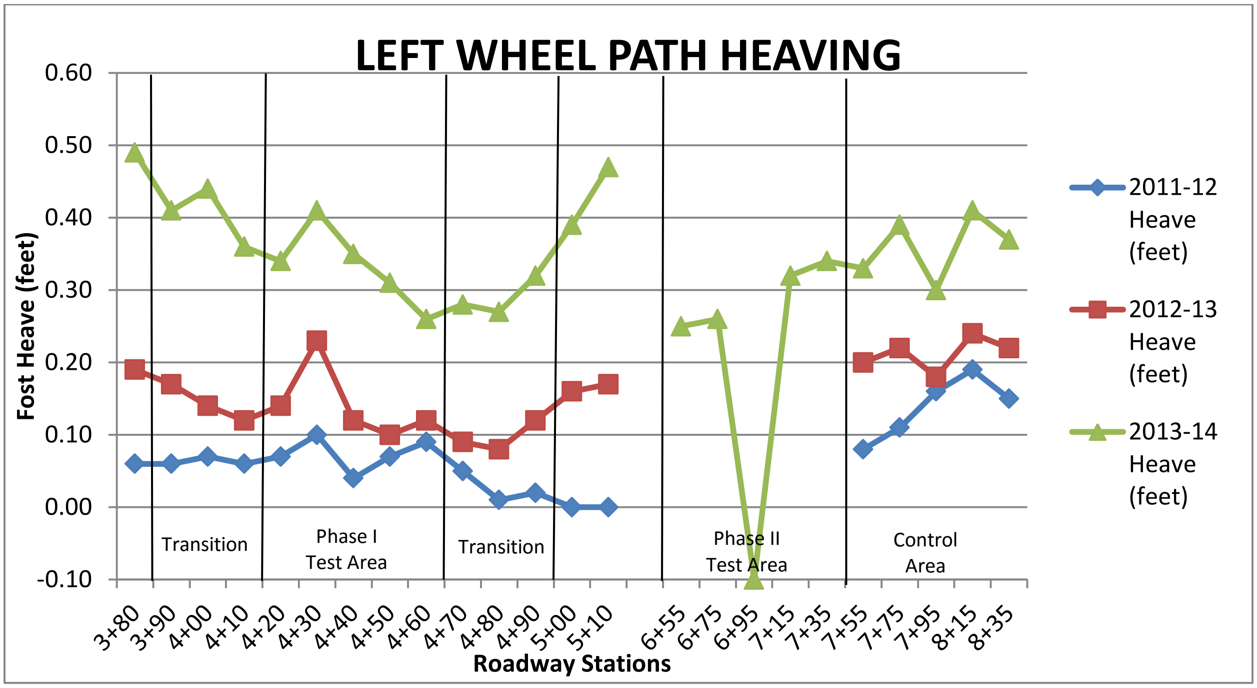
The general findings were that expanding polymer foam treatment of the roadway subbase materials improved frost heaving, rut formation and ride quality conditions when compared to the control area. However, the relative improvements were significantly less than expected. This may be due in part to the depth of the polymer injections. There was concern during installation that the expansive properties of the polymer foam might excessively lift the pavement surface if injected at shallow depths. While improving the deeper soils, the material directly below the pavement was still subject to saturation, the effects of differential frost movement and permanent rutting. The continued deformation of the pavement surface prevents the roadway from being classified as a candidate for the pavement preservation program. Such a result greatly diminishes the benefit/cost ratio of the treatment.

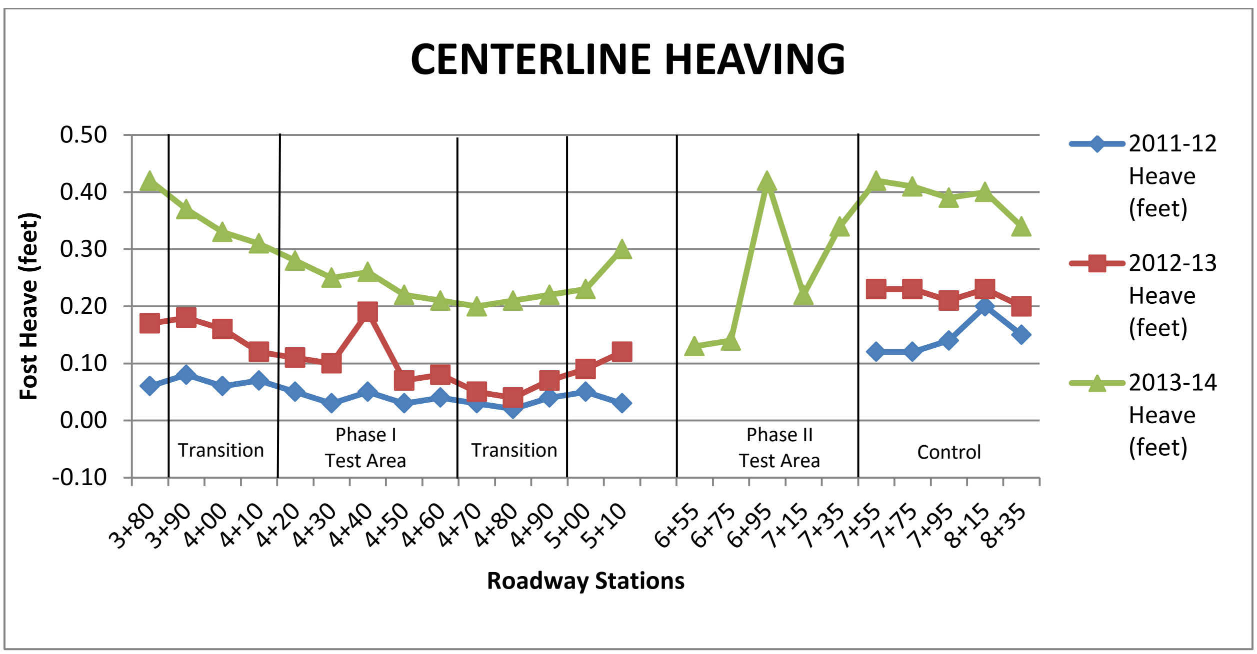
RECOMMENDATIONS

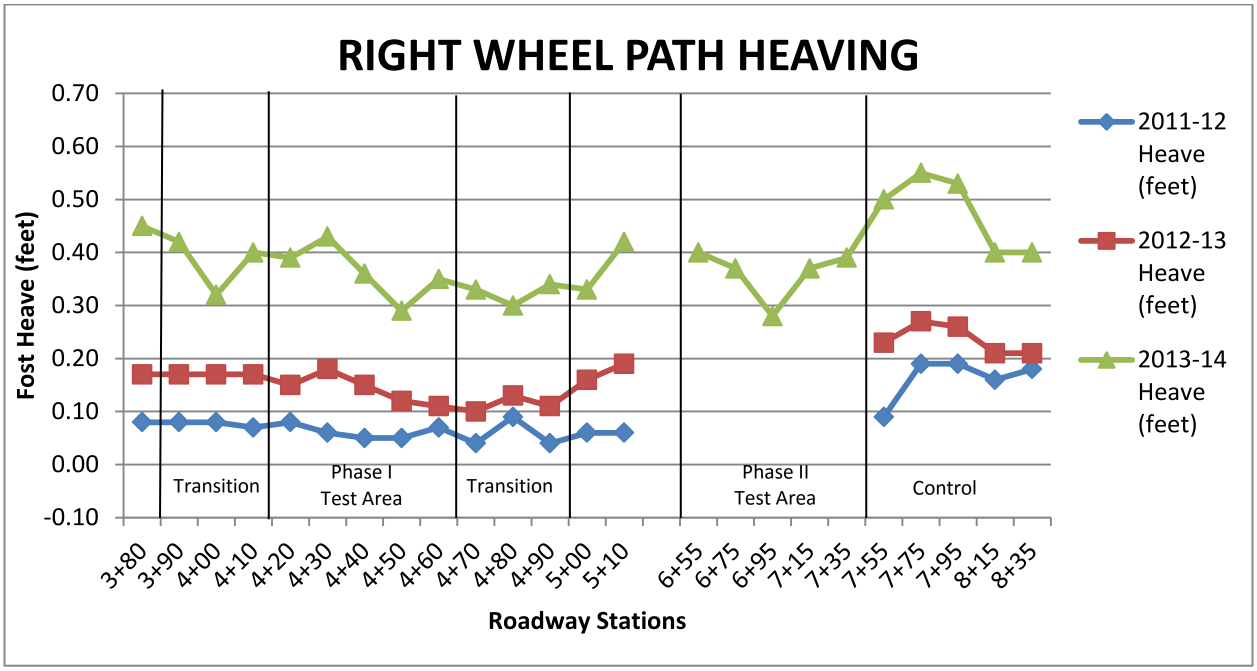
The representatives of the Technical Activities Group do not recommend the implementation of this technique for future roadway improvement projects.

APPENDIX A

PHASE I and II
FROST HEAVE DATA PLOTS
BY AMOUNT OF HEAVE


LEFT WHEEL PATH HEAVING
Fost Heave (feet)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
Transition
Phase I Test Area
Transition
Phase II Test Area
Control Area
3+80
3+90
4+00
4+10
4+20
4+30
4+40
4+50
4+60
4+70
4+80
4+90
5+00
5+10
6+55
6+75
6+95
7+15
7+35
7+55
7+75
7+95
8+15
8+35
Roadway Stations
2011-12 Heave (feet)
2012-13 Heave (feet)
2013-14 Heave (feet)


CENTERLINE HEAVING
Fost Heave (feet)
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
Transition
Phase I Test Area
Transition
Phase II Test Area
Control
3+80
3+90
4+00
4+10
4+20
4+30
4+40
4+50
4+60
4+70
4+80
4+90
5+00
5+10
6+55
6+75
6+95
7+15
7+35
7+55
7+75
7+95
8+15
8+35
Roadway Stations
2011-12 Heave (feet)
2012-13 Heave (feet)
2013-14 Heave (feet)


RIGHT WHEEL PATH HEAVING
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
Fost Heave (feet)
Transition
Phase I
Test Area
Transition
Phase II
Test Area
Control
3+80
3+90
4+00
4+10
4+20
4+30
4+40
4+50
4+60
4+70
4+80
4+90
5+00
5+10
6+55
6+75
6+95
7+15
7+35
7+55
7+75
7+95
8+15
8+35
Roadway Stations
2011-12 Heave (feet)
2012-13 Heave (feet)
2013-14 Heave (feet)

APPENDIX B

PHASE I and II
RIDE QUALITY DATA

Loudon 15680H Polyurethane Foam Test Area on NH 129

U_ID	Direction	SurveyDate	IRI - Left WheelPath	IRI - Right WheelPath	Rutting Left half	Rutting Right half	Rutting Average	Collection Info
2011001	South	3/15/2011	591.9	713.6	0.64	0.68	0.50	Before Surface Treatment
2011002	North	3/15/2011	559.9	487.8	0.78	0.82	1.03	Before Surface Treatment
2011003	South	11/2/2011	79.3	90.5	0.30	0.12	0.09	November - 2011
2011004	North	11/2/2011	87.5	147.9	0.87	0.10	0.11	November - 2011
2012001	South	2/29/2012	202.7	243.9	0.23	0.38	0.33	February - 2012
2012002	North	2/29/2012	242.7	377.7	0.22	0.55	0.55	February - 2012
2012003	South	6/19/2012	83.1	105.1	0.13	0.20	0.17	June - 2012
2012004	North	6/19/2012	108.2	185.7	0.11	0.26	0.10	June - 2012
2012005	South	11/6/2012	83.8	107.5	0.13	0.21	0.16	November - 2012
2012006	North	11/6/2012	102.2	179.3	0.12	0.23	0.14	November - 2012
2013001	South	3/27/2013	130.1	210.5	0.18	0.31	0.09	March - 2013
2013002	North	3/27/2013	195	243.4	0.19	0.40	0.17	March - 2013

Loudon 15680H Control Test Area on NH 129

U_ID	Direction	SurveyDate	IRI - Left WheelPath	IRI - Right WheelPath	Rutting Left half	Rutting Right half	Rutting Average	Collection Info
2011011	South	3/15/2011	476.6	486.1	0.68	0.44	0.53	Before Surface Treatment
2011012	North	3/15/2011	826.1	630.5	1.24	0.89	1.33	Before Surface Treatment
2011013	South	11/2/2011	73.9	119.1	0.27	0.07	0.1	November - 2011
2011014	North	11/2/2011	83.2	121.2	1.02	0.08	0.1	November - 2011
2012011	South	2/29/2012	254.1	357.2	0.23	0.23	0.41	February - 2012
2012012	North	2/29/2012	286.5	447.5	0.28	0.83	0.69	February - 2012
2012013	South	6/19/2012	88.2	142.7	0.12	0.13	0.13	June - 2012
2012014	North	6/19/2012	105.2	190.4	0.19	0.36	0.31	June - 2012
2012015	South	11/6/2012	90.2	135.8	0.13	0.12	0.14	November - 2012
2012016	North	11/6/2012	109.2	192.5	0.18	0.32	0.31	November - 2012
2013011	South	3/27/2013	335.1	307.5	0.25	0.17	0.24	March - 2013
2013012	North	3/27/2013	413.1	520.5	0.36	0.83	0.67	March - 2013