REPORT 2015 - 09

VERMONT AGENCY OF TRANSPORTATION

Research and Development Section
Research Report

ASSESSMENT OF URETEK DEEP INJECTION PROCESS

Report 2015 – 09

March 2015

ASSESSMENT OF URETEK DEEP INJECTION PROCESS

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Reporting on Work Plan 2012-R-04

STATE OF VERMONT
AGENCY OF TRANSPORTATION

RESEARCH & DEVELOPMENT SECTION

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16. Abstract

This project assesses the capacity of an in-situ urethane stabilized soil mass to halt subsidence on an Interstate highway. An area of subsidence is approximately 100 meters long in the southbound barrel of I- from mile marker 0.124 to 0.153 in Hartford, VT. The location's annual average daily traffic is amongst the highest in eastern Vermont, averaging 38,000 vehicles per day. Historically, the roadway section was originally constructed in the 1950's and it is believed that the majority of the fill material used was taken from the rock cut sections in the connecting ramps on the south side of the I-89/I-91 interchange.

Project Hartford IM 089-1 (60) was initiated and bids were let on the project in 2013 to stabilize the site and alleviate ongoing maintenance costs. For planning and design purposes, Applied Research Associates (ARA) consultants were contracted to determine the extent of the instability through a variety of noninvasive geophysical and non-destructive testing. This data was utilized to approximate the total amount of injection material that would be needed to stabilize the area through the injection process.

URETEK USA was subcontracted through J.A. McDonald to use a patented deep injection method to stabilize the underlying subsurface of the highway. URETEK 486, a family of two-component, lightweight expansive polymers developed by Bayer MaterialScience LLC of Pittsburgh, Pennsylvania was injected in the base soil in a grid pattern, typically 4-foot by 4-foot to stabilize and compact weaker or loose soils to improve the load bearing capacity.

The material was injected in cold temperatures successfully. This report summarizes the installation and first year data.

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VTRANS EXECUTIVE SUMMARY

A small segment of Interstate 89 developed a dip in the pavement extending across three lanes of Interstate 89 in the southbound barrel at mile maker in Hartford VT. The dip continued to form again on a decreasing interval after the pavement was shimmed to correct the dip for better ride.

With repeated repair and continuing monitoring, VTrans decided that an experimental treatment represented a cost effective technique to stabilize the area with minimal traffic disruption and lower costs than excavation and rebuilding the subgrade of the highway. The treatment is an injection of a multi-component urethane material that reacts after mixing. The hardening action of the urethane occurs in an intermixed state with the soil/stone matrix to strengthen the subgrade.

This project was completed successfully in November including nighttime construction activities. The technology was proven suitable for use in Vermont. In addition, the data acquired in the first year shows that the rate of subsidence was decreased by the project. Continued monitoring to confirm or rebut the early results and further define the stabilizing effects of the treatment.

VTrans learned several things in this project for future use. Completion of geophysical surveys a number of years prior to the final design did not contribute to accuracy of construction materials estimates. Construction materials overruns in injection materials may have been due to worsening conditions or insufficient geophysical testing. Future deployments should avoid delays between collection of engineering information and project delivery.

Subsurface stabilization projects have less reliable estimates of material quantities because of unknowns. Consideration of uncertainty may require some amendment of a fixed unit cost contract for stabilizing materials to assure competition and provide fairness to both contract parties. In this instance, the Contractor and manufacturer negotiated a reduced cost for overrun materials. The use of cost quantity curve may be an appropriate tool to address uncertainty fairly.

The use of injection technologies that use reactive polymers is a successful technique to provide stability. Refinements in design and construction processes are likely with continued deployment. Further pilot projects are urged to promote an additional tool for response to local subsidence and subgrade instability.

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TABLE OF CONTENTS

ABSTRACT

A stretch of Interstate 89 southbound from mile marker 0.124 to 0.153 in Hartford, VT has been showing signs of substructure instability for over two decades. The annual average daily traffic is amongst the highest in eastern Vermont, averaging 38,000 vehicles per day. Historically, the roadway section was originally constructed in the 1950's and it is believed that the majority of the fill material used was taken from the rock cut sections in the connecting ramps on the south side of the I-89/I-91 interchange.

To stabilize the site and alleviate ongoing maintenance costs, project Hartford IM 089-1 (60) was initiated and bids were let on the project in 2013. For planning and design purposes, Applied Research Associates (ARA) consultants were contracted to determine the extent of the issue through a variety of noninvasive geophysical and non-destructive testing. This data was utilized to approximate the total amount of material that would be needed to stabilize the area through the injection process.

URETEK USA was subcontracted through J.A. McDonald to use a patented deep injection method to stabilize the underlying subsurface of the highway. The process utilizes URETEK 486, a family of two-component, lightweight expansive polymers developed by Bayer MaterialScience LLC of Pittsburgh, Pennsylvania. The high-density polymer compound is injected in the base soil in a grid pattern, typically 4-foot by 4-foot to stabilize and compact weaker or loose soils to improve the load bearing capacity.

Six years had passed from the time when the data was collected and the project went out for bid. This left a large window when site conditions could worsen. The project originally scoped 111,000 pounds of polymer to complete stabilization however to stabilize under modified conditions a total of 249,634 lbs of polymer was used, equaling $2,057,492.

This report summarizes site conditions, construction details and performance to date.

INTRODUCTION

Bituminous concrete pavements deteriorate over time due to several distress factors including moisture issues, temperature extremes, inadequate structural layers, construction quality, temperature susceptibility including freeze thaw cycles, aging characteristics of the asphalt cement, and vehicular loading (*1*). Research has shown that water infiltration is one of the most common contributing factors that lead to accelerated deterioration. This can cause cracking, raveling, oxidation, stripping, and softening or weakening of the base and/or subbase leading to a loss of structural support and subsequently a shorter life span in asphalt pavements. Studies have shown that an increase in moisture from 16 to 18 percent in silty clay can cause a 75 to 100 percent reduction in strength, as measured by the California bearing ratio. Free water in granular base courses can easily reduce their strength by 25 percent or more under dynamic load (*2*).

Roadway subsidence is another cause for repair and maintenance. It indicates a failing or insufficient pavement substructure. Some subsidence instances can lead to catastrophic pavement failures. Depending on the nature of the issue, these failures may be sudden or gradual. To characterize subsidence failures it is critical to determine the extent of the problem, which is typically done using noninvasive and non-destructive geophysical testing methods (*3*).

Ever increasing construction costs combined with a rapidly deteriorating highway infrastructure has prompted State Transportation Agencies to seek cost effective methods for increasing the service life of pavements and limiting repeated maintenance burdens for the maintenance staff. In many cases, VTrans Operations Division will apply an asphalt overlay to increase smoothness and ride of the surface providing higher user satisfaction. This can be costly and in certain areas is not an ideal solution. In some cases, this practice only contributes to the problem thus reducing the time that a more permanent solution is needed. To correct these types of roadway deficiencies, Uretek USA has developed a deep soil injection method used to stabilize the underlying subsurface.

PROJECT LOCATION AND SUMMARY

A stretch of Interstate 89 southbound from mile marker 0.124 to 0.153 in Hartford, VT has been showing signs of substructure instability for over two decades. The annual average daily traffic is amongst the highest in eastern Vermont, averaging 38,000 vehicles per day. Historically, the roadway section was originally constructed in the 1950’s and it is believed that the majority of the fill material used was taken from the rock cut sections in the connecting ramps on the south side of the I-89/I-91 interchange (*3*). The site is shown in Figure 1.

Figure 1: Deep Injection Site – Prior to Injection.

According to VTrans route logs, the section received a bituminous concrete overlay in 1980 under project number IR 89-1 (1) (*4*). Since that rehabilitation project, this section of roadway has showed severe settlement issues. The subsidence issue has been noted. The subsidence has required VTrans Operations division to place temporary repair shim courses over the area on several occasions. Years and associated costs are listed in Table 1 below.

Due to these increased maintenance efforts and associated costs, a research project was initiated in 2007 to determine the extent of the issue through a variety of noninvasive geophysical and non-destructive testing. Applied Research Associates (ARA) consultants were contracted to conduct the geophysical testing and to summarize the site conditions. ARA used ground-penetrating radar (GPR), Capacitively-Coupled Resistivity (CCR), Falling Weight Deflectometer (FWD), and Cone Penetrometry (CPT) to investigate the underlying structural health of the roadway section. The site evaluation determined that the area showed a potential of insufficient surface drainage control, and that this which likely caused a slow migration of fines from the base material, leaving small but pervasive voids or low-density regions (*3*).

To stabilize the site and alleviate ongoing maintenance costs, project Hartford IM 089-1 (60) was initiated and bids were let on the project in 2013. For planning and design purposes, the data collected by ARA was utilized to approximate the total amount of material that would be needed to stabilize the area through the injection process.

Table 1: Approximate maintenance repairs and associated costs.

Year	# of Shims	Minimum # of Shims	Maximum # of Shims	Approximate Cost	Minimum Cost	Maximum Cost
1997	1 to 2	1	2	4000 to 12000	$4,000	$12,000
1998	1 to 2	1	2	4000 to 12000	$4,000	$12,000
1999	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2000	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2001	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2002	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2003	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2004	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2005	2	2	2	8000 to 12000	$8,000	$12,000
2006	4	4	4	16000 to 24000	$16,000	$24,000
2007	2	2	2	5000	$5,000	$5,000
2008	2	2	2	20000	$20,000	$20,000
2009	1	1	1	2000	$2,000	$2,000
2010	2	2	2	4000	$4,000	$4,000
2011	3	3	3	Paving Project	---	---
2012	0	0	0	---	---	---
Total		**24**	**32**		**$87,000**	**$163,000**

MATERIAL DESCRIPTION

Uretek USA of Tomball, Texas developed a patented deep injection method used to stabilize the underlying subsurface of highways. The process utilizes URETEK 486, a family of two-component, lightweight expansive polymers developed by Bayer MaterialScience LLC of Pittsburgh, Pennsylvania. The high-density polymer compound is injected in the base soil in a grid pattern, typically 4-foot by 4-foot to stabilize and compact weaker or loose soils to improve the load bearing capacity. It is hydro-insensitive, ensuring that it is unaffected by any water or wet soil that may lie under the surface pavement. The product is designed such that the soil will only accept what is needed. The material does not migrate far from the injection point. It expands up to a 1:25 ratio. Once injected, the material cures rapidly and reaches 90 percent strength in less than 15 minutes. Typically the method is used to lift pavements or concrete slabs but in this case the method was used to stabilize the pavement substructure in five foot layers up to twenty feet deep (*5*). Figure 2 and Figure 3 illustrate how the polymer and stabilization process works (*6*). Prior to injection, the manufacturer completes Dynamic Cone Penetrometer (DCP) testing to assess pre-injection site conditions and prepare a repair plan (*7*).

The URETEK 486 polymer family includes seven products, two of which were used on this project. The URETEK 486 STAR-4BD (Blue Dot) was used to provide lateral stabilization throughout the site and the URETEK 486-4 (Red Dot), a standard product designed to lift asphalt or concrete. According to Bayer MaterialScience, the patented polymers are developed to allow for easy penetration into soils while compacting surrounding soils and displacing water without detrimental dilution or loss of dimensional stability to the resin system (*8*).

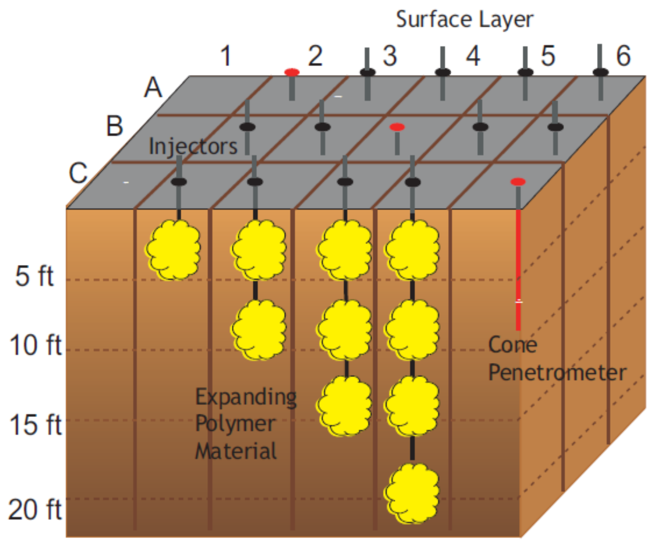

Figure 2: Expansive polymer material.

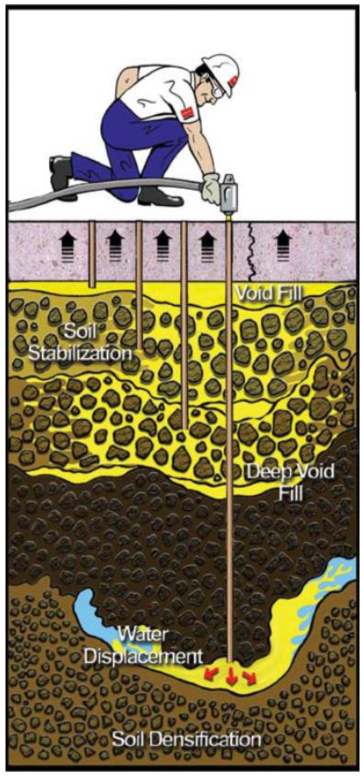

Figure 3: Soil stabilization process.

CONSTRUCTION

According to the project plans, the work to be performed included experimental deep soil injection, cold planing, pavement, traffic control and other highway related items. The project was awarded in the fall of 2013 to the low bidder, J. A. McDonald, Inc. of Lyndon Center, Vermont for a total bid cost of $1,350,203.00. The total bid price for the DCP testing, drilling the injection holes, the polymer injection totaled $1,017,600.00. The prime contractor selected URETEK USA as the subcontractor on the project to conduct the stabilization process and associated DCP testing (*9*).

DCP testing was performed on October 24, 25 and 28 in 2013. Tests were performed at seven locations, shown in Appendix A. Tests 1, 5, and 7 required additional drilling and testing due site conditions. These areas were located in the portion of the project that was continuously repaired by maintenance forces. Testing results were consistent with those reported by ARA in 2008. Results exhibited a large variance of site conditions throughout the site and a significant variability within the individual soil profiles where soft lenses were interspersed with stiff layers. They also indicated that asphalt thicknesses were irregular but typically exceeded 3 feet. Based on the results, URETEK USA determined the ideal injection pattern was a 4-foot by 4-foot grid at four depths, including -7 feet, -11 feet, -15 feet and -19 feet. The polymer for the injection included the following criteria (*10*):

- Minimum Free-Rise Density: 3.8 pcf
- Maximum Free-Rise Density: 4.2 pcf
- Minimum Compressive Strength (ASTM D 1621-10 - Standard Test Method for Compressive Properties of Rigid Cellular Plastics): 60 psi
- Minimum Tensile Strength (ASTM D 1622/D 1622M-14 Standard Test Method for Apparent Density of Rigid Cellular Plastics): 60 psi

All construction processes including any problems encountered are summarized below.

Drilling

J. A. McDonald, the prime contractor drilled all injections holes using a Tamrock Ranger 700 Drilling Rig, a hydraulic, self-propelled, self-contained, crawler based surface drilling rig equipped with a cabin and rod handling system. The Contractor began drilling the 2-inch diameter injection holes 20 feet in depth in the travel lane on October 29, 2013 once the injection plan based on DCP testing was approved. Once drilling commenced, vibration from drilling operation paired with the undersized drilling equipment caused unstable material along the shaft to collapse into the hole (*11*). The Contractor ceased operations until the following day and began drilling 2½-inch diameter holes in order to expedite drilling, produce a straighter hole, and reduce sloughing of the material into the holes (*12*). Drilling operations continued through November 4. Some holes had to be redrilled because URETEK encountered problems with inserting the injection tube bundles. The Contractor redrilled holes on November 5 and 6 and then inserted some injection tube bundles for the Subcontractor. The passing lane holes were drilled without incident from November 19 to 21 (*11*).

Injection

URETEK USA began injecting the site at the 7-foot depth from the southern end of the project in the travel lane once the Contractor had drilled a sufficient amount of holes ahead to ensure no disruption of the stabilization process on October 30 (*11*). Figure 4 through Figure 9 show the tube insertion and injection process.

Figure 4: Tamrock 700 Drill Rig – Drilling 2.5-inch Injection Holes.

Figure 5: Drilled Injection Hole (2.5 inches x 20 feet)

Figure 6: Injection Tubes.

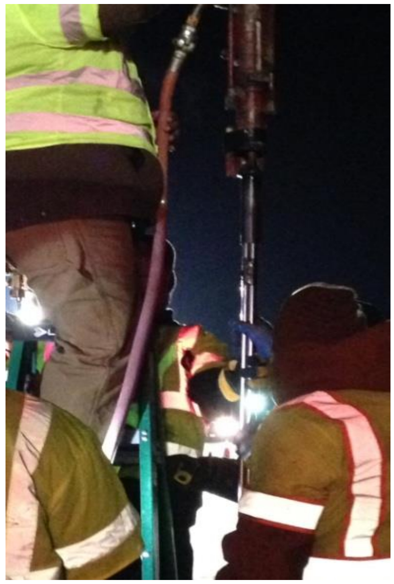

Figure 7: Inserting Tubes.

Figure 8: Injected Tubes.

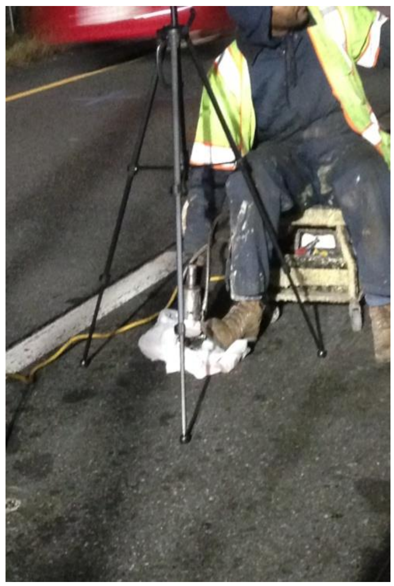

Figure 9: Injecting Polymer.

Over the course of the first five days of the injection process, a total of 37,157 pounds of polymer was used, equaling approximately 33 percent of the total estimated quantity of polymer to be used site wide with a large portion of holes and depths not filled. A memo to VTrans from URETEK USA dated November 8 summarized the operations including observations, pounds of polymer used through November 6 and material usage projected through November 7. The memo summarized that the average consumption per tube was as follows: -7-foot Elevation:

211.0 pounds; -11-foot Elevation: 294.8 pounds; -15-foot Elevation: 842.3 pounds; -19-foot Elevation: 705.0 pounds. The memo also noted the following:

- Puffs of dust rose from adjacent holes.
- Voids outside the circumference of the hole.
- Sloughing into the holes.
- The settled patch in Lane 2 (travel lane) appeared to be dropping further as drilling progressed.
- A new crack developed in the asphalt surface.

URETEK USA concluded that the higher than expected polymer consumption suggested that the void situation in the pavement system had deteriorated since the 2007 ARA site evaluation presumably due to the unabated transport of fines from the pavement system over the last six years. Also concluded was the movement of material due to disturbance/vibration associated with drilling operations may have caused possible consolidation of the underlying material (*12*).

Based on the unforeseen issues noted and large projected overage of material needed to complete the original scope of work at the site, URETEK USA provided a proposal to J.A. McDonald and VTrans that included recommendations to stabilize the site successfully (*13*). VTrans selected the option, which included:

- Injection at two elevations: -7 feet and -11 feet over the entire site, including the passing and travel lanes as well as the ramp and shoulders. The projected total pounds of polymer was 212,000 lbs, a projected overage of 101,000 lbs from originally scoped. This option held a 12-month unconditional warranty against the settlement of the pavement of more than ¼-inch (*13*).
- Injections at selected portions of the project at -15 feet and -19 feet. Areas injected at -15 feet carry an 18-month warranty and areas at -19 feet carry a 24-month warranty (*13*).

The Subcontractor proceeded as planned and the injection was completed the injection at the site including lifting the asphalt back to the original elevation on December 11, totaling 23 days of injection. A total of 378 holes were injected. The number of holes injected at the four depths and associated material usage is summarized in Table 2 below (*11*).

Paving

Due to the late season injection phase, all cold planing and paving activities were postponed until the spring of 2014. J.A. McDonald hired subcontractor Frank W. Whitcomb Construction of Colchester, Vermont to complete cold planing and paving operations, completed on May 29 and May 30, 2014. Figure 10 below shows the site after paving while conducting Falling Weight Deflectometer (FWD) testing.

Table 2: Injected Polymer Amounts (Pounds).

Lane	Depth	# of Holes	Pounds of Polymer
Travel, Ramp, and Shoulder	7'	226	61,573
	11'	226	40,731
	15'	58	27,844
	19'	53	33,038
	5' (Lifting)	29	6,096
	7' & 11'	*	9,427
	7', 11', 15'	*	9,287
	7', 11', 19'	*	9,236
	Total		**197,232**
Passing and Shoulder	7'	152	8,768
	11'	152	25,076
	7' & 11'	*	18,559
	Total		**52,403**
Project Total			**249,635**

*Rows shaded in gray are locations where the total amount of polymer injected was not recorded by individual depth.

Figure 10: Deep Injection Site – Post Paving.

DATA ANALYSIS

Falling Weight Deflectometer

A falling weight deflectometer (FWD) was used to assess and analyze the stiffness of the before and after conditions of the project. The FWD is a trailer mounted towed device that is capable of applying a various load through a circular plate causing the pavement to deflect. A 9,000 lb load closely approximates the effect of a moving wheel load, both in magnitude and duration. The applied load is measured by a heavy-duty precise load cell, located above the loading plate. The deflection data is acquired through a high-speed transducer. The transducer signal is sent to a data collection device. Later, the data is transferred to a computer where back-calculation processes begin to determine stiffness moduli for each layer. Data is analyzed using Dynatest's Elmod 6 software. The subbase material stiffness, as determined by the calculated moduli, can provide an indication of its condition and uniformity. FWD testing was completed in accordance with ASTM D 4694-09, "*Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device*," (*14*).

For this study, FWD testing was performed on October 18, 2013 (pre-injection), May 8, 2014 (post-injection, pre-paving), June 5, 2014 (post-paving), and October 14, 2014 (approximately one year post-injection). Figure 11 shows the subbase (below asphalt and aggregate base) elastic moduli results for each of 17 testing spots in the travel lane of the project. Locations 1, 2, and 3 are just southbound of the area that received Uretek injections, while 15, 16, and 17 are just north. These six locations comprise the control section, which are separated by the vertical lines in the figure. The control section show minor fluctuations in moduli between the various dates and can be considered unchanged from the period before the injections and after.

Within the experimental injection locations 7 through 11, elevated moduli values for the pre-existing conditions were detected, most likely due to the large amount of pavement that has been applied throughout many years; this area consists of the worst area of the subsidence. According to daily work reports, this area also coincides with the places where the largest amount of stabilizing and lifting material was injected. In most of these areas, the analysis shows that the injected material increased the stiffness of the subbase by roughly 50 percent and up to 300 percent at location 10. All post-injection testing indicate level values of moduli throughout the injection areas, as the three plots mirror one another. Passing lane analysis shows level moduli values throughout all 17 locations and four data collection events, all between 4 and 8 ksi.

FWD analysis for this project should be considered a rough estimate of what is actually in place, as there are many interferences, which may alter the data somewhat. There are two primary issues with the analysis. The first is the variable thicknesses of pavement that have been applied, as certain areas have received more than others since the construction of the interstate, with some areas upwards of four feet or more and others possibly at the lower end around a foot; accurate pavement depths at each FWD analysis location are not available. The second is the large thickness of asphalt pavement itself; in many areas, the asphalt plus aggregate base thickness is around seven feet and the FWD begins to lose reliability beyond six feet of depth.

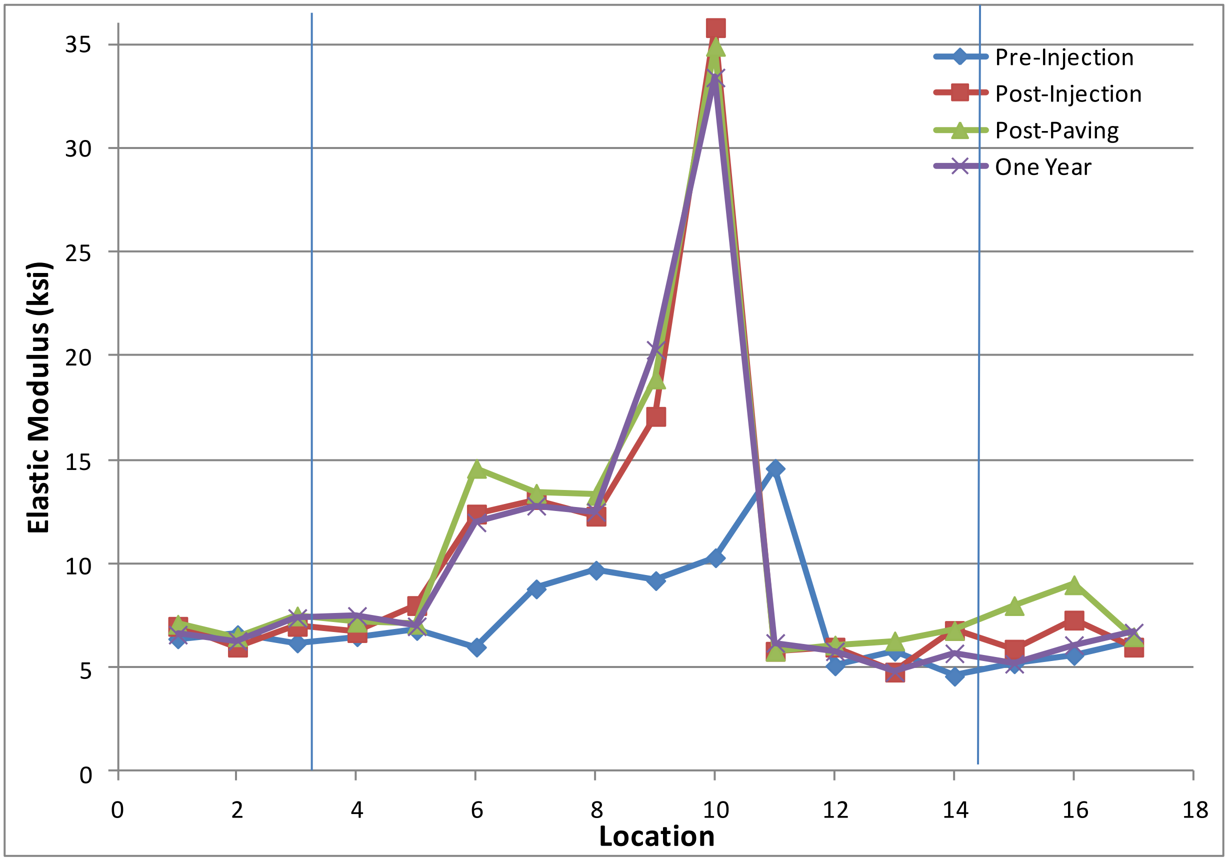

Figure 11 Travel lane elastic moduli (ksi) values for four data collection events. Locations within the two vertical lines received the Uretek injections.

Survey

To monitor the site the VTrans Survey Bureau conducted a 3D survey prior to the injection, following the injection, prior to paving, after paving and twice following the post-paving survey. Due to the original scope of the project, it was believed that a 3D survey referencing benchmark points would be sufficient to monitor the overall site for any settlement. However, the warranty as previously described included pavement settlement of ¼-inch, deeming the survey data collected to be inconclusive. The scale at which the surveys were conducted was not close enough in detail to determine if any settlement had occurred.

Moving forward the site will be surveyed again to recover control points for the previous surveys and a more detailed survey including firm control of roadway elevations to 1/100th of a foot will be conducted in December 2014, February 2015 and April 2015. It is anticipated that surveys will be required on a semi-annual basis after April.

COST ANALYSIS

The original contract included 111,000 lbs of polymer to complete the stabilization based on results from the 2007 ARA report summarizing subsidence at the site. However due to the changes detailed above a much larger amount of polymer was required to stabilize the site. The cost per pound from the original bid price was $8.60 per pound. The original 111,000 lbs plus an additional 27,750 lbs prior to the revised scope of work was paid for at the $8.60/lb price, totaling 138,750 lbs for $1,193,250.00. For the additional polymer, URETEK USA chose to provide VTrans with a reduced rate of $7.74/lb, totaling $858,242.16. In total, 249,634 lbs of polymer was used, equaling $2,057,492. The total cost as built was $2,508,370.07 including deep soil injection, cold planing and paving operations, traffic control, and other highway related items incidental to construction. Currently it is unclear whether the process is cost effective or not.

SUMMARY AND RECOMMENDATIONS

To date the site has not required additional maintenance repairs. Site visits will continue on a semi-annual basis, to document the condition of the site. The duration of the study will be until adequate conclusions can be made. The site will continue to be monitored using FWD and 3D survey until deemed necessary.

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Approved Date 6/14/12
Planning & Programming Engineer
Federal Highway Administration

Prepared By: Wendy Kipp
Date: June 11th, 2012

STATE OF VERMONT
AGE NCY OF TRANSPORTATION
MATERIALS AND RESEARCH SECTION

WORK PLAN FOR
RESEARCH INVESTIGATION
Assessment of Uretek Deep Injection Process
Work Plan No. 2012-R-4

BACKGROUND:

Bituminous concrete pavements deteriorate over time due to several distress factors including moisture issues, temperature extremes, inadequate structural layers, construction quality, temperature susceptibility including freeze thaw cycles, aging characteristics of the asphalt cement, and vehicular loading (*1*). Research has shown that water infiltration is one of the most common contributing factors that lead to accelerated deterioration. This can cause cracking, raveling, oxidation, stripping, and softening or weakening of the base and/or subbase leading to a loss of structural support and subsequently a shorter life span in asphalt pavements. Studies have shown that an increase in moisture from 16 to 18 percent in silty clay can cause a 75 to 100 percent reduction in strength, as measured by the California bearing ratio. Free water in granular base courses can easily reduce their strength by 25 percent or more under dynamic load (*2*).

Roadway subsidence is another cause for repair and maintenance. It indicates a failing or insufficient pavement substructure. Some subsidence instances can lead to catastrophic pavement failures. Depending on the nature of the issue these failures may be sudden or gradual. To characterize subsidence failures it is critical to determine the extent of the problem which is typically done using noninvasive and non-destructive geophysical testing methods (*3*).

Ever increasing construction costs combined with a rapidly deteriorating highway infrastructure has prompted State Transportation Agencies to seek cost effective methods for increasing the service life of pavements and limiting repeated maintenance burdens for the maintenance staff. In many cases VTrans Operations Division will apply an asphalt overlay to increase smoothness and ride of the surface providing higher user satisfaction. This can be costly and in certain areas is not an ideal solution. In some cases, this practice only contributes to the problem thus reducing the time that a more permanent solution is needed. To correct these types of roadway deficiencies, Uretek USA has developed a deep soil injection method used to stabilize the underlying subsurface.

OBJECTIVE:

The purpose of this study is to examine and evaluate the constructability, overall performance and cost effectiveness of using this repair method. Research personnel will assess the existing pavement condition prior to construction to document all distresses, construction practices, and visit the sites annually to document any failures.

PROPOSED LOCATIONS:

One location within the state which has been of concern for quite some time is along Interstate 89 southbound from mile marker 0.1 to 0.2 in Hartford, VT. The annual average daily traffic is amongst the highest in eastern Vermont, averaging 38,000 vehicles per day. Historically, the roadway section was originally constructed in the 1950's and it is believed that the majority of the fill material used was taken from the rock cut sections in the connecting ramps on the south side of the I-89/I-91 interchange (*3*). According to VTrans route logs, the section received a bituminous concrete overlay in 1980 under project number IR 89-1 (1) (*4*). Since that rehabilitation project this section of roadway has showed severe settlement issues. The subsidence issue has been noted and has required VTrans Operations division to place temporary repair shim courses over the area on several occasions. Years and associated costs are listed in Table 1 below.

Year	# of Shims	Minimum # of Shims	Maximum # of Shims	Approximate Cost	Minimum Cost	Maximum Cost
1997	1 to 2	1	2	4000 to 12000	$4,000	$12,000
1998	1 to 2	1	2	4000 to 12000	$4,000	$12,000
1999	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2000	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2001	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2002	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2003	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2004	1 to 2	1	2	4000 to 12000	$4,000	$12,000
2005	2	2	2	8000 to 12000	$8,000	$12,000
2006	4	4	4	16000 to 24000	$16,000	$24,000
2007	2	2	2	5000	$5,000	$5,000
2008	2	2	2	20000	$20,000	$20,000
2009	1	1	1	2000	$2,000	$2,000
2010	2	2	2	4000	$4,000	$4,000
2011	3	3	3	Paving Project		
Total		**24**	**32**		**$87,000**	**$163,000**

Table 1: Approximate Repairs and Associated Costs

Due to these increased maintenance efforts and associated costs a research project was initiated in 2007 to determine the extent of the issue through a variety of noninvasive geophysical and non-destructive testing. Applied Research Associates (ARA) consultants were contracted to conduct the geophysical testing and to summarize the site conditions. ARA used ground-penetrating radar (GPR), Capacitively-Coupled Resistivity (CCR), Falling Weight Deflectometer (FWD), and Cone Penetrometry (CPT) to investigate the underlying structural health of the roadway section. The site evaluation determined that the area showed a potential of insufficient surface drainage control, and that this which likely caused a slow migration of fines from the base material, leaving small but pervasive voids or low-density regions (*3*).

MATERIAL:

To correct these types of roadway deficiencies, Uretek USA has developed a deep injection method used to stabilize the underlying subsurface. The process utilizes an expansive polymer that is hydro-insensitive, ensuring that it will be unaffected by any water or wet soil that may lie under the surface pavement. Typically the method is used to lift pavements or concrete slabs but in this case the method will be used to stabilize the pavement substructure in five foot layers up to twenty feet deep. The process is expected to permanently correct the settlement issue on site and alleviate future maintenance (*4*).

The method involves two critical components to ensure effectiveness. The system injects a high density expanding polymer compound, URETEK 486, into the base soil to stabilize and compact the weaker soils. The polymer is designed such that the soil will only accept what is needed. The material will not migrate far from the injection point and when the soils are sufficiently stabilized a bump will be noticed at the surface.

According to the scope of work provided by URETEK USA, the work to be completed is as follows:

1) Drill 325 host holes, making use of a grid pattern based upon a spacing of approximately 4 feet;
2) Place bundled injection tubing to direct polymer injection in four stages;
3) Grout holes after injection.

QUALITY ASSURANCE:

According to a memo from URETEK USA all materials are quality inspected prior to leaving the manufacturer's Bayer facility. Polyurethanes are quite versatile and compatible with a large number of other materials. There is no way to know if there is something in the soil that may have an interaction with the reacting polymer unless soil sampling is completed.

SURVEILLANCE AND TESTING:

1. **Possible Testing:**

    - **DCP:**

    - DCP testing may be completed to provide information about soil strength. The blow counts can be correlated to the W-value associated with the Standard Penetration Test (SPT) by using a relationship developed by the manufacturer: W (SPT) = 0.766 x W (DCP). The correlation allows you to “tap into” other sources of data such as previous reports and test results. The results are used to:
        - Identify weak layers in the soil mass so an injection pattern can be developed;
        - Contribute to the development of material estimates. Weaker soils typically require more polyurethane than stronger soils; and
        - Assist in evaluating the effectiveness of polyurethane injection by comparing pre-injection DCP results to post-injection DCP results.
- **FWD:**
    - URETEK USA recommends that FWD testing is conducted:
        - Immediately before injection;
        - 24 hours after injection;
        - Periodically after treatment, the Research Staff will comparing #1 and #2 FWD testing and will highlight the stiffness improvement made due to the injection process and comparing #2 and #3 will illustrate the durability and long-term effectiveness of the injection process.
        - If selected, 10 tests will be completed in 100 foot intervals within the 0.10 rehabilitation section, 2 on either side of the section for comparison purposes and 1 random test within the 0.10 section and will be completed by VTrans Pavement Management Unit.
- **IRI:**
    - URETEK USA recommends a ride quality profile be established at the following intervals:
        - Immediately before the injection;
        - 24 hours after the injection;
        - Periodically after treatment, the Research Staff will compare #1 and #2 and will highlight the ride quality improvement made due to the injection process and comparing #2 and #3 will illustrate the durability and long-term effectiveness of the injection process.
        - The testing increment will be adjusted to 300’ and will be completed by VTrans Pavement Management Unit.
- **Survey:**
    - Typically pre and post-injection elevation surveys are completed by URETEK USA. The surveys provide historical data about what was accomplished by the injection process and more importantly, the surveys are tied to permanent benchmarks in case there are settlement

issues in the future. VTrans Survey will be asked to survey the site annually until the evaluation is complete.

2. **Construction:**

   The work will be completed at night based on the traffic conditions in the area. The work should take two nights to complete. At the time of the application Research personnel will be onsite and record temperature, relative humidity, precipitation/cloud cover, wind condition, ambient air, pavement temperatures, time of day, and equipment condition will be recorded. Photographs and observations will be recorded.

3. **Site Visits:**

   A preconstruction site visit will be conducted prior to injection to document existing site conditions. Photographs and general observations will be recorded. After each application is complete, a site visit will be conducted. This will be followed by monthly visits for the first three months and then biannually in the winter and summer months for a period of five years.

COST:

URETEK USA provided a cost estimate based upon the 2007 ARA report. Based on that data, it is estimated that 88,000 pounds of 486 polymer material at $7.50 per pound is needed totaling $660,000. The cost for labor and mobilization is $107,500. It is understood that the subgrade may have changed since 2007. URETEK USA will invoice the prime contractor for only the amount of polymer needed to complete the project with approval from VTrans. The cost will not increase but be $7.50 per pound. All project costs will be paid for by the construction project. All additional costs including all site visits and testing during pre, during, and post construction will be paid for through the construction project. The estimated total for this is: $6,676.00. All additional site visits, testing, and report preparation will be paid for by the Research program under the task entitled, "Evaluation of Experimental Features." The total amount charged to Experimental Features will be approximately $14,700.00. All estimated costs are listed in Table 2 below.

	FFY	Research Cost	FWD Cost	IRI Cost	Survey Cost
Pre-Construction	FFY12	$272.00	$1,000.00	$500.00	
Construction	FFY12	$816.00	$1,000.00	$500.00	
Post Construction	FFY12	$1,088.00	$1,000.00	$500.00	
Total Construction Cost	**FFY12**	**$2,176.00**	**$3,000.00**	**$1,500.00**	
Year 1	FFY13	$136.00	$1,000.00	$500.00	$1,000.00
Year 2	FFY14	$136.00	$1,000.00	$500.00	$1,000.00
Year 3	FFY15	$136.00	$1,000.00	$500.00	$1,000.00
Year 4	FFY16	$136.00	$1,000.00	$500.00	$1,000.00

Year 5	FFY17	$1,656.00	$1,000.00	$500.00	$1,000.00
Total Experimental Feature Cost		**$2,200.00**	**$5,000.00**	**$2,500.00**	**$5,000.00**
Overall Total		**$3,832.00**	**$11,000.00**	**$5,500.00**	**$5,000.00**

Table 2: Total Estimated Research Costs

STUDY DURATION:

The project will be under evaluation for the length of time required to obtain valid conclusions on the performance and effectiveness of the repair method but not less than three to five years.

REPORTS:

An initial and final report will be published once the evaluation is complete, but not sooner than 3 years after the rehabilitation. Because of the interest in the site it is recommended that an a nnual update be done after survey data is taken.

Reviewed by: ____________________

William Ahearn, P.E.
Materials and Research Engineer
Date:

REFERENCES:

1. SHRP (1993). “Distress Identification Manual for the Long-Term Pavement Performance Project.” SHRP-P-338. Strategic Highway Research Program. National Research Council. Washington D.C.

2. Ponniah, Joseph E. and Kennepohl, Gerhard J. “Crack Sealing in Flexible Pavements: A Life-Cycle Cost Analysis.” Transportation Research Record 1529. pp. 86-94.

3. Subsidence Report