Stabilization Procedures to Mitigate Edge Rutting for Granular Shoulders – Phase II

CONSTRUCTION MANAGEMENT AND TECHNOLOGY

Final Report
January 2011

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

A multifaceted investigation was undertaken to develop recommendations for methods to stabilize granular road shoulders with the goal of mitigating edge ruts. Included was reconnaissance of problematic shoulder locations, a laboratory study to develop a method to test for changes in granular material stability when stabilizing agents are used, and the construction of three sets of test sections under traffic at locations with problematic granular shoulders.

Full results of this investigation are included in this report and its appendices. This report also presents conclusions and recommendations based on the study results.

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STABILIZATION PROCEDURES TO MITIGATE EDGE RUTTING FOR GRANULAR SHOULDERS – PHASE II

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Principal Investigator
Charles T. Jahren
Associate Professor
Institute for Transportation, Iowa State University

Co-Principal Investigator
David J. White
Associate Professor
Institute for Transportation, Iowa State University

Research Assistants
Thang Huu Phan
Chase Westercamp
Peter Becker

Authors
Charles T. Jahren, David J. White, Thang Huu Phan, Chase Westercamp, and Peter Becker

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A report from
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-4015 Fax: 515-294-0467
www.intrans.iastate.edu

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EXECUTIVE SUMMARY

Problem Statement

Several conditions coincide to cause edge ruts in granular shoulders. Air movements (generated by traffic) blow fine particles away from the pavement edges, which would otherwise serve as binders to hold the shoulder materials together and resist rutting. When vehicles go off-track and drop off the edge of the pavement, they displace the larger, remaining particles.

The drainage from the pavement surface is concentrated at the edge, softening the shoulder materials, and exacerbating the displacement process. The deeper binding materials that haven't been blown away are compacted by off-tracking vehicles into a hard crust one to three inches below the pavement edge.

When a shallow wedge of unbound material is replaced near the pavement edge, it is quickly displaced, because it doesn't have the stability that comes from being knitted into the underlying materials.

Objectives

- Develop a series of strategies for mitigating edge rut problems using various mixtures and gradations of granular materials and various stabilization agents.
- Rate the performance of a subset of the above-mentioned strategies by constructing and observing test sections.
- Recommend strategies based on the results of test section performance.
- Assist the Iowa Department of Transportation (DOT) in implementing the use of the recommended strategies.

Research Description

A multifaceted investigation was undertaken to develop recommendations for methods to stabilize granular road shoulders with the goal of mitigating edge ruts. The research investigation included:

- Reconnaissance of problematic shoulder locations,
- A laboratory study to develop a method to test for changes in granular material stability using stabilizing agents,
- Construction and observation of three sets of test sections under traffic at locations with problematic granular shoulders.

Research began with a list of 29 problematic shoulder sections throughout Iowa DOT District 2, as documented by DOT maintenance personnel.

A field investigation was conducted throughout District 2 to document the conditions at these problematic sections. The investigation included conducting dynamic cone penetrometer (DCP) tests, collecting samples of the shoulder aggregate, and taking elevation profiles and site photos.

Using the DCP field data, California Bearing Ratio (CBR) plots of the problematic shoulders were developed for each location. Elevation profile data from each location was plotted to illustrate the shoulder's elevation progressing away from the pavement's edge. For each location, the results of laboratory testing for grain size and Atterberg limits were summarized.

Several stabilizing agents were considered and used in constructing the test sections for this study:

- Calcium chloride
- Magnesium chloride
- Base One®
- DUSTLOCK®

Calcium chloride and magnesium chloride are applied as liquid salt solutions that suppress dust and stabilize by retaining moisture. Base One is a liquefied silica and soda ash emulsion that binds and stiffens certain soils and granular materials. DUSTLOCK is a trade name for a soybean soapstock and it was used because maintenance personnel in District 2 had a previous positive experience using the same product applied to the shoulder of US 18 near Garner on July 25, 2000.

Phase II Test Section Construction Locations

US Hwy	Direction	Vicinity
20	Eastbound	West of Jesup
75	Southbound	North of Sioux Center
20	Westbound	West of Jesup

Key Findings

Conclusions

- Problematic shoulders are generally stiff enough to carry expected traffic loads for emergency pull-off and temporary parking. Material gradations are generally finer than specified for new construction and cross slopes are often steeper than called out on cross sections for new construction. However, such differences in what is expected for original construction are consistent with damage that would be expected during use and maintenance (degradation of size due to breakage and abrasion and loss of material through erosion and winter and summer maintenance).

Therefore, it seems likely that edge ruts develop from a combination of vehicle off-tracking and time elapsed between maintenance cycles, rather than defects regarding original geometry and material gradation or from structural weakness.

Some effort to renew cross slope and material gradation may be helpful in mitigating edge ruts. In addition, a shorter maintenance cycle would most likely be required to mitigate edge ruts.

- Calcium chloride, magnesium chloride, and Base One did not provide noticeable improvements on the US 20 shoulders. However, they were easily applied and have the potential to be applied with the Iowa DOT's own maintenance staff, using its own equipment that could be modified from winter use.

  These methods were attempted because it was hypothesized that an important failure mode was that fine particles near the pavement edge were being removed by wind erosion, leaving only large particles that are easily displaced by off-tracking vehicles.

  These products bind fine particles, mechanically with Base One and by attracting moisture with calcium chloride and magnesium chloride. Apparently, some other mechanism causes the edge ruts, despite the presence of fine particles near the pavement edge.

- If full-depth reclamation is used to incorporate stabilizers, the Iowa DOT does not currently own and operate the necessary equipment to compact and stabilize the reclaimed material. To provide the needed compaction effort, heavier equipment would have to be purchased or rented.

  In particular, it would be necessary to have a pneumatic compactor that could operate bi-directionally. Typically-available, pull-behind compactors do not allow enough passes to be made quickly enough when consideration is given to the time required to safely turn the units, especially on limited access highways.

- DUSTLOCK appears to wear well in locations where the shoulder material provides a stable base and vehicles do not off-track to the extent that they do on the US 20 test section. In areas of heavy off-tracking, preliminary indications are that stabilizing the shoulders reduces the number of maintenance cycles to half of what they would be without the stabilizer.

- The laboratory test method for investigating stabilizer performance appeared to be a reasonable effort that provided some information about stabilized material behavior in confined situations. However, the method would have to be combined with a test similar to an asphalt rut test to detect instability for unconfined circumstances.

Recommendations

- Consider using DUSTLOCK for shoulders with stable material for roads with moderate traffic (about as much as on US 18 near Garner, which is 6,000 to 6,500 Annual Average Daily Traffic/AADT).

- For problematic areas with unstable materials, consider paving 2 to 4 ft strips next to the pavement. It might be possible to develop construction contracts similar to patching contracts to facilitate such improvements. Also, it may be possible to include such an improvement with a patching contract.

- Consider experimenting further with the topical applications calcium chloride and magnesium chloride to moisten shoulder material, so it is easier to grade and compact properly in dry weather.

- Continue the use of geogrid and flyash where necessary to stabilize soft subgrades beneath the shoulder material (in situations where such soft subgrades are problematic).

- Consider experimenting further with Base One where shoulder stiffness is insufficient.

- Limit scarification to light scarification that is only slightly deeper than edge ruts that are being repaired.

- Consider greater use of bi-directional rollers when shoulder repairs and maintenance require heavy compaction. The Iowa DOT's current self-propelled pneumatic rollers will likely be satisfactory for many such applications.

- Consider the development of lightly-paved shoulders for areas beyond rumble strips. Consider providing deep, lightly-bound bases using various stabilizing agents.

- Consider increasing the frequency of adding new shoulder material in areas with steep cross slopes and overly fine gradations of existing granular shoulder material.

- Consider developing methods to redistribute shoulder material from areas that have low cross slope to areas that have high cross slope. Such a system might include laser scanning or Light Detection and Ranging (LiDAR) to establish the location of materials, and trimming equipment to strike off areas with low cross slope.

Implementation Benefits

Efforts to eliminate edge ruts are important for several reasons. Granular shoulders with rutting and drop-off may contribute to drivers losing control and running off the road. Possible results are property damage, injuries, and/or fatalities.

INTRODUCTION

Investigations on shoulder maintenance and design have revealed that edge ruts in granular shoulders are an important and persistent safety issue that is challenging to remedy.

Several conditions coincide to cause edge ruts in granular shoulders. Air movements generated by traffic blow fine particles away from the pavement edges, which would otherwise serve as binders to hold the shoulder materials together and to resist rutting. When vehicles go off-track and drop off the edge of the pavement, they displace the larger, remaining particles. The drainage from the pavement surface is concentrated at the edge, softening the shoulder materials, and exacerbating the displacement process. The deeper binding materials that have not been blown away are compacted by the off-tracking vehicles into a hard crust one to three inches below the pavement edge. When a shallow wedge of unbound material is replaced near the pavement edge, it is quickly displaced because it does not have the stability that comes from being knitted into the underlying materials.

A previous investigation resulted in the development of two strategies to stabilize granular shoulders, especially for areas that had poorly stabilized earth fill underneath the granular layer: fly ash stabilization and Geogrid placement (White et al. 2007). However, these strategies address foundational issues that exist beneath the granular layer and edge rutting is a process that occurs mostly within the granular layer.

As part of the same investigation, three strategies were tested to address the edge-rutting problem. Two of the strategies were Portland cement stabilization, and soybean soapstock stabilization. A third strategy involved the use of a topical treatment sold under the trade name Soil-Sement. None of these strategies was successful. The Soil-Sement formed a hard, brittle crust that broke up quickly under traffic. There were several challenges in properly proportioning and mixing the Portland cement-stabilized material, which resulted in a weak product that rutted quickly; however, better results may be provided with a better construction process.

The soybean soapstock strategy was developed because maintenance personnel in Iowa Department of Transportation (DOT) District 2 had a previous positive experience using the same product applied to the shoulder of US 18 near Garner on July 25, 2000 (unpublished process improvement team notes provided by Mark Black, Iowa DOT District 2 Maintenance). The stabilization process resulted in a durable crust that remained in place after seven years of service. The traffic count on this road was 6,000 to 6,500 average annual vehicles per day (1999, 2003, and 2007 City of Garner traffic flow map at www.iowadotmaps.com). Although the experiment was successful, it was not repeated because the material was proprietary and a method to purchase it within the Iowa DOT purchasing process of that time could not be found.

The soapstock that was purchased for the 2007 investigation was different from that previously used in 2000 and coagulated in the distributor truck, plugging the application spray nozzles and requiring considerable remedial effort from the maintenance crew. After the field experiment, Iowa State University located the original source of the soybean soapstock and conducted a laboratory investigation on granular shoulder material that is stabilized with this soapstock. The results were very promising; however, researchers had expended the allowable time and budget for the previous investigation.

This report documents the extension of the previous investigation to further the ideas mentioned above and to investigate other promising strategies that could potentially address the edge rut problem on granular shoulders with more success.

Efforts to eliminate edge ruts are important for several reasons. Granular shoulders with rutting and drop-off may contribute to drivers losing control and running off the road; the possible result of running off the road is a fatality.

In Australia, loss of control on granular shoulders was found to contribute to 17% of fatal crashes (Armour 1984). In the United States, single-vehicle run-off-the-road crashes are the highest crash type in rural areas nationally. About one in three fatalities are the result of a single-vehicle run-off-the-road crash (AASHTO Roadside Design Guide 2002). As a result, the estimated annual cost of run-off-the-road crashes in the United States is $80 billion. The AASHTO (1998) strategic safety plan identifies reducing run-off-the-road crashes as a high-priority emphasis area in the effort to achieve a significant reduction in highway crashes.

In Iowa, 25% of fatal crashes involved a single vehicle that runs off the road (Souleyrette et al. 2001). The opportunity to improve road safety makes it desirable to undertake the research effort described in this report. In addition to possible safety improvements, possible increases in maintenance efficiency further justify this research effort.

Objectives

- Develop a series of strategies for mitigating edge rut problems using various mixtures and gradations of granular materials and various stabilization agents.
- Rate the performance of a subset of the above-mentioned strategies by observing test sections.
- Recommend strategies based on the results of test section performance.
- Assist the Iowa DOT in implementing the use of the recommended strategies.

FIELD RECONNAISSANCE

Research for the mitigation of shoulder edge ruts and pavement drop-offs for granular shoulders began with a list of 29 problematic shoulder sections throughout District 2 as documented by Iowa DOT maintenance personnel (See Table 1). Latitude and longitude coordinates where assigned to each problematic section to assist in locating them using either Google maps or a global positioning system (GPS) unit.

Table 1. Iowa DOT District 2 edge rut issue locations by maintenance garage

Garage	Location
Mason City	US 18: 1. 195.95 to 196.20 westbound - before the Nora Springs exit* 2. 179.5 to 179.55 eastbound - toward the interstate*
Hanlontown	US 65 north of Manly:# 1. 210.2 to 210.4 just south of Kensett 2. 214.1 to 214.4 north of Kensett 3. 214.8 to 215.1 north of Kensett
Charles City	Hwy 18 east of the Rudd RR overhead*
Allison	Hwy 3 - Milepost 212.6 to 213.1 (2,643 feet)* Hwy 3 - Milepost 215.16 to 215.63 (2,187 feet) Hwy 14N - Milepost 164.52 to 164.87 (1,637 feet) Hwy 57 - Milepost 31.67 to 31.87 (1,056 feet)
Waverly	Hwy 63: 1. Milepost 175.0 south by trailer court southbound (700 feet) 2. Milepost 174.5 500 ft south of 2736 driveway SW (2,350 feet) County Line 3. Milepost 172.5 S of C-57 northbound (1,700 feet) US 218: 1. South of milepost 191.25 southbound (700 feet)* 2. Milepost 192.55 northbound (1,000 feet) 3. From C-57 northbound (800 feet) IA 3: 1. West of Waverly by milepost 220 (1,500 feet) 2. By 10th Ave westbound (1,256 feet) 3. By milepost 216 westbound (1,100 feet) 4. By milepost 217 Station No. 292 eastbound (375 feet)
Waukon	IA 9 - Milepost 284.10 to 284.45 right curve at Lycurgus Church IA 51 - Milepost 2.35 to 2.45 and 3.85 to 3.95 right north of Postville
Decorah	IA 9 - Milepost 241.75 to 242.25 left big curve east of Cresco* US 52, Milepost 144.15 to 144.35 right “Sande’s old place”
Waterloo	US 63 - Milepost 154.55 north 800 ft US 63 - Milepost 153.60 north 500 ft US 63 - Milepost 168.20 to 168.70 US 20 - Milepost 245.68 to 245.70* US 20 - Milepost 243.20 to 243.30*

* High priority
\# On curves, not a high priority, but a constant problem. This road will be overlaid in the coming years and suggested as a candidate for paved shoulders by garage personnel.

A field investigation was conducted throughout District 2 to document the conditions at these problematic sections. The investigation included conducting dynamic cone penetrometer (DCP) tests, collecting samples of the shoulder aggregate, and taking elevation profiles and site photos (See Figures 1 through 3). The DCP test data were recorded for the six to eight inches of granular shoulder material, in addition to the subgrade layer for a depth of up to 1m below the surface of the shoulder.

To obtain the elevation profile data, a piece of angle iron 7 ft (180 cm) in length was set on the surface of the pavement's edge with its opposing end clamped to a small piece of angle, hammered vertically into the shoulder. With the horizontal angle attached to its vertical support using a C clamp, a torpedo level was placed in the center of the angle and the G clamp was adjusted, accordingly, to level the angle iron with the edge of the pavement (See Figure 3). Elevation profile measurements were recorded every 4 in. (10 cm) from the pavement edge to the end of the 7 ft (180 cm) angle.

Figure 1. Shoulder drop-off near pavement edge Highway 18 milepost 195.95-196.2 westbound June 4, 2008

Figure 2. Shoulder drop-off Highway 63 milepost 172.5 northbound June 4, 2008

Figure 3. Elevation profile measurement

A granular sample was taken from the top six inches of shoulder aggregate from each location and placed in a one-gallon Ziploc bag for later grain size distribution analysis and Atterberg Limit testing. Some shoulder locations had recently been spread with new aggregate by the Iowa DOT maintenance crews, so a granular sample was taken from the top surface containing the new granular shoulder material, in addition to a sample taken from a lower depth of the shoulder containing the older granular material.

In the laboratory, course aggregate sieve analyses, fine aggregate sieve analyses, and hydrometer tests were carried out to develop a grain size distribution. Atterberg Limits testing indicated that most of the samples were non-plastic.

The results of the reconnaissance testing are displayed in Appendix A.

Analysis of Problematic Shoulder Data

Using the DCP field data, California Bearing Ratio (CBR) plots of the problematic shoulders were developed for each location (See Figures 4 and 5). In addition to the DCP field data, elevation profile data from each location was reduced to illustrate the shoulder's elevation progressing away from the pavement's edge (See Figure 6). For each location, the results of laboratory testing for grain size and Atterberg limits were summarized (See Figure 7). The results from the field and test data collection effort are provided in Appendix A.

The test results are summarized in Table 2. Gradations generally were 10 to 20% finer than the fine gradation limit for Iowa DOT Class A aggregate. This would be consistent with a shoulder material that was delivered within specification tolerance and worn to a finer gradation through use. An exception to this observation was US 65 around mileposts 210 to 215. The old aggregate here was 30 to 50% above the fine gradation limit. At most of these locations, new aggregate had just been spread and the new aggregate samples were within specification tolerances.

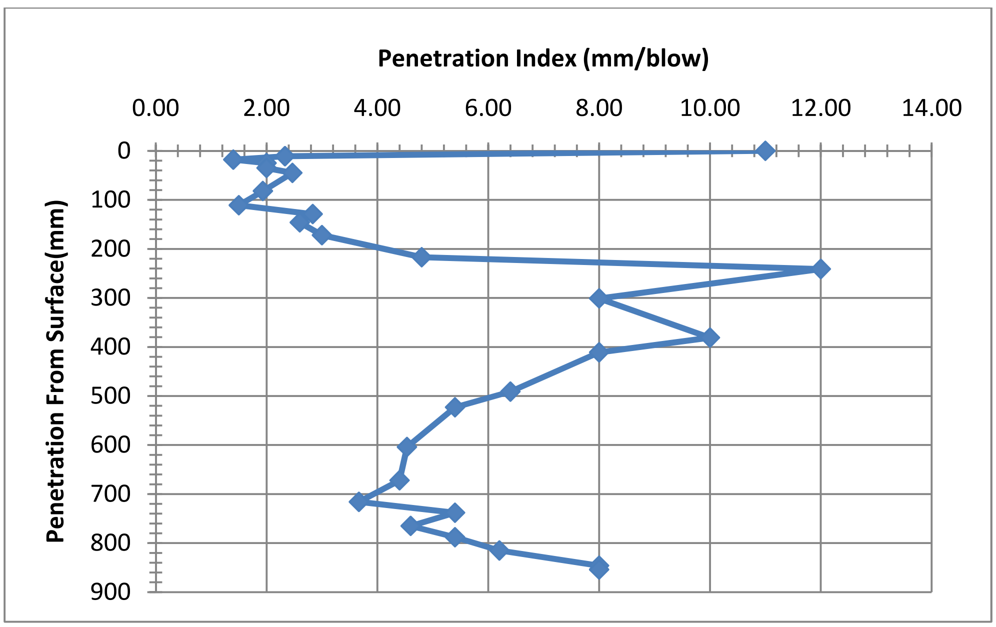


Figure 4. DCP test results Highway 3 milepost 215.16-215.63 June 4, 2008

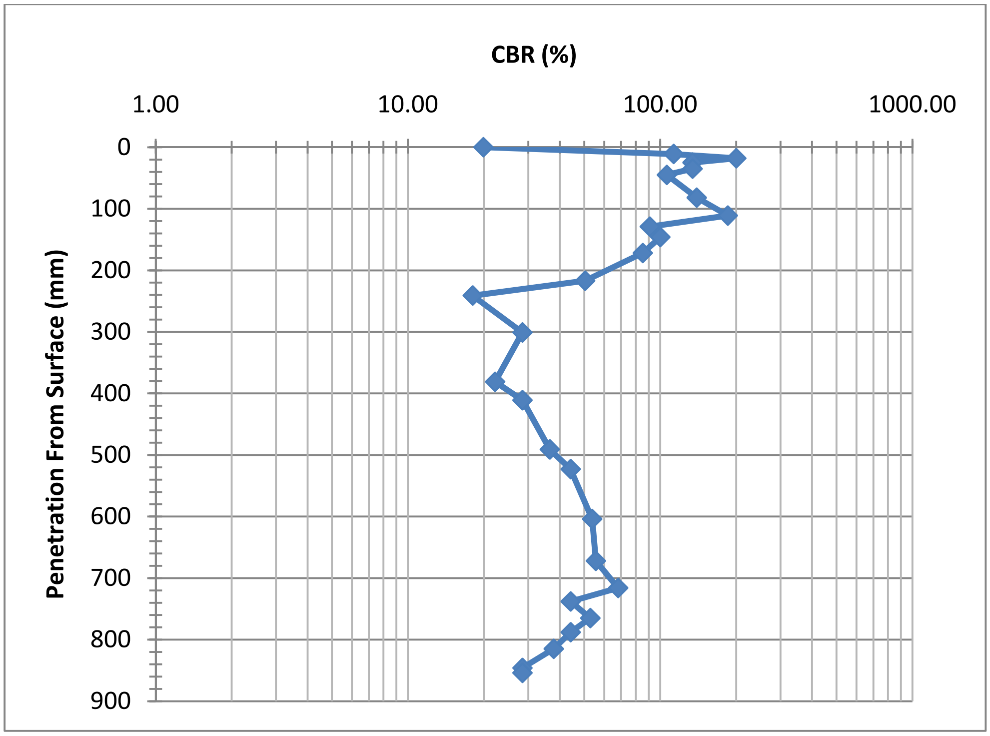


Figure 5. CBR measurements for Highway 3 milepost 215.16-215.63 June 4, 2008

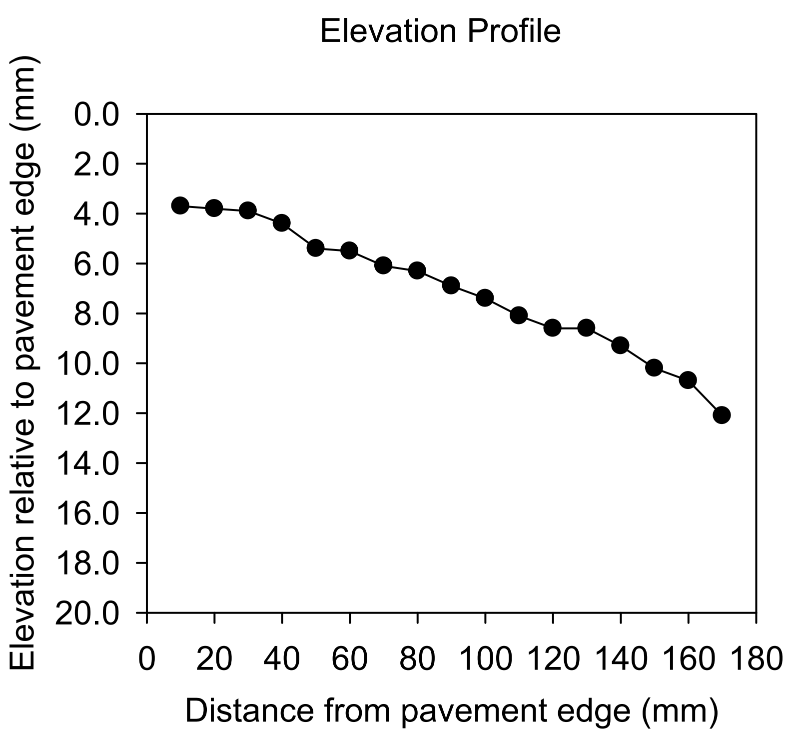
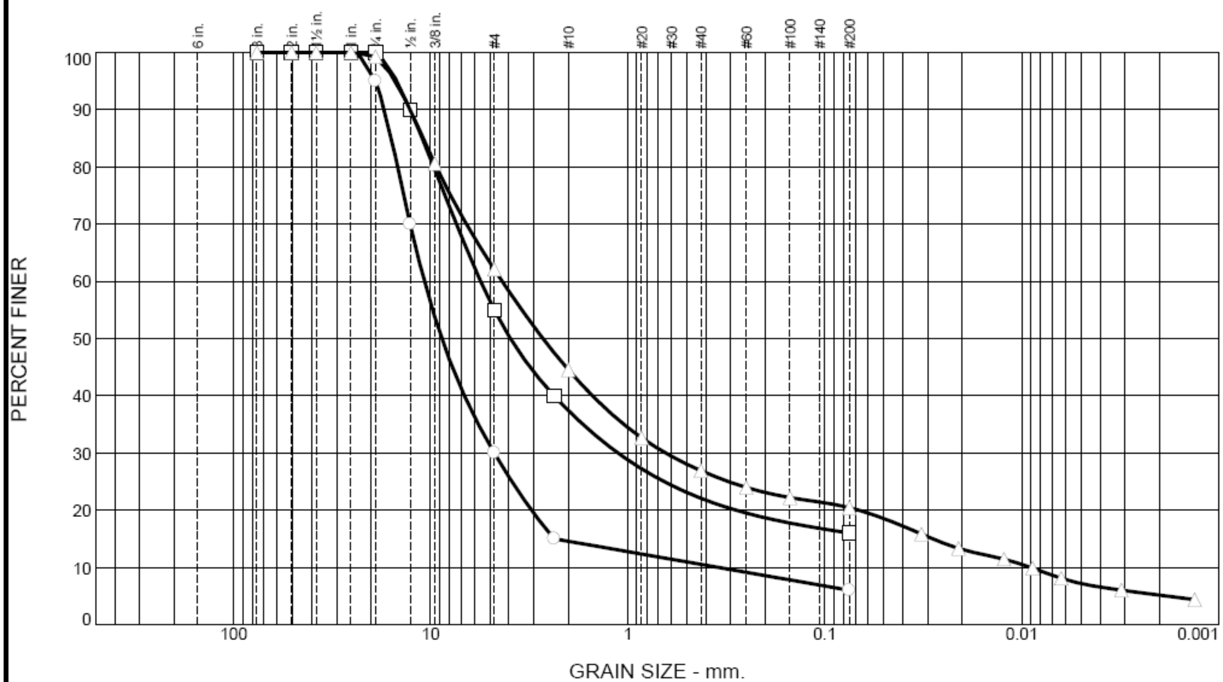


Figure 6. Elevation profile relative to the pavement edge for Highway 3 milepost 215.16-215.63

Particle Size Distribution Report



	+3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	AASHTO	PL	LL
○	0.0	70.0	24.0	6.0		GP-GM	A-1-a		
□	0.0	45.0	39.0	16.0		GM	A-1-b		
△	0.0	37.9	41.7	13.2	7.2	SM	A-1-b	NP	

SIEVE inches size	PERCENT FINER ○	□	△
3	100.0	100.0	100.0
2	100.0	100.0	100.0
1.5	100.0	100.0	100.0
1	100.0	100.0	100.0
.75	95.0	100.0	99.3
.5	70.0	90.0	
.375			80.6

GRAIN SIZE	○	□	△
D_{60}	10.7566	5.5749	4.3306
D_{30}	4.7500	1.1204	0.6429
D_{10}	0.3474		0.0090

COEFFICIENTS	○	□	△
C_c	6.04		10.59
C_u	30.97		480.63

SIEVE number size	PERCENT FINER ○	□	△
#4	30.0	55.0	62.1
#8	15.0	40.0	
#10			44.6
#20			32.7
#40			26.9
#60			24.0
#100			22.2
#200	6.0	16.0	20.4

Material Description

○ IDOT Class A/B Aggregate Lower Specification

□ IDOT Class A/B Aggregate Upper Specification

△ Hwy 20 MP 243.2 - 243.3 EB

REMARKS:

○

□

△

○ Location: IDOT Class A/B Aggregate Lower Specification Sample Number: 1

□ Location: IDOT Class A/B Aggregate Upper Specification Sample Number: 1

△ Location: Hwy 20 MP 243.2 - 243.3 EB Sample Number: 1

Iowa State University
Civil, Construction and Environmental
Engineering Department

Client: Iowa Highway Research Board

Project: Shoulder Research II

Project No.: 4747738 Figure

Tested By: Chase Westercamp

Figure 7. Particle size analysis for Highway 20 milepost 243.2–243.3 eastbound

Table 2. Summary of Test Results for Problematic Shoulders

Garage	Location	Range of CBR % in first 6 in. of depth exclusive of first reading	Rut Depth in inches 4 in. from edge of pavement	Cross slope % at 5.25 ft from edge of pavement	% above fine limit for Class A gradation @ #4
Mason City	US 18 MP 195.95 to 196.20 WB*	17 to 65	2.2	4.1	18.4
	US 18MP 179.5 to 179.55 EB	NS 18 to 35 SS 62 to 500+	2.9 1.5	14.4@ 8.4	NS 9.9 SS 18.7
Hanlontown	US 65 MP 210.2 to 210.4	18 to 97	0.7	2.4	*-17.3 #31.3
	US 65 MP 214.1 to 214.4	16 to 49	1.5	7.9	34.1
	US 65 MP 214.8 to 215.1	26 to 92	0.8	3.2	*8.2 #35.4
Charles City	US 18 MP 202 E of Rudd RR Overpass*	12 to 35	1.1	1.8	9.0
Allison	IA 3 MP 212.6 to 213.1*	68 to 151	0.7	1.7	6.9
	IA 3 MP 215.16 to 215.63	91 to 200	1.5	6.7	21.0
	IA 14 MP 164.52 to 164.87	4 to 48	1.9	7.8	24.9
	IA 57 MP 31.67 to 31.87	7 to 9	1.5	22.1	10.8
Waverly	US 63 MP 175.0 S by trailer court SB	24 to 97	1.1	2.0	18.1
	US 63 MP 174.5 500 ft S of 2736 driveway SW 2,350 ft County Line	25 to 97	1.1	2.0	17.3
	US 63 MP 172.5 S of C-57 NB 1,700 ft	11 to 33	2.1	6.9	0.2
	US 218 S of MP 191.25 SB*	21 to 31	1.7	8.7	9.6
	US 218 MP 192.55 NB 1,000 ft	18 to 33	1.7	8.7	10.8
	US 218 MP 193 from C-57 NB 800 ft	14 to 113	1.4	7.3	*0.7 #7.4
	IA 3 MP 220 W of Waverly 1,500 ft	22 to142	2.2	9.3	12.8
	IA 3 by 10th Ave WB 1,256 ft	25 to 74	2.3	11.6	21.4
	IA 3 by MP 216 WB 1,100 ft	96 to145	1.7	8.3	19.9
	IA 3 by MP 217 Sta. No. 292 EB 375 ft	85 to167	2.0	8.5	12.2
Waterloo	US 63 MP 154.55, North 800 ft	33 to 212	0.8	4.9	4.2
	US 63 MP 153.60, North 500 ft	22 to 79	0.7	4.5	8.5
	US 63 MP 168.20 to 168.70	10 to 172	1.3	5.6	19.8
	US 20 MP 245.68 to 245.70*	30 to 292	1.6	3.8	31.6
	US 20 MP 243.20 to 243.30*	35 to 42	1.7	2.6	7.0

NS = North Shoulder
SS = South Shoulder
* New Aggregate
# Old Aggregate
@ Measured 3.28 ft from edge of pavement

Table 3. Cross slope summary for problematic shoulders

Cross Slope Range	Number of Instances	Percent
Less than 3%	6	23
3% to 5%	5	19
5% and above	15	58

FIELD RECONIASANCE FINDINGS FOR PROBLEMATIC SHOULDERS

Observed edge rut depths ranged from 0.7 to 2.9 in. The results of the field reconnaissance investigation revealed that shoulder cross slopes were in more than half the cases greater than 5% (Table 3, the specified cross slope for new construction is 4%) and that the material gradation was usually finer than that specified for new material. These observations are consistent with a situation where a shoulder might have been originally constructed to the correct specifications and the cross slope increased due to loss of material from snow plowing and wind and water erosion and the gradation became finer through abrasion and wear in service.

In general, the shoulders were sufficiently stiff to function properly; in only two cases were DCP readings taken that inferred CBR measurements of less than 10. Therefore, the problematic shoulders did not have consistent shortcomings that were detected by the measurements performed during the field reconnaissance phase of this investigation.

STABILZING AGENTS

Several stabilizing agents were considered for use in edge rut mitigation. The construction process for each is briefly described in the following sections, as summarized from the product literature.

Base One®

Base One stabilizer is produced by Team Laboratory Chemical Corp. of Detroit Lakes, Minnesota (http://www.teamlab.net/). It is an emulsion of heat-liquefied silica sand and soda ash that also includes surfactants and emulsifying agents.

Base One can be delivered in 55-gallon drums and is diluted in water before application using a water distributor truck. The recommended rate for normal dilution is 55 gallons of Base One per 5,000 gallons of water (1:90 Base One:water). Application of Base One requires .005 gallons of undiluted agent per square yard per inch depth of granular material. It is important to note that the total amount of water varies depending on field conditions (moisture content, wind, temperature, etc.). The material that will be stabilized must have a binder (clay) content of 8 to 15%. To stabilize a quarter-mile length of surface that is 8 ft wide and 6 in. deep, 35.2 gallons of Base One would typically be required.

Base One can be re-worked, but such action may require rewetting the road so that the blade is able to cut into the hardened surface. In the case of aggregate shoulders, it is typical to maintain them by top-dressing the surface with 13.75 gallons of Base One and water mixture per quarter mile.

Base One can be applied using a blade mix process or used in conjunction with a stabilizing machine for full-depth reclamation. Equipment required for applying Base One includes a stabilizer, in the case of full depth reclamation, a water/distributor truck for the Base One and water solution, a compactor (rubber tired roller for blade mixing and sheep's foot and smooth drum roller for full depth reclamation), and a motor grader with a scarifying attachment. For very hot and windy days requiring additional moisture, a second water truck may be required to apply straight water prior to the Base One application.

The construction procedure for Base One is as follows (Base One product literature):

1. Windrow the material to be stabilized with a motor grader blade.
2. Apply the Base One and water solution to the road surface with a distributor truck and compact.
3. Start placement by cutting out enough material from the windrow with a motor grader to make 3/4-1 in. lift laid loosely across the road surface.
4. Apply Base One and water solution to the laid out material and mix it uniformly as the blade is laying the material out across the road.
5. Shape the lift to the proper slope.
6. Compact the lift until it is hard. Add additional water if needed.
7. Repeat steps 2 through 6 until the entire windrow has been placed.
8. Top dress the final road surface with Base One and water solution; shape to develop the final crown and profile with the motor grader.
9. Compact the final surface extensively until it is firm and hard or until the surface starts to dry out.
10. The lay down sections are recommended to be approximately 1/4 to 1/2 mile in length.

Soiltac®

Soiltac is a Biodegradable, liquid copolymer produced by Soilworks®, LLC of Chandler, Arizona, (http://www.soilworks.com/). The recommended topical application rate for roadway shoulders is 0.056 gallons per square yard of undiluted concentrate or 0.84 gallons per square yard of diluted concentrate (1:14 Soiltac:water).

After the initial application, a maintenance application will be required within 12 to 24 months. The maintenance application rate is typically 30% the original cumulative application rate.

Soiltac is intended to be topically applied (the resulting penetration depth is 1/8 to 2 in.), mixed with a reclaimer, or applied using a combination of the topical and reclaimer application. When a reclaimer is used for a stabilized depth of 6 in., an application rate of 0.36 gallons per square yard of undiluted concentrate is recommended. When the diluted stabilizing agent is incorporated using a reclaimer, the amount of water required to achieve optimum moisture must be field-determined by a proctor test (ASTM D 2216-92). The in-place moisture content can be determined by the average of four in-place readings with a nuclear density gauge.

Equipment required for a topical treatment using Soiltac includes a motor grader equipped with scarifying attachment, a compactor, and two water trucks (one for applying Soiltac and one for water). If Soiltac is to be mixed in, a reclaimer would be required in addition to the other equipment. (Soiltac product information dated 1/16/08.)

Soil-Sement®

Soil-Sement is a polymer emulsion that is manufactured by Midwest Industrial Supply, Inc. of Canton, Ohio (www.midwestind.com).

Prior to construction, the moisture content of the soil should be determined to select the proper application rate of the stabilizing agent. Construction application involves tilling the top 4 to 6 in. of soil with a reclaimer and applying the chemical with a distributor truck at a rate of 1 gallon per 20 square feet using a dilution rate of 2:1 (water:chemical.)

Immediately following the first application, a smooth drum roller should be used to compact the material. After finishing the initial application and compaction effort, a topical application of the Soil-Sement should be made at the rate of 1 gallon per 50 square feet using a dilution rate of 7:1 for moist aggregate and 9:1 for dry aggregate.

Typically, the majority of the stabilizer should be used for the reclaiming application and the remainder applied as a topical application. For 100 gallons of Soil-Sement, 95 gallons should be used in the reclaiming effort and 5 gallons should be applied topically. Equipment required includes a reclaimer, a motor grader equipped with scarifying attachment, a compactor, and two water trucks (one for the chemical and one for water).

DUSTLOCK®

DUSTLOCK is acidulated soapstock, which is a by-product of the vegetable oil refining process. It is produced by Environmental Dust Control, Inc. of Currie, Minnesota (http://www.dustlock.com/). In Iowa, an applicator for this stabilizing agent is Boer and Sons, Inc. in Boyden, Iowa (http://www.boerandsons.com/content/view/16/29/).

DUSTLOCK should be applied topically at a standard undiluted rate of 1 quart per square yard at a temperature above 50°. If colder temperatures exist, heating prior to application will assist in penetration of the stabilizer into the aggregate.

If any powdered dust is present on the surface aggregate prior to application, or if the DUSTLOCK begins to curdle upon contact with the aggregate, water should be applied topically at a rate slightly less than that for the DUSTLOCK.

The stability of recycled asphalt has reportedly been considerably improved when treated with DUSTLOCK. Product literature indicates that the driving surface will be somewhat similar to that of asphalt.

To manage the stickiness of the stabilizing agent after application, a final surface coat of sand, pea gravel, or possibly limestone screenings is also helpful. In the past, some compaction effort from pneumatic or smooth drum rollers has also been helpful. If a smooth drum roller is used, the drum must be continuously wetted down to prevent the DUSTLOCK from sticking to it. If a reclaimer is used, compaction of the aggregate prior after reclaiming and before the application of the DUSTLOCK may be necessary. A maximum of 1 in. of loose material should be available on the surface of the aggregate to maximize the penetration depth of the product. The finer the particles are on the surface, the tighter the DUSTLOCK will bind.

Application equipment required for DUSTLOCK includes a motor grader equipped with scarifying attachment, a compactor, and two water trucks (one for DUSTLOCK application and one for water). Optionally, a shoulder reclaimer can be used to scarify the aggregate and mix DUSTLOCK into the shoulder. (Undated DUSTLOCK Applicator's Manual.)

Magnesium Chloride (DustGard®)

DustGard is a magnesium chloride-based dust suppressant and soil stabilizer produced by North American Salt Company of Overland Park, Kansas (www.nasalt.com). Magnesium chloride is a commodity material that could be purchased from several sources either as solid flakes or as a brine solution with concentrations of up to 31%. The flakes can be mixed with water to make the solution.

DustGard is the trade name for the magnesium chloride solution that was used for this investigation. An application rate of .225 gallons per square yard of the brine is recommended. For one -quarter mile of 8 ft wide shoulder, a total of 264 gallons of magnesium chloride are required. For application using a reclaimer, magnesium chloride solution should be applied in two applications each at a rate of .225 gallons per square yard.

Use a motor grader blade to bring the surface to the correct cross slope and to remove surface roughness. Before application, the surface should be smooth, compacted, yet permeable. Some compaction may be necessary after blading. The surface should be moist before application because the moisture will break the surface tension and allow the chemical to penetrate more fully than it would for a dry surface.

Application equipment required includes a motor grader equipped with scarifying attachment, a compactor, and two water trucks (one for the magnesium chloride solution and one for water). Optionally as reclaimer could be used to scarify the aggregate and mix the chemical solution into the shoulder. (DustGard product literature Spring 2010 http://www.dustgard.com/assets/Newsletter-Final.pdf.)

Calcium Chloride

Calcium chloride is a commodity material that can be purchased from a number of suppliers. It can be purchased as solid flakes or as a solution. The flakes can be mixed with water to make the solution. Solutions are often 38% calcium chloride and as high as 40%. For full-depth reclamation using calcium chloride, the recommended application rate is 0.25 gallons per square yard of solution for every 2 in. of material to be stabilized.

The surface should first be tilled using a reclaimer and then sprayed with water to achieve suitable moisture conditions. With the granular material properly tilled, calcium chloride should be applied to the surface. Following application, the stabilizer should be used once again to mix the calcium chloride into the granular material. Proper grading and shaping to the desired profile should be done following stabilization to ensure drainage. After shaping the roadway surface using a motor grader, a smooth drum vibratory compactor can used to compress the materials together. Following compaction, a second topical seal coat application of calcium chloride can be applied at a rate of 0.20 gallons per square yard.

Application equipment required for full-depth reclamation using calcium chloride requires a reclaimer, motor grader equipped with a scarifying attachment, a smooth drum vibratory compactor, and two water trucks (one for calcium chloride application and one for water).

The aggregate that is being stabilized must have a uniform gradation; in particular, it must include a substantial percentage of fine material with some plasticity (typically 10 to 30% fines). The surface must have a cross-slope of 3 to 4% and good drainage. It is essential to loosen about 3/4 in. of the existing surface and leave it loose at a uniform depth across the roadway. Pre-wetting the surface is recommended to facilitate full absorption of product. (Dow Chemical Company's "A Guide to Full-Depth Reclamation with LIQUIDOW Calcium Chloride" product literature, May 2003, reviewed at http://www.glchloride.com/brochure/Brochure%20-%20Liquidow%20-%20Full%20depth%20reclamation%20guide.pdf)

FALL 2008 TEST SECTIONS

Calcium chloride, magnesium chloride and Base One were chosen as the first round of stabilizers to be tested for their performance in mitigation of shoulder edge ruts and pavement drop-offs for granular shoulders.

Highway 20 in Waterloo, Iowa was chosen as the test section location due to its historically poor shoulder conditions and frequency of edge drop-offs. The test sections were set up on the eastbound shoulder beginning with calcium chloride, progressing on to magnesium chloride, and ending with Base One farthest to the east (See Figure 8).

Calcium chloride and magnesium chloride test sections were divided into eight 500 ft subsets including: topical 2 ft wide application, topical 4 ft wide application, double scarification with a full-width topical application, single scarification with a full-width topical application, full-depth reclamation with no stabilizer, full-depth reclamation with 2 ft width application, full-depth reclamation with 4 ft width application, and full-depth reclamation with an 8 ft width application.

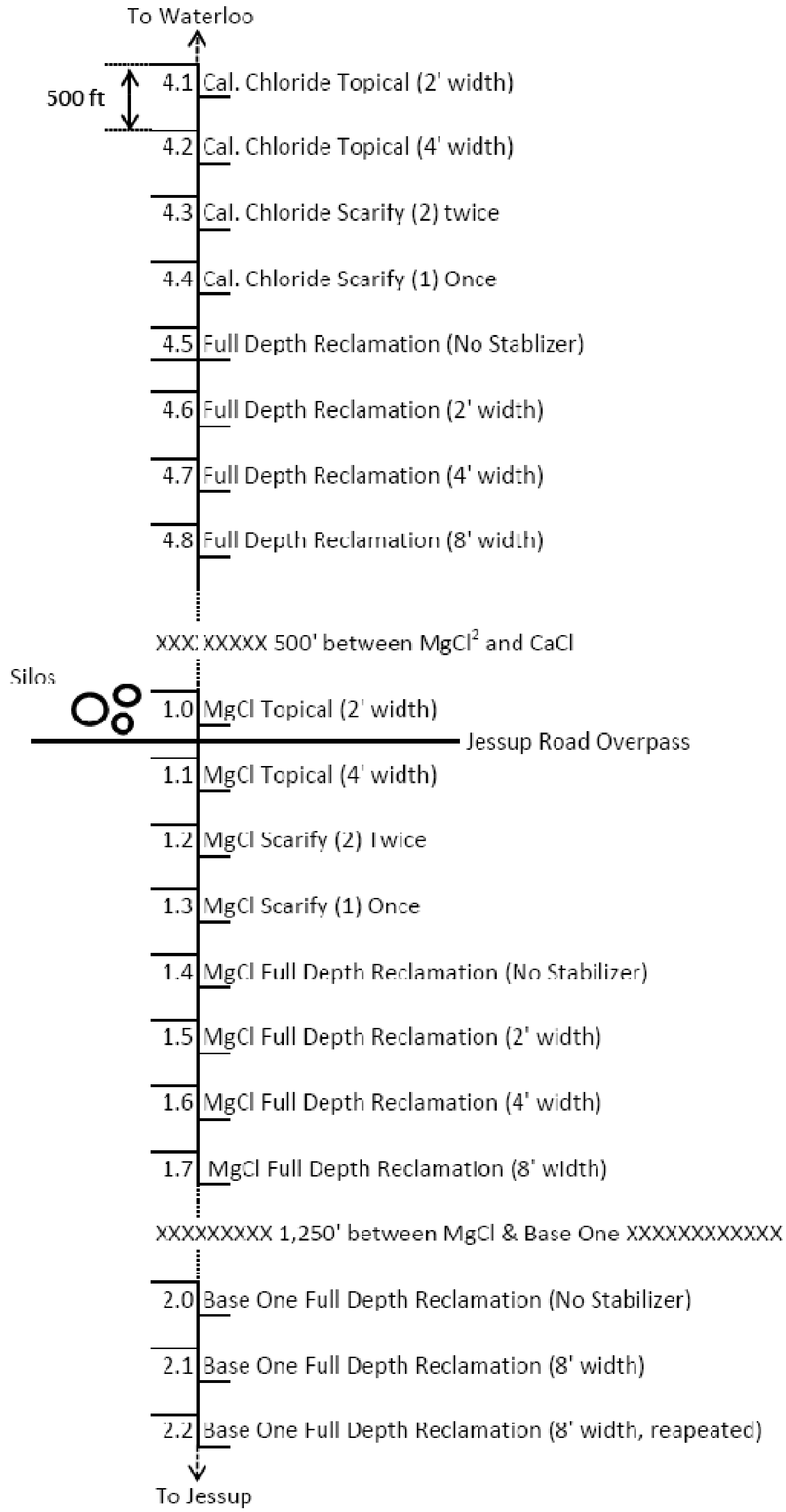


Figure 8. Test section layout for Fall 2008

The BaseOne test section was divided into four 500 ft subsets including: full-depth reclamation with no stabilizer, full-depth reclamation with 2 ft width application, full-depth reclamation with 4 ft width application and full-depth reclamation with an 8 ft width application.

Preconstruction Reconnaissance

One cross-slope measurement was taken for each test section and one DCP test was taken for each chemical (See Appendix B).

Test Section Construction

Test section construction was executed October 14 and 15, 2008. The equipment composition is listed in Table 4. One operator attended each piece of equipment. The distributor trucks were only on site while the chemical was being sprayed.

Table 4. Equipment composition for test section construction

Equipment Description	Owner (and Comment)
Traffic control warning sign trucks (two)	Iowa DOT
Crash attenuator truck	Iowa DOT
Dump body brine truck	Iowa DOT (used to spray Base One solution)
Dump truck with pull-behind pneumatic roller	Iowa DOT
Road grader	Iowa DOT
Garage supervisor’s pickup truck	Iowa DOT
CAT RM 500 road reclaimer	Reilly Construction Co., Inc., Ossian, Iowa
Distributor truck for magnesium chloride	Heffron Services, Inc., Van Meter, Iowa
Distributor truck for calcium chloride	Jerico Services, Inc., Indianola, Iowa

Topical Applications

Topical applications were executed by using a using the road grader to correct edge ruts and then the distributor truck to spray the chemical on the shoulder surface (See Figure 9). The width of the spray pattern was adjusted by plugging the spray nozzles on the spray bar of the distributor truck.

Scarification Applications

Scarification applications were executed by using the road grader to correct edge ruts, spraying the shoulder with the distributor truck and then scarifying the shoulder edge in attempt to incorporate the chemical deeper into the road shoulder (See Figure 10). When the shoulder was scarified twice, scarification was executed before and after chemical application.

Figure 9. Distributor truck spraying calcium chloride on shoulder surface

Figure 10. Road grader scarifying shoulder material

Full-Depth Reclamation Applications

Full-depth reclamation applications were executed by using a rented CAT RM 550 road reclaimer and various pieces of equipment provided by the district's Waterloo Garage. The process commenced with the road reclaimer reclaiming the shoulder to a depth of 6 in. (See Figures 11 and 12).

Figure 11. Front view of road reclaimer

Figure 12. Rear view of road reclaimer

Next, the chemical was sprayed on the surface (See Figure 13) and the shoulder was reclaimed again. For the 2 ft and 4 ft wide chemical applications, the shoulder was reclaimed to the full 8 ft width of the reclaimer and the spray bar of the distributor was plugged as necessary to limit the chemical application width. The road grader made passes as necessary to reposition the shoulder material (See Figure 14). Then, the surface was compacted with passes of the pull-behind pneumatic roller (See Figure 15).

Figure 13. Dump body brine truck spraying Base 1 solution

Figure 14. Road grader

Figure 15. Pull-behind compactor

Magnesium Chloride

Magnesium chloride was sprayed at an average density of 0.29 gallons per square yard using the supplier's distributor truck.

Calcium Chloride

Calcium chloride was sprayed at an average density of 1.05 gallons per square yard using the supplier's distributor truck.

Base One

Iowa DOT personnel mixed the Base One stabilizer in the dump body brine truck tanks according to the supplier's instructions. Several passes of the brine truck were required to obtain the recommended application density. This was because the usual application density for brine in winter operations is much lower than the recommended application density of Base One.

Two full-width applications of Base One were made. One section (2.1) was a trial run, while the research team and Iowa DOT personnel experimented and adjusted operations. The second section (2.2) represents the best attempt of using the product with the available equipment.

Post Construction Observations

Immediately after construction, the full-depth reclaimed sections were sufficiently soft so that the rear tires of an unloaded 3/4-ton pickup truck sunk 3 to 4 in. into the shoulder surface (See Figure 16). The pull-behind compactor could not provide enough passes quickly enough, nor to the depth of compaction required, to stabilize the road surface. Because the truck could not back up with the compactor, it was necessary for the truck to take very long round trips from one exit to another on Highway 20 (with its controlled access design). Thus, few passes could be made in the available time.

Figure 16. Pickup truck tire rut that indicated the typically soft conditions one day after full-depth reclaiming

By the following week, much of the shoulder had stabilized, so it could support a 3/4 ton pickup truck (See Figure 17), but a few soft spots remained (See Figure 18).

Figure 17. Magnesium chloride full-depth after one week

Figure 18. No stabilizer, full-depth, still soft one week later

Post Construction Field Reconnaissance

Following test strip construction, post-construction field reconnaissance data collection for the stabilized test sections included: elevation profiles, DCP testing, photo updates, and aggregate sampling. Two field reconnaissance data collection trips were completed in the Fall of 2008 with the remainder occurring in the Spring of 2009.

Elevation profiles and photo updates were carried out at each test strip subset (20 in all), while DCP testing was conducted on only the full 8 ft width stabilized test sections (for each stabilizer). In addition, DCP testing, elevation profiles, aggregate sampling, and photo updates were performed for a control section. A set of three aggregate samples were taken for each stabilizer and control section at the full-width reclamation section, 1 ft, 3 ft, and 5 ft from the pavement edge.

Because the principal focus for the post-construction field reconnaissance was taking elevation profiles and updating photos, the number of DCP tests and other activities was adjusted to what could be completed in one working day with a crew of two field technicians.

In addition to regular testing, the technicians identified areas where the shoulders were especially hard or soft and took additional DCP tests at those locations. The technicians also looked for areas where edge ruts were developing and noted them. In addition, they collected sets of aggregate samples in locations where edge rutting was problematic. (Field data collection activity is summarized in Table 5.)

Field data for the Waterloo test sections was reduced in the same manner as the 29 problematic shoulder locations located throughout District 2. In addition, CBR measurements for each reconnaissance trip were plotted together (See Figure 19).

Table 5. Summary of field observations for Fall 2008 test sections

Date	Photos	Elevation Profiles	DCP	Gradation
10/02/08 Pre-Construction	All	2 per test section group and 1 control section	All	none
11/02/08 Post-Construction #1	All	All	1.7, 2.1, twice in 4.8, and control sections 1 and 2	3 samples* for control section and each group of test sections
11/20/08 Post-Construction #2	All	All	1.7, 2.0, 2.1, 4.6, 4.7, 4.8, and Control Sections 1 and 2.	None
02/06/09 Post - Construction #3	1.0, 4.5, 4.6, 4.7, and control section 1	None	None	None
03/01/09 Post - Construction #4	1.0, 4.5, 4.6, 4.8, and control section 1	None	None	None
03/12/09 Post - Construction #5	All	All	None	None
04/23/09 Post - Construction #6	None	All	All	None

* 1 ft, 3 ft, and 5 ft from edge of pavement

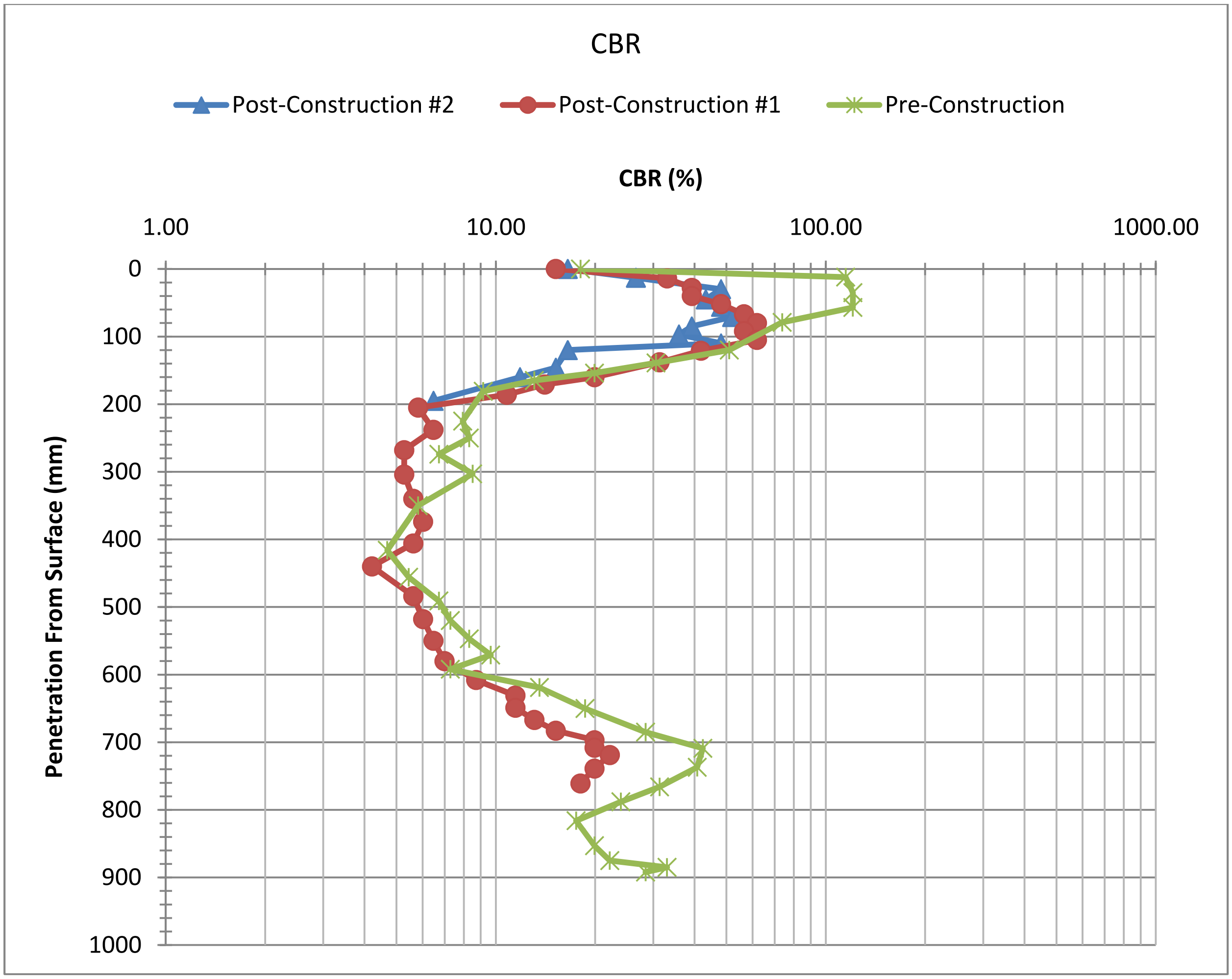


Figure 19. Sample CBR measurements plotted for magnesium chloride test section near Waterloo, Iowa

Gradations

Aggregate samples for gradations were taken for each group of test sections (one each for magnesium chloride, calcium chloride, and Base One), plus one for each control section. The results were typical of those found for the intial field reconaisaince: the gradation was somewhat finer than the limits for new aggregate and following the same general shape of the target gradation.

Photos

The photos documented rutted and muddy areas of the test sections, as well as the general conditions near the pavement edge. The locations of muddy and rutted areas are summarized in Table 6 and explained in the following narrative.

Table 6. Location of ruts and muddy areas

	Test Section	11/2/08 Postcon #1	11/20/08 Postcon #2	2/6/09 Postcon #3	3/1/09 Postcon #4	3/12/09 Postcon #5
4.1	CaCl Topical (2' width)					
4.2	CaCl Topical (4' width)					
4.3	CaCl Scarify (2) twice					
4.4	CaCl Scarify (1) once					
4.5	Full Depth Reclamation (No Stabilizer)	L	L	L	L	L
4.6	Full Depth Reclamation (2' width)		L	L	L,M	L
4.7	Full Depth Reclamation (4' width)		L	H,M	L,M	L
4.8	Full Depth Reclamation (8' width)		L	L,M	L,M	L
CTL 1	1, 500 ft	L		L	L,M	H,M
1.0	MgCl Topical (2' width)				H,M	H,M
1.1	MgCl Topical (4' width)					
1.2	MgCl Scarify (2) Twice		L			
1.3	MgCl Scarify (1) Once					
1.4	MgCl Full Depth Reclamation (No Stabilizer)	L			ND	L,M
1.5	MgCl Full Depth Reclamation (2' width)	L	L	L	ND	L,M
1.6	MgCl Full Depth Reclamation (4' width)	L		H, M	ND	L,M
1.7	MgCl Full Depth Reclamation (8' width)	L	L	L	ND	L,M
CTL2	1250 ft			L		
2.0	B1 Full Depth Reclamation (No Stabilizer)		L, M	L,M	ND	
2.1	B1 Full Depth Reclamation (8' width)				ND	
2.2	B1 Full Depth Reclamation (8' width, repeated)	L		L	ND	

L = Light rutting under 2 in.
H = Heavy rutting over 2 in.
M = Muddy
ND = Not Documented

Over the course of the winter, the pavement edge gradually became more compacted and free from the larger floating aggregate particles. The edge drop off appeared to vary from 1/2 to 2 in. There was no apparent difference between treated and untreated areas. The full-depth reclaimed areas had experienced light rutting when examined during the first two post construction visits in November 2008.

In February 2009 maintenance personnel notified the research team that some areas included in the test sections were experienceing heavy rutting during winter thaw periods. These areas were documented with photos. The locations were the full-depth reclamatioin areas for each of the stabilizing agents. In addition, Control Section 1 experienced some rutting (See Figure 20).

Figure 20. Rutting on Control Section 1 in February

The heaviest rutting was in sections 1.6 and 4.7. In addtion sections 1.6, 2.0, 4.7, and 4.8 were moisture-saturated and muddy. During a subsequent visit to observe conditions as the frost was going out March 1, 2009, a researcher documented with photos that the rutted, muddy conditions persisted in sections 4.5 through 4.8, Control Section 1 and section 1.0. The observer had limited time at the location and did not document conditions at other locations, but indicated that the worst conditions were documented.

During another visit March 12, 2009, the observer documented that the heavily-rutted areas extended from Control Section 1 into test section 1.0. For sections 4.5 through 4.8, lightly-rutted conditions persisted; however, the material was less saturated and muddy in comparison to the pervious visit. Sections 1.4 through 1.7 were lightly-rutted, moisture-saturated and muddy.

Due to time constraints, photos were not taken during the last postconstruction visit April 23, 2009. Researchers had not taken elevation profile measurements since November 2008, so prioritiy was given to taking those measurements.

However, some research team members have performed some informal photo documentation after formal field reconiassance ended. Conditions appeared to be little changed from those that were present before test section construction took place (See Figure 21). And, difficulties maitaining the shoulder near the pavement edge prevailed (See Figure 22).

Figure 21. Mostly good calcium chloride full-depth 8 ft wide June 2009

Figure 22. Calcium chloride scarify twice June 2009

CBR Correlated from DCP Measurements

CBRs were estimated from DCP measurements (ASTM D 6951-03). Pre-construction CBR percentages ranged from 30 to 250 within the top 6 in. of shoulder material. All locations that were tested had a substantial amount of material with a CBR percent greater than 100. The control sections were not tested; however, it seems reasonable to assume that their CBR percentages would have had a similar range.

After construction, the most unstable sections were DCP tested November 2 and 20, 2008 (See Table 7). The resulting CBR percentages ranged from 15 to 70. Control Section 1 also became unstable and its CBR percentages were calculated 20 to 40. Control Section 2, which remained stable, calculated to have a percentage range of 30 to 170 with a substantial amount of material exceeding a CBR of 100. With DCP testing April 23, 2009, the CBR percentage calculated to range between 15 and 70. Control Section 2, which calculated as the stiffest of all the sections, calculated to range from 20 to 50 percentage points. Control Section 1 and test section 2.1 (Base One, full-depth reclamation, 8 ft wide) tied for being the stiffest at 70 percentage points at their stiffest layers.

Table 7. Range of CBR (%) from DCP in top 6 in. of shoulder material 2008 Waterloo test sections

<table>
<tr><th>Section</th><th>Pre-Construction
10/2/08</th><th>Post-Construction
#1 & #2 (combined)
11/2/08 & 11/20/08</th><th>Post-Construction #6
4/23/10</th></tr>
<tr><td>4.6 CaCl (2 ft wide)
Full-Depth Reclamation</td><td>80-250</td><td>15-40</td><td rowspan="3">30-70
(one measurement taken for all subsections 4.X)</td></tr>
<tr><td>4.7 CaCl (4 ft wide)
Full-Depth Reclamation</td><td>80-200</td><td>25-40</td></tr>
<tr><td>4.8 CaCl (8 ft wide)
Full-Depth Reclamation</td><td>50-200</td><td>15-25</td></tr>
<tr><td>Control Section 1</td><td>NT</td><td>20-40</td><td>30-70</td></tr>
<tr><td>1.7 MgCl (8 ft wide)
Full-Depth Reclamation</td><td>30-120</td><td>30-50</td><td>20-60</td></tr>
<tr><td>Control Section 2</td><td>NT</td><td>30-170</td><td>20-50</td></tr>
<tr><td>2.1 Base One (8 ft wide)
Full-Depth Reclamation</td><td>150-200</td><td>30-70</td><td>35-70</td></tr>
</table>

NT = Measurement Not Taken

Elevation Profiles

Edge rut depths at 4 in. from the pavement edge and percentage of cross slope at 5.25 ft from pavement edge were calculated from elevation profile measurements (See Table 8 for a summary).

Before contruction, edge rut depths ranged from 0.6 to 2.7 in. After construction (November 2, 2008), edge rut depths ranged from 0.2 to 0.9 in. Thereafter, edge rut depths steadily increased until they ranged from 0.6 to 2.7 in.

Iowa DOT Road Design Details 7135 and 7136 indicate that newly-constructed shoulders should have a cross slope of 4% to 6%. Before construction, 52% of the sections had cross slopes within 1% of this target, with 38% above the target and 10% below. After construction (November 2, 2008), the number of sections within 1% of this target remained at 52%. However the number of sections with a cross slope above this range increased to 33% with the number below decreased to 15%.

By April 23, 2009, most of the sections had an increased cross slope with only 29% within the target range, only one measurement (5%) below the target range, and 67% of the measurements above the target range (See Table 9). This would be consistent with shoulder material migrating away from the pavement edge and possibly into the ditch by a combination of snow plowing, water and wind erosion, and displacement by vehicles.

A noticeable pattern of rut depth or cross slope measurements did not develop in favor of any particular stabilizer or application technique. This matched visual observations by researchers and maintenance personnel. Before construction, rut depth varied by more than 2 in. By April 23, 2009, the same amount of variation had returned.

Table 8. Edge rut depths and percentage of cross slope calculated from elevation profile measurements

	Depth of Edge Rut 4 in. from Edge of Pavement (in.)					Cross Slope 5.25 ft from Edge of Pavement (%)				
Test Section	10/2/08 Precon	11/2/08 Postcon #1	11/20/08 Postcon #2	3/12/09 Postcon #5	4/23/09 Postcon #6	10/2/08 Precon	11/2/08 Postcon #1	11/20/08 Postcon #2	3/12/09 Postcon #5	4/23/09 Postcon #6
4.1 CaCl Topical (2' width)	0.6	0.3	0.3	0.3	0.6	2.5	2.6	3.8	2.6	3.4
4.2 CaCl Topical (4' width)	2.8	0.7	0.9	1.6	3.1	6.0	3.9	3.8	2.8	3.3
4.3 CaCl Scarify (2) twice	1.0	0.3	0.3	0.8	2.0	1.0	2.1	1.9	0.8	2.5
4.4 CaCl Scarify (1) Once	2.7	0.3	0.4	1.9	2.7	3.7	2.9	3.4	3.4	4.1
4.5 Full-Depth Reclamation (No Stabilizer)	2.0	0.2	0.4	1.5	2.3	2.6	4.3	3.5	2.3	3.9
4.6 Full-Depth Reclamation (2' width)	1.2	0.4	0.7	0.9	1.4	4.9	6.1	6.5	5.5	6.9
4.7 Full-Depth Reclamation (4' width)	0.8	0.9	0.3	1.1	1.6	4.8	4.8	4.3	4.1	5.8
4.8 Full-Depth Reclamation (8' width)	1.0	0.2	0.3	0.6	0.8	4.4	5.4	4.8	4.7	6.3
CTL 1 500 ft	1.8	0.2	0.4	0.6	1.4	1.4	3.1	2.7	3.6	4.3
1.0 MgCl Topical (2' width)	1.0	0.7	0.6	0.8	1.1	3.8	3.9	3.9	6.2	6.6
1.1 MgCl Topical (4' width)	1.0	0.4	0.8	0.8	1.4	4.5	4.5	4.2	1.0	5.0
1.2 MgCl Scarify (2) Twice	1.2	0.9	0.3	1.6	2.2	2.6	4.8	4.7	3.8	6.3
1.3 MgCl Scarify (1) Once	0.8	0.6	0.2	0.9	1.2	4.9	4.6	4.9	3.8	6.6
1.4 MgCl Full-Depth Reclamation (No Stabilizer)	0.7	0.7	0.3	1.3	1.6	4.1	5.4	4.8	5.1	7.2
1.5 MgCl Full-Depth Reclamation (2' width)	0.6	0.4	0.5	0.9	1.4	3.9	4.4	3.8	3.3	5.8
1.6 MgCl Full-Depth Reclamation (4' width)	0.5	0.9	0.6	2.0	2.6	4.8	5.2	5.3	4.4	6.3
1.7 MgCl Full-Depth Reclamation (8' width)	1.8	0.3	0.2	0.9	1.2	6.3	5.4	5.0	4.9	6.9
CTL 2 1,250 ft	1.8	0.8	0.0	1.2	1.6	1.4	4.5	5.2	6.8	5.9
2.0 B1 Full-Depth Reclamation (No Stabilizer)	0.9	0.9	0.8	1.3	1.4	4.9	5.4	3.8	5.0	5.9
2.1 B1 Full-Depth Reclamation (8' width)	0.8	0.4	0.4	1.0	1.3	2.5	3.1	2.7	2.6	3.6
2.2 B1 Full-Depth Reclamation (8' width, repeated)	0.9	0.4	0.7	1.0	1.5	2.9	5.8	5.9	4.6	8.1

Table 9. Summary of cross slope measurements

	10/2/08		11/2/08		4/23/09	
Cross Slope Range	**# of Instances**	**%**	**# of Instances**	**%**	**# of Instances**	**%**
Less than 3%	7	38	3	15	1	5
3% to 5%	11	52	11	52	6	29
5% and above	2	10	7	33	14	67

LABORATORY TESTING

Testing of Stabilizing Agents

Following the completion of the test section program during October 2008, a new set of test sections were contemplated for the summer of 2009. Three types of stabilizers were considered, including BENEBIND, Soil-Sement, and DUSTLOCK. Laboratory testing was conducted to document the behavior of these stabilizers when applied to typical shoulder aggregate. DCP testing was conducted on the control and stabilized aggregate specimens to determine the effects of the stabilizers. Photo documentation was carried out for every step of the procedure.

Mass Loss and Photo Document Conditions of the Stabilizers

The stabilizer samples, including BENEBIND, Soil-Sement, and DUSTLOCK, were collected into evaporating pans and maintained at room temperature for two days (see Figures 23 and 24).

Figure 23. Initial conditions of: a) BENEBIND, b) DUSTLOCK, and c) Soil-Sement

Figure 24. After two days: a) BENEBIND, b) DUSTLOCK, and c) Soil-Sement

The samples were weighed to determine their mass losses (See Table 10).

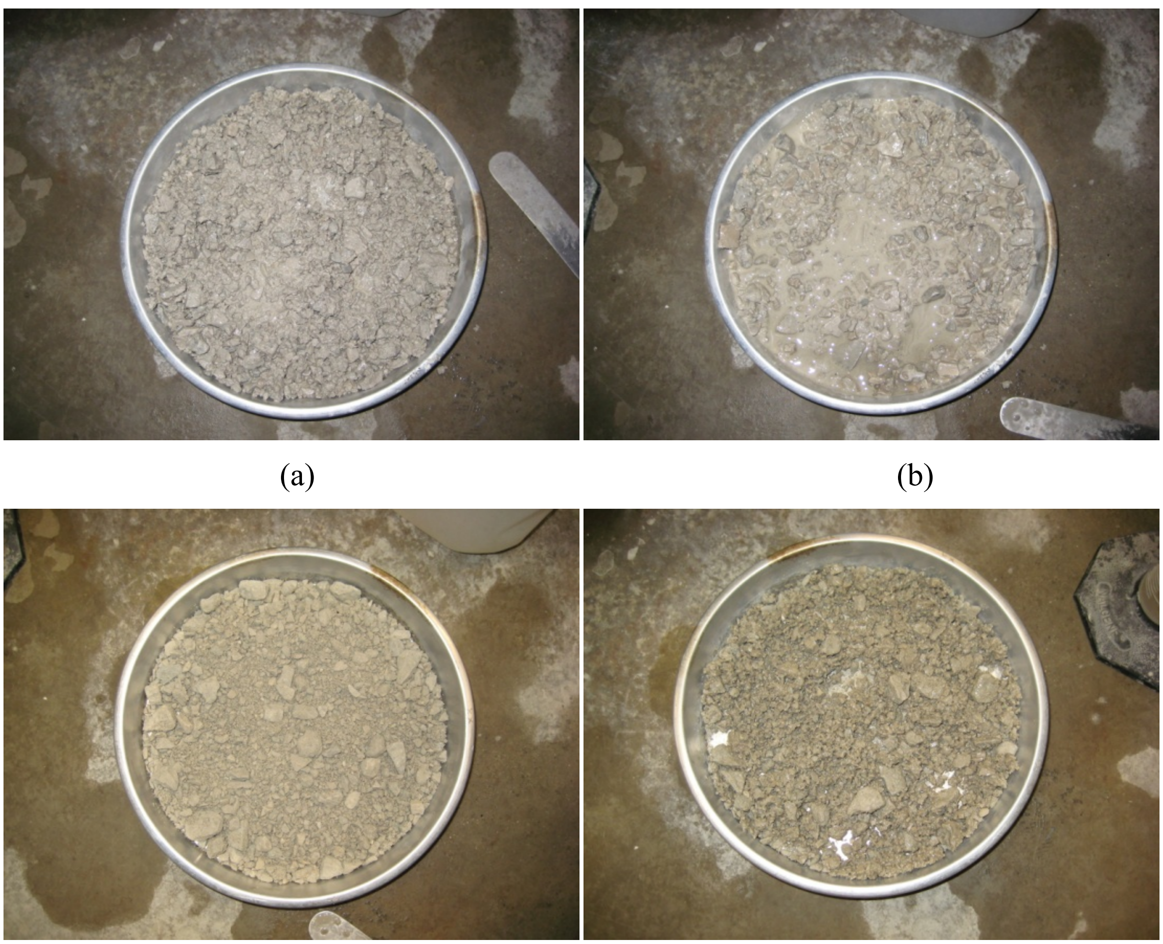
Table 10. Mass loss of samples after two days in laboratory conditions

Stabilizing Agent	Mass of Pan (g)[1]	Initial Mass of Pan + Stabilizer (g)[2]	Mass of Pan + Stabilizer After 2 Days (g)[3]	Percent Loss* (%)
BENEBIND	16.93	69.53	56.02	25.7
DUSTLOCK	97.95	247.24	217.00	20.3
Soil-Sement	15.21	35.88	23.79	58.5

* Percent Loss = ((2 – 3)/(2 – 1))

Mixing Stabilizers and Aggregate (1 to 2 inches depth)

These tests were conducted with small specimens of stabilizing agent and aggregate without a measured application rate. The purpose was to allow the research team to become familiar with the stabilizers and the behaviors of the stabilized aggregate.



(a) (b) (c) (d)

Figure 25. a) Wet aggregate, b) wet aggregate with DustGard, c) moist aggregate, and d) moist aggregate with DustGard

Note: The mixture of moist aggregate and DustGard is slightly sticky. Moisture content of the aggregates strongly affected the dilution rate of the stabilizing agent, resulting in mixtures that behave differently.

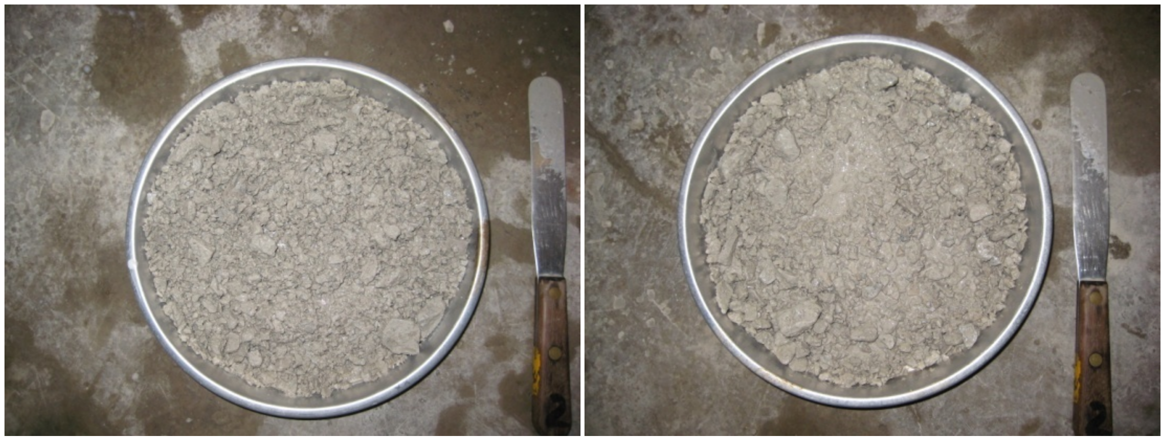
(a) (b)

Figure 26. a) Mixture of aggregate and Soil-Sement and b) Mixture of aggregate and diluted Soil-Sement

Note: The mixture of moist aggregate and Soil-Sement is slightly sticky.

Figure 27. Mixture of aggregate and diluted Base One

Note: The mixture is not sticky.



(a) (b)

Figure 28. Mixtures of: a) aggregate and Soiltac and b) aggregate and diluted Soiltac

Note: The mixtures are not sticky.

(a) (b) (c)

Figure 29. Mixtures of: a) aggregate and BENEBIND, b) aggregate and diluted BENEBIND, and c) diluted BENEBIND

Note: The aggregate is well mixed with diluted BENEBIND compared with undiluted BENEBIND. Both mixtures are very sticky.

Figure 30. Mixture of aggregate and DUSTLOCK

Note: The stabilizer was easily mixed with the aggregate. The mixture is sticky.

Preparation for a Series of Laboratory Tests

The stabilizing agents were mixed with limestone aggregate at various rates and then compacted in compaction molds to form specimens that were 12 in. (30.5 cm) in diameter and 9 in. (22.9 cm) thick. The specimens were cured in either outdoor air or laboratory conditions and then tested using a DCP. DCP profiles obtained from the specimens were analyzed and used to compare the effects of stabilizing agents on the stabilized specimens.

Test Series Equipment List

- Air compressor
- Air compactor
- Compaction molds (7)
- Aggregate mixer
- Water hose
- Extension cables (2)
- Scoops (2)
- Tape measure
- Stopwatch
- Drop hammer (reserved)
- Shovels (1 big, 1 small)
- Camera
- Cloth
- Scale
- DCP

Testing Procedure

- The compaction molds were marked on the inner surface at every 3 in. level.
- One compaction mold was used to compact the un-stabilized aggregate specimen (for the control specimen).
- Six compaction molds were used for six mixtures of stabilized aggregate.
- In each mold, the aggregate was compacted into three layers, 3 in. per layer. The specimen height is 9 in.
- Compaction duration is 30 seconds per layer.
- The mixer was washed and cleaned with a cloth when stabilizing agents were changed.
- Photos were taken to document every step of the process.
- DCP tests were conducted on the specimens after seven days (ASTM D 6951-03). The preference was for one DCP test per specimen. Additional DCP tests on one specimen were avoided, because the specimen may have been disturbed by the first DCP test.

Table 11. Compacted volume of each specimen

Specimen type	Compaction mold diameter (cm)	Area (cm2)	Thickness (in.)	Thickness (cm)	Volume (cm3)	Volume (gals)
1	30.5	730.6	9	22.9	16702	4.4
2	30.5	730.6	12	30.5	22269	5.9

Amount of Aggregate per Specimen

- Eight buckets of well-graded limestone aggregate from Spangler lab were collected.
- An aggregate specimen was taken for moisture content determination (Result: 2.4%).
- Equal amounts of aggregate were used for each mold.
- One specimen was taken from each of the six different stabilizing agents and placed in a separate container.
- For each specimen, the aggregate was equally divided into three buckets. Each bucket contained 26 lbs of moist aggregate (2.4% moisture content).
- The stabilizing agent (either full-strength or diluted) was equally divided into three containers.
- For each specimen, three batches of stabilized aggregate were mixed to provide material for three compacted layers. Each batch used one bucket of moist aggregate (26 lbs) and one container of stabilizing agent.

Table 12. Summary of aggregate amount for each specimen

Number of compacted layers	3
Weight of moist crushed limestone for each layer (lbs)	26
Moisture content (%)	2.4
Total weight of moist aggregate (lbs)	78

Since the height of the compaction mold was 12 in., the researchers decided to compact the aggregate to a height of 9 in. to allow for some freeboard. The characteristics of a compacted specimen were used to calculate for moisture content at 100% saturation (See Table 13).

Table 13. Moisture content at 100% saturation

Parameter	In SI units	In English units
Diameter, d (cm) or (in.)	30.5	12
Area, A (cm^2) or (ft^2)	730.6	0.79
Height, h (cm) or (in.)	17.5	6.9
Volume, V (cm^3) or (ft^3)	12786	0.452
Weight of moist specimen, W (kg) or (lb)	26.3	58.0
Moisture content (%)	2.1	2.1
Weight of dry specimen, Ws (kg) or (lb)	25.8	56.8
Specific gravity	2.72	2.72
Volume of solid, Vs (cm^3) or (ft^3)	9548	0.337
Volume of void, Vv (cm^3) or (ft^3)	3240	0.114
Weight of water at 100% saturation, Ww100% (kg) or (lb)	3.2	7.1
Volume of water at 100% saturation, Vw100% (cm3) or (ft3)	3240	0.114
Moisture content at 100% saturation, w100% (%)	12.6	12.6

The amount of water in a 9 in. high specimen is summarized in Table 14.

Table 14. Volume of water existing in the moist aggregates for a 9 in. height specimen

Parameter	In SI unit	In English unit
Diameter, d (cm) or (in.)	30.5	12
Area, A (cm^2) or (ft^2)	730.6	0.79
Height, h (cm) or (in.)	22.9	9
Volume, V (cm^3) or (ft^3)	16702	0.589
Weight of moist specimen, W (kg) or (lb)	35.4	78.0
Moisture content (%)	2.4	2.4
Weight of dry specimen, W_s (kg) or (lb)	34.6	76.2
Specific gravity	2.72	2.72
Volume of solid, V_s (cm^3) or (ft^3)	12802	0.452
Volume of void, V_v (cm^3) or (ft^3)	3878	0.137
Volume of water in the aggregates with a moisture content of 2.4%, V_w (cm^3) or (ft^3)	829	0.029
Volume of water at moisture of 3%, V_{w}_3% (cm^3) or (ft^3)	1037	0.037

First Series of Stabilizing Agent Tests

Stabilizing Agents

Six stabilizing agents were tested:

- Base One
- BENEBIND
- DUSTLOCK
- Soil-Sement
- Soiltac
- Magnesium chloride (DustGard)

Summary of Stabilizing Agent Application

Among the stabilizing agents for this series of testing, the application rates specified by the manufacturers are normally stated in terms of the stabilizing agent volume (either diluted or full strength) per a unit area on the applied surface. Aggregate layers are usually stabilized by topical application of the stabilizing agent. Base One was the only stabilizing agent that gave application rate in terms of aggregate volume.

The research team intended to use the generally recommended rates provided by the manufacturers for this series of tests. When the manufacturer's rate was expressed in terms of unit area, a volumetric rate was calculated assuming that the topically-applied material penetrated to a depth of 6 in. Table 15 summarizes the amount of stabilizing agent and water used to prepare the specimens.

Table 15. Summary the amount of stabilizing agents and water used for mixtures

Stabilizing agent	Undiluted rate (gal./yd^2)	Diluted rate (gal./yd^2)	Volume of stabilizing agent (ml)	Volume of water added (ml)	Note
Base One	0.005	0.455	15.3	1380	Base One:water = 1:90, rate is in gal/yd^2/in.
BENEBIND	0.5	2	256	768	Dilution rate is 1:3*
DUSTLOCK	0.5	0	256	0	
DustGard	0.45	n/a	230	337	1% water was added
Soil-Sement	0.05	0.15	268	536	Dilution rate is 1:2*
Soiltac	0.056	0.84	179	674	At 4% water, specimen is very wet

* Dilution rate expressed as stabilizing agent:water

Stabilizing Agent Application Rate Calculations

Base One

The manufacturer's recommended dilution rate for normal conditions is 55 gallons of Base One per 5000 gallons of water (so Base One:water is1:90). Application of Base One requires 0.005 gallons of undiluted agent per square yard of 1 in. deep granular material. It is important to note that the amount of dilution required varies depending on field conditions, such as moisture content, wind, and temperature.

Compaction mold surface area, A = 0.09 yd^2

Layer thickness, t = 9 in.

Amount of Base One, V_{BO} = 0.09*0.005*9 = 0.00405 gal/specimen = 15.3 cm^3/specimen

Amount of water, V_w = 90*VBO = 0.3645 gal/specimen = 1379.8 cm^3/specimen

Note: The manufacturer recommends that the material being stabilized have a binder (clay) content of 8 to 15%.

BENEBIND

The manufacturer's recommended topical application rate is 0.25 gal/yd^2 (946.35 cm^3/yd^2) of undiluted stabilizing agent. According to the product literature, the recommended dilution rate is 3:1 of BENEBIND:water. Initially, researchers calculated a possible volumetric rate for stabilizing agent addition based on the mentioned topical rate using the following procedure:

$V_{BENEBIND}$ = [946.35*0.09]*[9 in./6 in.] = 128 cm^3/specimen
V_{water} = 128/3 = 43 cm^3/specimen

However, the normal range of application rates for stabilizing agents that are mixed with 6 in. of aggregate run from 0.25 gal to 0.75 gal per yd^2. In this lab test, a target rate of 0.5 gal/yd^2 of total fluids (both BENEBIND and water) was used. A dilution rate of 1:3 (stabilizing agent/water) seemed to be more reasonable than the rate of 3:1 that was specified in the product literature. Therefore, the researchers used an actual application of $V_{BENEBIND}$ = 256 cm^3/specimen and V_{water} = 768 cm^3/specimen for the test specimen.

DUSTLOCK

The manufacturer's recommended topical application rate is 1 quart/yd^2 (0.25 gal/yd^2 or 946 cm^3/yd^2) of undiluted stabilizing agent. Since the manufacturer did not provide an application rate to be used when the DUSTLOCK is mixed into the aggregate, a target rate of 0.5 gal/yd^2 was used. As with BENEBIND, this rate was chosen because it is in the middle of the typical range for other stabilizing agents.

$V_{DUSTLOCK}$ = 2*[946*0.09]*[9 in./6 in.] = 256 cm^3/specimen

DustGard (magnesium chloride)

The manufacturer's recommended rate is 0.225 gallon/yd^2 of undiluted stabilizing agent for each of two separate applications. Thus, the total application rate is 0.45 gal/yd^2. Calculations for the specimen with an area of 0.09 yd^2 and a height of 9 in. are as follows:

$V_{DustGard}$ = [0.45*0.09]*[9 in./6 in.] = 0.06075 gal/specimen = 230 cm^3/specimen

The manufacturer recommends that the material be wetted before DustGard is applied.

Note: Since the manufacturer recommends moisturizing the aggregates before topically applying the stabilizing agent, diluting the stabilizing agent before mixing it in with the aggregate appeared to be a good practice. When the researchers prepared the specimen, DustGard was diluted by the addition of water (337 cm3), which weighed 1% of the weight of the dried aggregate sample. The dilution (230+337 = 567 cm^3/specimen) was used to mix with the aggregate.

Soil-Sement

Recommended rate for a 4 to 6 in. reclaimed layer is 0.05 gallon/ft^2 of diluted Soil-Sement (so water:Soil-Sement is 2:1). The average thickness is considered to be 6 in. For a specimen of 0.786 ft^2 (730.6 cm^2) and 9 in. thick, the volume of the diluted Soil-Sement should be:

$V_{dilution}$ = [0.05*0.786/5 in.]*9 in. = 0.0707 gal/specimen = 267.6 cm^3/specimen
$V_{Soil\text{-}Sement} = V_{Dilution}/3$ = 0.0236 gal/specimen = 89.2 cm^3/specimen
$V_{water\ (total)}$ = 0.0471 gal/spec. = 178.4 cm^3/specimen

Volume of the current water with a moisture content of 2.4% is:

$V_{w\text{-}current}$ = [76 lbs – 74.2 lbs]/62.4 = 0.0289 ft^3 = 815.3 cm^3

Note: To follow the manufacturer's recommendations, the researchers must use 0.05 gal/ft^2 = 267.6 cm^3 of Soil-Sement per specimen, not 267.6 cm^3 of diluted Soil-Sement. The target value for total water is $V_{water\ total}$= 535.2 cm^3/specimen. Therefore, to prepare the specimen properly, the total volume of the diluted Soil-Sement that should be used for one specimen is $V_{dilution}$ = 268 + 535 = 803 cm^3. However, the total amount of water in the specimen should not be in excess of the optimum moisture content of the aggregate, which is about 4%. The volume of water at 4% moisture content is:

$V_{w\text{-}4\%}$ = [815.3 cm^3 / 2.4]*4 = 1358 cm^3

Since the volume of water already in the aggregate is 815 cm^3 and the amount of stabilizing agent is 268 cm^3, the amount of water to add to the mixture is

$V_{w\text{-}addition}$ = 1358 – (815 + 268) = 275 cm^3

Soiltac

The manufacturer's recommended topical rate is 0.056 gal/yd^2 of undiluted stabilizing agent, or 0.84 gal/yd^2 of diluted agent. The dilution rate is for water:Soiltac is 14:1.

According to the manufacturer's product literature, Soiltac may be topically applied, mixed in with a reclaimer, or applied using a combination of these two methods. The manufacturer reports that the resulting penetration depth is 1/8 to 2 in. (0.3 to 5 cm) if the product is topically applied. If Soiltac is mixed in with a reclaimer, an application rate of 0.360 gals per square yard of undiluted concentrate is recommended. To calculate the amount of water required for dilution, it is necessary to find the amount of water necessary to achieve optimum moisture by conducting a proctor test (ASTM D 2216-92). The amount of dilution water is then adjusted so that the addition of diluted Soiltac will produce a mixture at the optimum moisture content.

For this test of a 9 in. thick specimen, the amount of Soiltac calculates as:

Area of the specimen: $A = 730.6\ cm^2 = 0.0874\ yd^2$

Total Volume, $V = 16701.9\ cm^3 = 4.4$ gal

Volume of undiluted Soiltac,

V_{ud} = [0.0874*0.36/6 in.]*9 in. = 0.0472 gal = 178.7 cm^3/specimen

Assume that the optimum moisture content is, $w_{opt} = 4\%$

Weight of aggregate in the specimen, $W_s = 74.2$ lbs

Weight of water at the optimum moisture content, $W_{opt} = 0.04*74.2 = 2.97$ lbs

Given that the current moisture content is 2.4%, the amount of water to be added is:

$W_{adding\ W} = 0.016 * 74.2 = 1.19$ lbs
$V_{adding\ W} = 1.19/62.4 = 0.019\ ft^3 = 0.142$ gal = 538 cm^3/specimen

Note: In the process of preparing the specimen, an amount of water equal to 2% moisture content of the specimen was added to the Soiltac to make up a volume of diluted Soiltac = 179+538+136 = 853 cm^3 diluted Soiltac. The aggregate had a moisture content of 2%. Thus, target total volume of fluids for the mixture was 1348 cm^3 to provide a 4% moisture content. During compaction of the specimen, the researchers observed that the specimen was saturated after compaction at this moisture content (4%). As a result, the diluted stabilizing agent seeped out of the bottom of the specimen during the compaction process.

Specimen Preparation and Compaction

Each specimen was prepared in one metal compaction mold. The mold had a diameter of 12 in. (30.5 cm) and a height of 12 in. (30.5 cm) (See Figure 31). The tabs were not large enough area or thickness so that the researchers could keep their feet sufficiently far away from the mold in case the compactor jumped out of the mold. However, this problem was later resolved by placing two 2x4 in. (5x10 cm) beams, 4 ft (122 cm) long, over the tabs that the researchers could stand on. The compactor was also kept inside the mold by placing a 2 ft (61 cm) high wooden frame around the mold (See Figure 32).

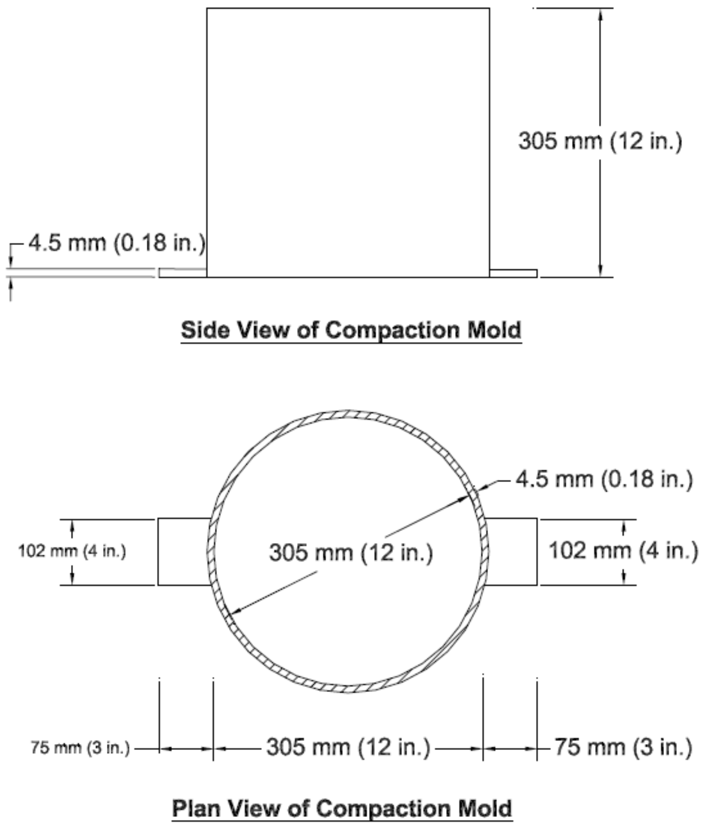


Figure 31. Elevation and plan views of compaction mold

Figure 32. Wooden frame to protect the compactor from jumping out of compaction mold

Each specimen was compacted into three layers. Each layer was 3 in. (7.62 cm) thick.

An electric mixer was used to mix the aggregate and stabilizing agent (See Figure 33). The mixer had a volume of 0.78 ft^3 (22,122 cm^3) and was capable of mixing up to 25 ft^3 (7000 cm^3) of aggregate. Each of three batches of aggregate and stabilizing agent (corresponding to each of the three layers) was mixed separately.

Figure 33. Preparation of one batch of aggregate/stabilizing agent mixture

Each layer was compacted using an air compactor (See Figure 34a). Air pressure was set at 551.6 kPa (80 psi) for the compactor. The duration of the compaction was set at 30 seconds. This procedure was used for the first (lower) and second (middle) lifts. The third (upper) lift was first compacted with the air compactor for 15 seconds. Then compaction continued with 50 blows of a Marshall hammer (See Figure 34b).

This hammer had a total weight of 16.9 lbs (7.7 kg) and the drop weight of 7.3 lbs (3.3 kg). The drop height of the hammer was 18.1 in. (0.46 m). The Marshall hammer was used to compact the area near the wall of the mold, where the air compactor could not reach. Another period of 15 seconds of air compaction was then applied to the third lift to provide a total of 30 seconds of air compaction per layer. Finally, the Marshall hammer was used to apply another 25 blows to finish the surface of the specimen.

(a) (b)

Figure 34. Specimen compaction: a) air compactor and b) surface finishing with the Marshall hammer

Following the previously outlined procedure, seven specimens were prepared. A control specimen was first prepared using moist (2.4%) aggregate. Six other specimens were prepared by using mixtures of moist aggregate and each of the six stabilizing agents (See Figure 35).

Figure 35. Specimen layout of the first testing series

The specimens were prepared in this order:

1. Base One
2. Soil-Sement
3. Soiltac
4. DustGard
5. DUSTLOCK
6. BeneBind

Strength Testing of the Specimens Using DCP Tests

DCP tests (ASTM D 6951-03) were conducted on each of the seven specimens, seven days after the specimens were prepared (See Figure 36).

Figure 36. DCP testing on dry specimens after seven days

The stabilized specimens at the time of testing were completely dry and hard to the touch. However, the control specimen was still moist to the touch. There were heavy rains during the seven-day curing period and an especially heavy rain occurred during the night before the tests were conducted. Although the specimens were completely covered, water pooled at the bottom of the control specimen may have infiltrated by suction to the top; this may be the reason for the apparent additional moisture in the control specimen. The stabilizing agents may have inhibited such suction for the stabilized specimens.

The DCPs did not seem to disturb the specimens, so the specimens were then saturated with water and kept moist for three days (See Figure 37). In addition, rainy weather during these three days ensured that the specimens remained saturated. DCP tests were conducted on the undisturbed areas of the saturated specimens.

Figure 37. Specimens are saturated and kept three days for DCP testing in saturated conditions

DCP profiles of the specimens in moist and saturated conditions are included in Appendix C. The average Dynamic Penetration Index (DPI) values obtained from DCP tests on specimens in moist and saturated conditions are summarized in Table 16.

Table 16. Average DPI values obtained from DCP testing

	Average DPI Values (mm/blow)		
Specimen	**Moist Condition[1]**	**Saturated Condition[2]**	**Ratio***
Control #1	16.8	17.5	1.0
Control #2	6.4	-	2.7**
Base One	2.8	7.3	2.6
BENEBIND	5.0	8.5	1.7
DustGard	4.4	5.1	1.2
DUSTLOCK	4.8	7.8	1.6
Soil-Sement	2.6	6.7	2.6
Soiltac	4.5	9.9	2.2

* Ratio = Saturated Condition[2]/Moist Condition[1]

** Compared with the average DPI of control specimen #1 in saturated condition

Because the control specimen #1 and other stabilized specimens were moist, their strength might have been considerably reduced. The average DPI value of the control specimen #1 was 16.8 (mm/blow). This value is low compared to the average DPI of 6.4 of the control specimen #2, which was DCP tested right after its preparation and is comparable with its average DPI of 17.5 in saturated condition.

The strength of the stabilized specimens was improved as their average DPI values in moist condition ranged from 2.6 to 5.0. The specimens using Soil-Sement and Base One stabilizing agents provided the lowest average DPI value (2.6 and 2.8). The other four specimens (using the other four stabilizing agents) had similar average DPI values (from 4.4 to 5.0).

The average DPI value of the control specimen #1 in a saturated condition was approximately similar with the average DPI in a moist condition. The average DPI values of the stabilized specimens in a saturated condition increased by 1.2 to 2.6 times, compared with those in a moist condition. The average DPI values of the stabilized specimens were equal to the range from 29% to 57% of the average DPI value of the control specimen in a saturated condition.

Second Series of Stabilizing Agent Tests

The second test series was conducted to further investigate three stabilizing agents: BENEBIND, DUSTLOCK, and Soil-Sement. Each type of stabilizing agent was used for two different specimens at different rates

For each pair of specimens, 50% more and 50% less stabilizing agent and water was used in comparison to the specimen that was compacted on June 9, 2009. If the new specimen would be saturated by the addition of stabilizing agent and water, the amount of added water was reduced to avoid saturation, while the amount of the stabilizing agent was held steady. . One control specimen was prepared using crushed limestone aggregate only and no stabilizing agent.

Application Rate of Stabilizing Agents

The specimens were allowed to cure for seven days before the first set of DCP tests for the second series was conducted in dry conditions. The specimens were then soaked and allowed to cure an additional three days and a second set of DCP tests for the second series was conducted in saturated conditions. Table 17 summarizes the amount of stabilizing agent and dilution water used.

The optimum moisture content for the crushed limestone aggregate was assumed to be 4%, corresponding with an amount of water of 1382 ml per specimen. It was noted that the amount of water existing in the moist aggregate was approximately 829 ml per specimen given that moisture content of the moist aggregate was 2.4%. The difference in these amounts was 553 ml. Therefore, the amounts of water and stabilizing agent that were specified for specimen numbers 1 and 5 were calculated so that the resulting mixtures would be at optimum conditions.

Table 17. Summary of the amount of stabilizing agent and water used for mixtures

Specimen number	Stabilizer	Topically undiluted rate (gal./yd^2)	Volume of Stabilizing agent (ml)	Volume of water (ml)	Note
1	BENEBIND	0.75	384	1152	Actual amount added was only518 ml to avoid saturation
2	BENEBIND	0.25	128	384	
3	DUSTLOCK	0.75	384	0	
4	DUSTLOCK	0.25	128	0	
5	Soil-Sement	0.075	402	804	Wet when mixed with aggregate at 3% moisture
6	Soil-Sement	0.025	134	268	

Specimen Preparation and Compaction

The specimens in this series were compacted in a manner that was similar to that of the previous specimens. Due to considerations regarding equipment availability, specimens 5 and 6 were compacted on June 29, 2009, while specimens 1 through 4 were compacted on June 30, 2009. Several adjustments were made to the compaction process:

- The moist aggregate was collected and stored for three days in plastic buckets and before the specimens were compacted.
- The buckets of aggregates were stacked into two layers so that the upper buckets were exposed to more sunlight then the lower buckets. This resulted in more moisture loss from the upper buckets.
- Researchers estimate that the moisture content of the aggregate in the upper and lower buckets were approximately 2% and 3%, respectively. However, this was not confirmed by testing.
- The third layer of +50% Soil-Sement was completely saturated and too wet for compaction. Therefore, this specimen was fabricated with only two layers (resulting in an approximate 5 in. total height). The aggregate in the two remaining layers appeared to the researchers to be noticeably wetter than the aggregate in the other specimens.
- The +50% Soil-Sement specimen was not fully dry after seven days. It was noted that the first four days after the specimens were compacted were sunny and hot. The following two days were partly rainy; however, the specimens were completely covered during the rain. The day on which the DCP testing was conducted was partly sunny.
- Another DCP test was conducted on the +50% Soil-Sement specimen on the eighth day. The purpose was to see if one more day in dry conditions would improve the stability of the specimen.

Figure 38. Specimen layout of the second testing series

Strength Testing of the Specimens Using DCP Tests

All of the specimens except for specimen 5 were dry after seven days of curing. During the curing period, the first four days after specimen compaction were sunny with high temperatures. The two following days were partly rainy, but the specimens were well covered. The last day was hot and partly sunny. Since specimen 5 was still moist after seven days of curing, two DCP tests were conducted on this specimen on days 7 and 8. Its surface on the eighth day was dry. DCP profiles of the specimens in dry and saturated conditions are shown in Appendix C.

The average DPI values obtained from DCP tests on dry and saturated specimens are summarized in Table 18. The average DPI values of the control specimen in dry and saturated conditions were 4.7 and 11.9, respectively. The average DPI values of the stabilized specimens in dry conditions were 1.8 to 4.2, depending on the type and rate of the stabilizing agents. These DPI values were from 4.6 to 7.8 in saturated conditions and were in a range from 1.4 to 3.3 times of those for dry conditions.

The stabilized specimens using 50% more stabilizing agent generally had lower average values of DPI than those of the specimens that used 50% less of the stabilizing agents. However, the average DPI value of the -50% Soil-Sement specimen was lower than that of the +50% Soil-Sement specimen. This could be explained because the +50% Soil-Sement specimen had a total fluid content that was above optimum moisture content for that specimen, resulting in less effectiveness in compaction and a higher void ratio.

Table 18. Average DPI values obtained from DCP testing

Specimen	Average DPI Values (mm/blow)		
	Dry Condition[1]	Saturated Condition[2]	Ratio*
Control	4.7	11.9	2.5
BENEBIND (+50%)	1.8	6.0	3.3
BENEBIND (-50%)	3.2	4.7	1.5
DUSTLOCK (+50%)	3.0	4.6	1.5
DUSTLOCK (-50%)	4.2	7.8	1.9
Soil-Sement (+50%)**	4.3	6.2	1.4
Soil-Sement (+50%)	3.8	6.2	1.6
Soil-Sement (-50%)	2.6	5.0	1.9

* Ratio = Saturated Condition[2]/Dry Condition[1]

** The specimen was not fully dry after seven days of curing

Third Series of Stabilizing Agent Tests

The third testing series was conducted on one stabilizing agent, DUSTLOCK, at various application rates. Seven compacted specimens were prepared in laboratory conditions including one control specimen, one specimen at target rate, and five other stabilized specimens using +15%, +30%, +50%, -15%, and -30% target rates.

Application Rates of the Stabilizing Agent

Crushed limestone aggregate material with a moisture content of 2.2% was used to prepare the specimens. Table 19 summarizes the application rates. The control specimen was prepared using only crushed limestone aggregate.

Table 19. Summary the amounts of the stabilizing agent DUSTLOCK used for mixtures

Specimen Number	Percent Added Compared with Target Rate	Topically Undiluted Rate (gal./yd^2)	Volume of Stabilizing Agent per Specimen (ml)
1	Target amount	0.50	256.0
2	+15%	0.575	294.4
3	+30%	0.65	332.8
4	+50%	0.75	384.0
5	-15%	0.425	217.6
6	-30%	0.35	179.2

The specimens were allowed to cure for six days before the first set of DCP tests was conducted in dry conditions in the laboratory on July 27, 2009 (See Figure 39).

Figure 39. Specimen layout of the third series of tests

Strength Testing of the Specimens Using DCP Tests

The specimens were cured in the laboratory for six days. DCP testing was then conducted on the dry specimens on the sixth day. The average DPI values of the DCP profiles of the specimens are summarized in Table 20.

DCP test results showed that the stiffness of the stabilized significantly increased after curing for 17 days. DPI values obtained from the tests after 17 days were about 10 to 40% of the DPI values obtained from the DCP tests at day 6th. DCP result of the second test on the control sample indicated that its stiffness decreased with time. However, it was not necessarily the case because the first DCP test on the control sample had reduced the stiffness of the specimen. The control specimen had been already disturbed by the first DCP test. This also indicated that the stabilizing agents not only well prevented the specimens from disturbing by the first series of DCP tests, but also increased stiffness of the specimens.

Table 20. Average DPI values obtained from DCP testing on dry specimens

Specimen	Average DPI Values (mm/blow)		
	Dry Condition (6 days)[1]	Dry Condition (17 days)[2]	Ratio*
Control	3.8	5.5	1.4
DUSTLOCK (target rate)	2.8	1.1	0.4
DUSTLOCK (+15%)	2.9	0.3	0.1
DUSTLOCK (+30%)	3.5	0.2	0.1
DUSTLOCK (+50%)	3.3	0.2	0.1
DUSTLOCK (-15%)	3.1	0.2	0.1
DUSTLOCK (-30%)	3.2	0.3	0.1

* Ratio = 17 day Dry Condition[2]/6 day Dry Condition[1]

FIELD INVESTIGATION ON US 75 NORTH OF SIOUX CENTER, IOWA

Introduction

US 75 near Sioux Center is a two-lane highway with high volume traffic. The Average Daily Traffic (ADT) volume is 6,800 vehicles, which includes 812 trucks and buses (2002 Volume of Traffic on the Primary Road System of Iowa at http://www.iowadotmaps.com/). The granular shoulders of this highway quickly develop edge ruts and were a selected test location for edge-rut mitigation strategies. Test sections were constructed on the southbound shoulder of the highway using DUSTLOCK, a soybean oil-based dust suppressant.

Staging Test Strips

Construction of the test sections were preceded by the construction of a series of staging test strips using the same stabilizing agent off the highway in a stockpile area near Hull, Iowa on July 29, 2009 (See Figure 40). Each staging test strip was constructed using a varied application rate and various construction procedures. The most suitable application rates and construction procedures were then applied to the field investigation test sections.

The five staging test strips had dimensions that ranged from 75 ft (22.9 m) to 85 ft (25.9 m) long and were 3.5 ft (1.1 m) wide (See Figure 41). The grain size distribution of the aggregate material of the ground surface is shown in Figure 42. According to the Unified Soil Classification System (USCS), the aggregate sample was classified as GP – poorly graded gravel.

Figure 40. Staging test strips near Hull, Iowa (Aerial photo from Yahoo! Maps)

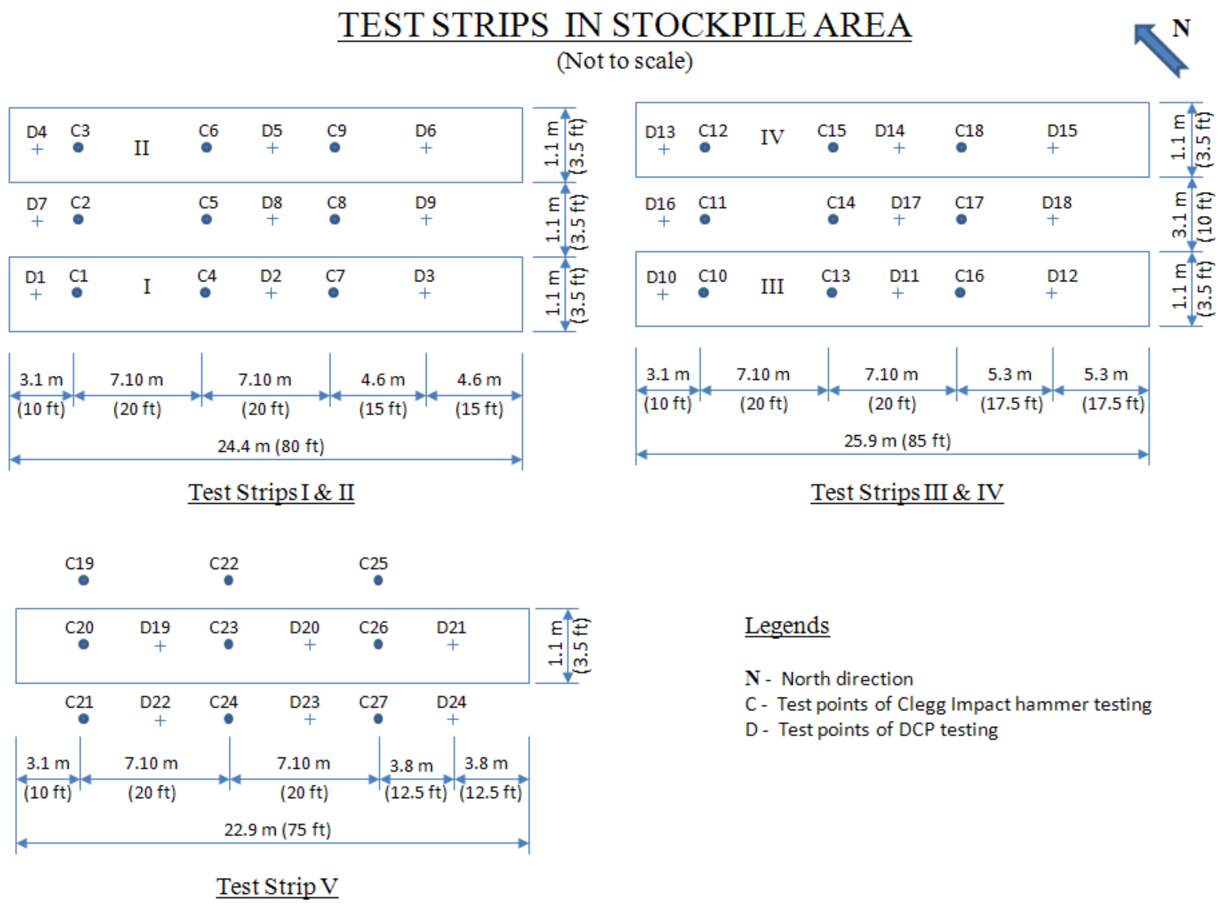


Figure 41. Staging test strips in stockpile area near Hull, Iowa

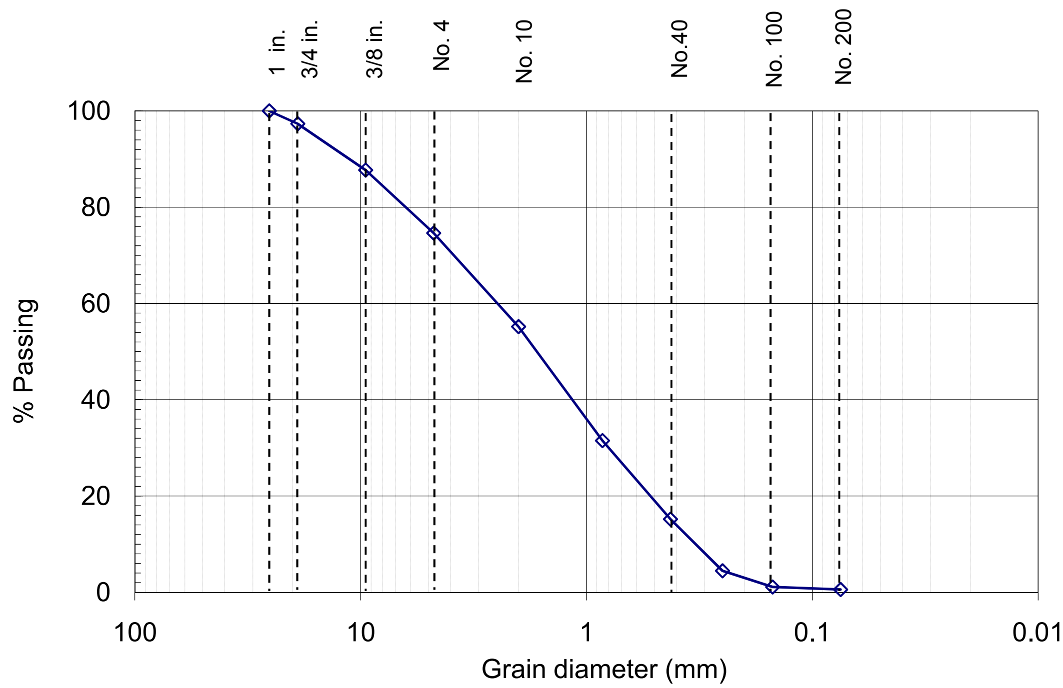


Figure 42. Grain size distribution of aggregates from the stockpile near Hull, Iowa

The construction procedures used to stabilize staging test strips 1 through 5, are described below.

1. Procedure for Staging Test Strip 1

- The aggregate material is scarified to a depth of 2 in. (50 mm) (See Figure 43).
- The stabilizing agent (DUSTLOCK) is sprayed at the rate of .75 gal/yd^2 (4527 ml/m^2) for the first time (See Figure 44).
- The scarified aggregate material is mixed with the stabilizing agent for the first time (See Figure 45).
- The stabilizing agent (DUSTLOCK) is sprayed at the rate of .75 gal/yd^2 (4527 ml/m^2) for the second time.
- The scarified aggregate material is mixed with the stabilizing agent for the second time.
- Sand is broadcast on the test strip (See Figure 46).
- The material is compacted using a smooth drum roller (See Figure 47).

Figure 43. Scarifying ground surface using a milling machine

Figure 44. Spraying of the stabilizing agent on the scarified surface

Figure 45. Mixing aggregate material with the stabilizing agent

Figure 46. Sand broadcasting

Figure 47. Compaction using a smooth roller

2. Procedure for Staging Test Strip 2

- The aggregate material is scarified to a depth of 2 in. (50 mm) (See Figure 43).
- Water is sprayed over the scarified aggregate material. The rate of water application was estimated at .75 gal/yd^2 (4527 ml/m^2).
- The scarified aggregate material is mixed with the sprayed water using a milling machine.
- The stabilizing agent (DUSTLOCK) is sprayed at the rate of .75 gal/yd^2 (4527 ml/m^2) (See Figure 44).
- The scarified aggregate material is mixed with the stabilizing agent (See Figure 45).
- Sand is broadcast on the test strip (See Figure 46).
- The material is compacted using a smooth drum roller (See Figure 47).

3. Procedure for Staging Test Strip 3

- The aggregate material is scarified to a depth of 2 in. (50 mm) (See Figure 43).
- Water is sprayed over the scarified aggregate material. The rate of water application was estimated at .75 gal/yd$^{2\,(}$4527 ml/m^2).
- The scarified aggregate material is mixed with the sprayed water using a milling machine.
- The material is compacted using a smooth drum roller. The material is compacted

using the dual rear wheels of a truck. The stabilizing agent (DUSTLOCK) is topically applied. The application rate was estimated at .75 gal/yd^2 (4527 ml/m^2) (See Figure 44).

- Sand is broadcast on the test strip (See Figure 46).
- The material is compacted using a smooth drum roller (See Figure 47).

4. Procedure for Staging Test Strip 4

- Water is sprayed over the unscarified aggregate material. The rate of water was estimated at .75 gal/yd^2 (4527 ml/m^2).
- The wet aggregate material is scarified to a depth of 1 in. (25 mm) (See Figure 43).
- The stabilizing agent (DUSTLOCK) is topically applied. The applied rate was estimated at .75 gal/yd^2 (4527 ml/m^2) (See Figure 44).
- Sand is broadcast on the test strip (See Figure 46).
- The material is compacted using a smooth drum roller (See Figure 47).

5. Procedure for Staging Test Strip 5

- The stabilizing agent (DUSTLOCK) is topically applied. The applied rate was estimated at .75 gal/yd^2 (4527 ml/m^2).
- Sand is broadcast on the test strip.

Construction of Test Areas and Test Results on Shoulder of Highway US 75

Test areas were constructed at three locations on the southbound shoulder of US 75 near Sioux Center, Iowa (See Figure 48).

A preconstruction field investigation indicated that the granular shoulder along US 75 in the area was rutted due to heavy traffic. Rutting usually occurred on the shoulder surface within 12 in. (300 mm) from the pavement edge to a depth of 2.54 in. (50 mm) (See Figures 49 and 50).

Test results are summarized at the end of each subsection describing construction for that Test Area. Complete test results are provided in Appendix D.

Figure 48. Test areas on southbound shoulder of US 75 near Sioux Center, Iowa (aerial photo from Yahoo! Maps)

Test Area I

Area I ranged north from milepost 139.70 to the corner of US 75 and 380th Street (See Figure 49). This area included two sections, which were constructed using different construction procedures. Section I was filled with Class A aggregate and compacted by two passes of a dump truck. Water was then sprayed on the area. The stabilizing agent (DUSTLOCK) was topically applied. The applied rate was estimated at .72 gal/ yd^2 (4346 ml/m^2). Two passes of sand were broadcast on the test section. The construction of section I was stopped at this point. Section II was stabilized using Procedure 4.

Figure 49. Shoulder condition at Test Area I before stabilization

Figure 50. Shoulder rutting at Test Area I before stabilization July 28, 2009

Cross sectional elevation profiles, DCP tests, and samples were taken from the shoulder before it was stabilized. The depth of pavement drop-off was measured as part of the process of obtaining the cross-sectional elevation profiles. Typical elevation profile of the shoulder before stabilization is shown in Figure 51.

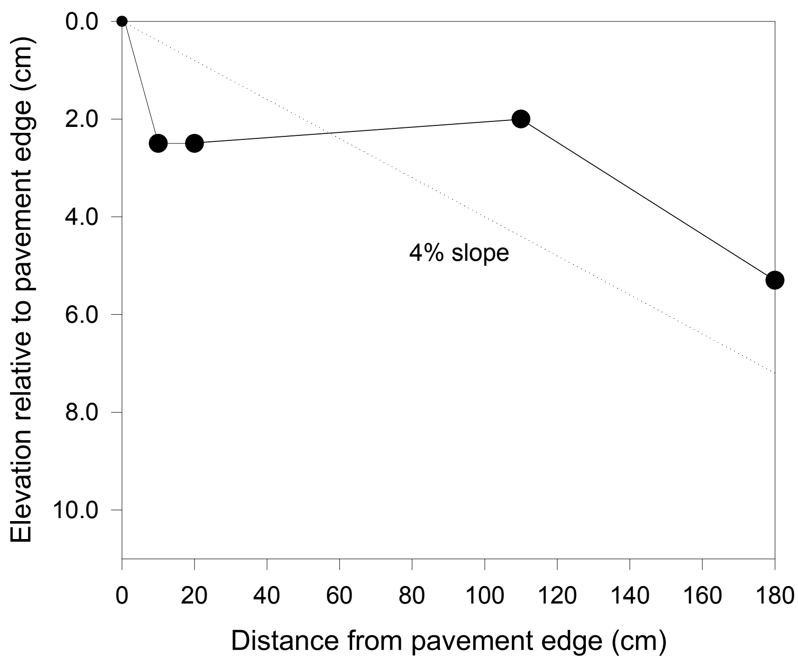


Figure 51. Typical elevation profile of shoulder in Test Area I before stabilization

Class A aggregate materials composed mainly of crushed quartzite and a small portion of recycled asphalt concrete (RAC) were used to fill the edge ruts before the stabilization process. An aggregate sample was collected from a stockpile at the Iowa DOT's garage in Rock Valley, Iowa and was classified as GW – well-graded gravel, according to the USCS. The grain size distribution of the aggregates is shown in Figure 52.

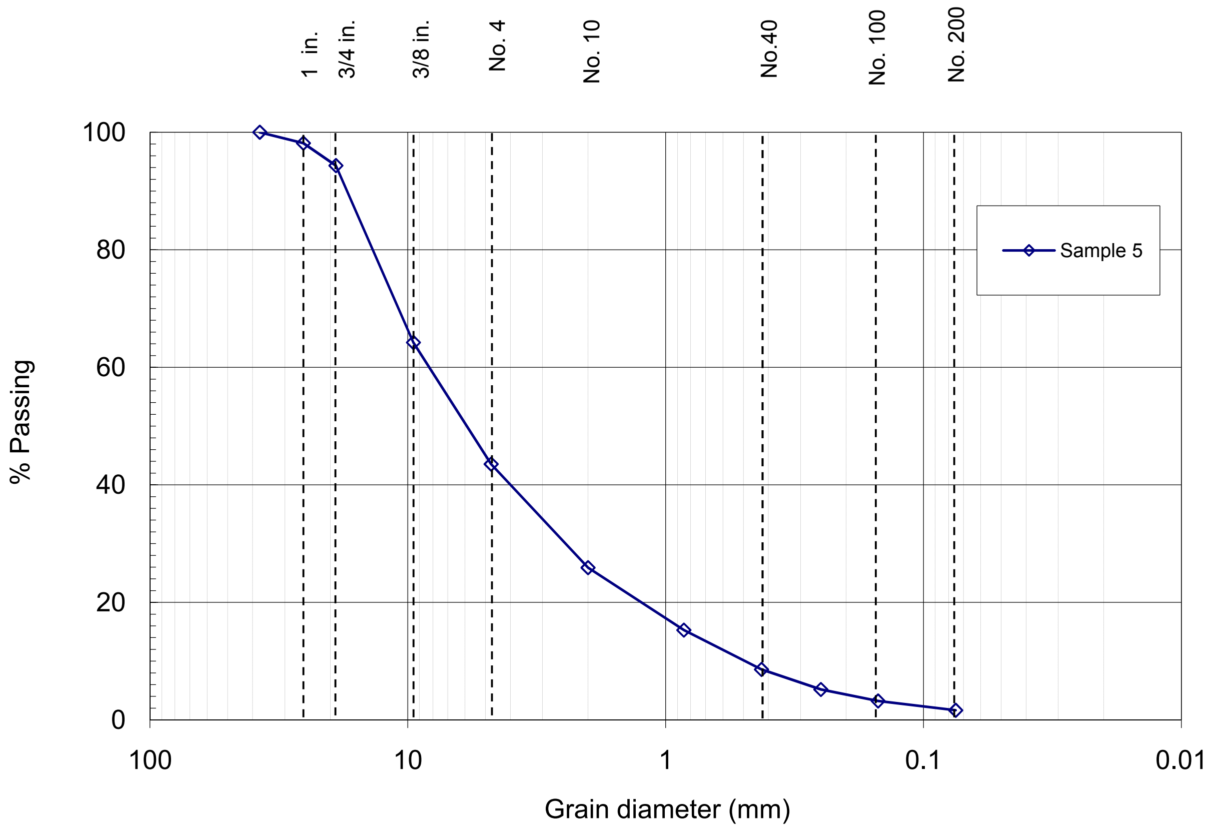


Figure 52. Grain size distribution of the RAC and crushed quartzite aggregates collected from the Iowa DOT stockpile in Rock Valley, Iowa

The stabilization process of Section I is shown in Figure 53. This test procedure followed these steps: compaction with dump truck, spraying of water, topical application of DUSTLOCK, and, finally, broadcasting of sand.

Figure 53. Stabilization procedure of Test Area I Section I on southbound shoulder of US 75 near Sioux Center, Iowa July 29, 2009

The stabilization process of Section II is shown in Figure 54. The test procedure followed these steps: compaction with dump truck, spraying of water, topical application of DUSTLOCK, broadcasting of sand, smooth drum roller compaction, truck compaction, and, finally, finishing with smooth drum roller.

Figure 54. Stabilization procedure of Test Area I Section II on southbound shoulder of US 75 near Sioux Center, Iowa July 29, 2009

Test sections and test points of Test Area I are shown in Figure 55. Tests were conducted at nine points using elevation profiles, Clegg impact hammer, and DCP. Elevation profile measurements of the stabilized shoulders at given test points were for immediately after the stabilization (August 6, 2009), about two months after the construction (October 27, 2009), and about 10 months after construction (June 8, 2010).

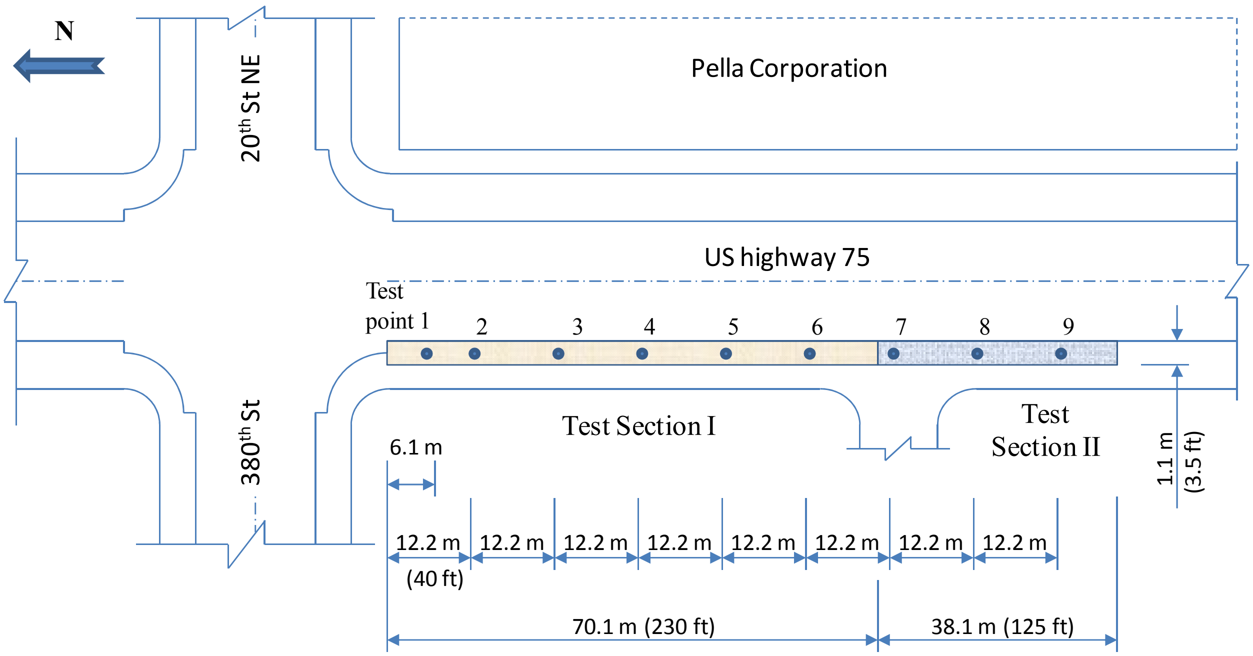


Figure 55. Test Area I on southbound shoulder of US 75 near Sioux Center, Iowa

In the elevation profile, the solid line represents the elevation of the first measurement, the dashed red line with dots at the measurement points represents the second measurement , and the dashed blue line represents the third measurement. The profiles show that the shoulder generally lost elevation after two years in service and that the edge rut had returned in places after 10 months in service (See Figures 56 and 57). Repeated trafficking was considered as the likely cause. Despite the previously mentioned damage noted on many parts of the test section (especially away from the driveway area), the stabilized shoulder material remained completely intact.

Figure 56. Looking north from Point 9 at Test Area I on southbound shoulder of US 75 near Sioux Center, Iowa June 8, 2010.

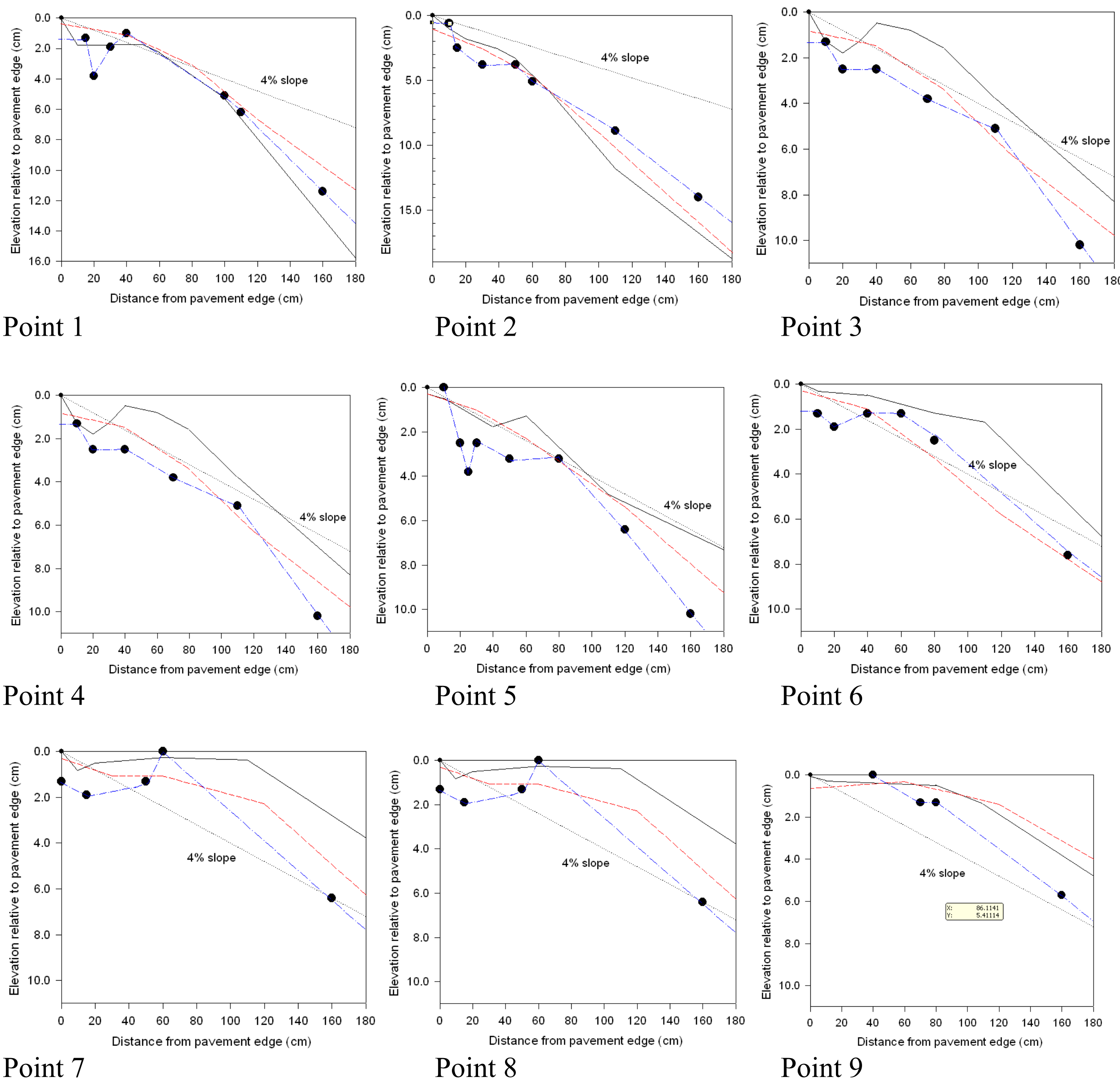


Figure 57. Test Area I on southbound shoulder of US 75 near Sioux Center, Iowa

Stiffness of the stabilized shoulder in Clegg impact value (CIV) and CBR values varying from 13.9 to 23.2 and from 18.8 to 43.1, respectively, indicated that shoulder stiffness was widely variable (See Table 21).

Table 21. CIV and CBR values for Test Area I

Test point	8/6/2009		10/27/2009		6/8/2010		
	CIV	CBR[1]	CIV	CBR	CIV	CBR[2]	Ratio*
1	N/A	N/A	N/A	N/A	9.1	10.1	N/A
2	13.9	18.8			11.0	13.2	1.4
3	19.6	32.5			10.1	11.7	2.8
4	18.3	29.1			11.1	13.4	2.2
5	23.2	43.1	N/A	N/A	9.6	10.9	4.0
6	19.6	32.5			9.4	10.6	3.1
7	20.4	34.8			11.2	13.6	2.6
8	18.5	29.6			10.7	12.7	2.3
9	18.3	29.1			10.9	13.1	2.2

* Ratio = 2/1

Test Area II

An aggregate sample was collected from the shoulder area of Test Area II. The aggregate was mechanically analyzed and classified as GP – poorly graded gravel (USCS) or A-1-a (AASHTO) (See Figure 58).

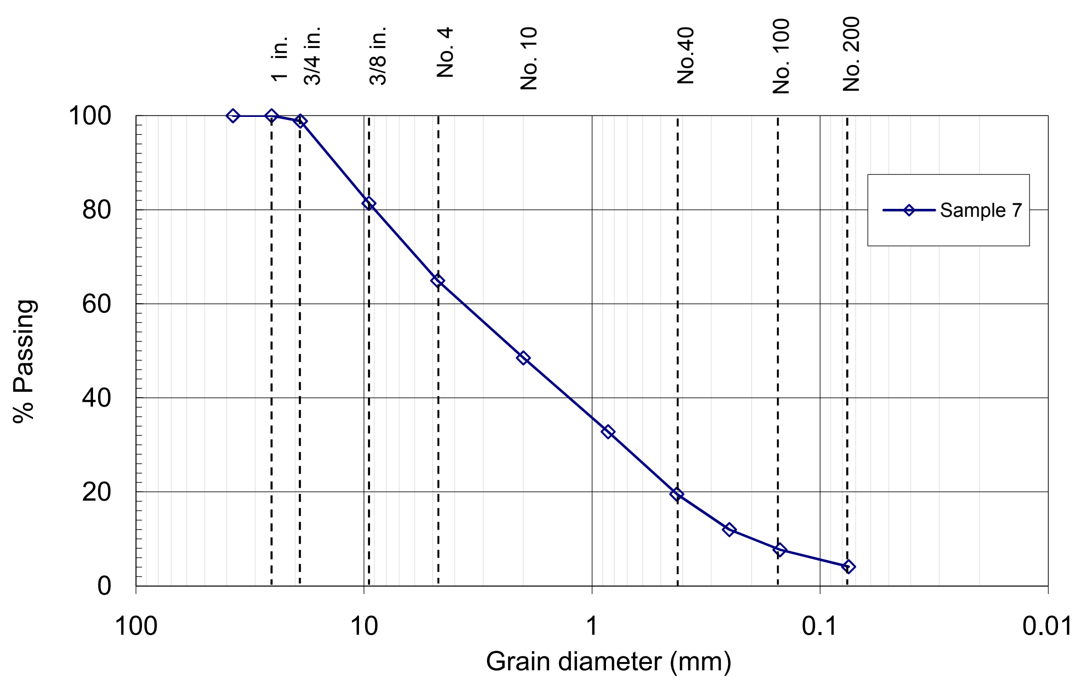


Figure 58. Grain size distribution of the RAC and crushed dolomite aggregates collected from Test Area II on southbound shoulder of US 75 near Sioux Center, Iowa

Test Area II was divided into three sections (I, II, and III) (See Figure 59). Each section was stabilized by a different procedure. Additional Class A aggregate was used to level the shoulder surface of Sections I and II. Water was then sprayed over the three sections at a rate of approximately 0.72 gal/yd^2 (See Figure 60).

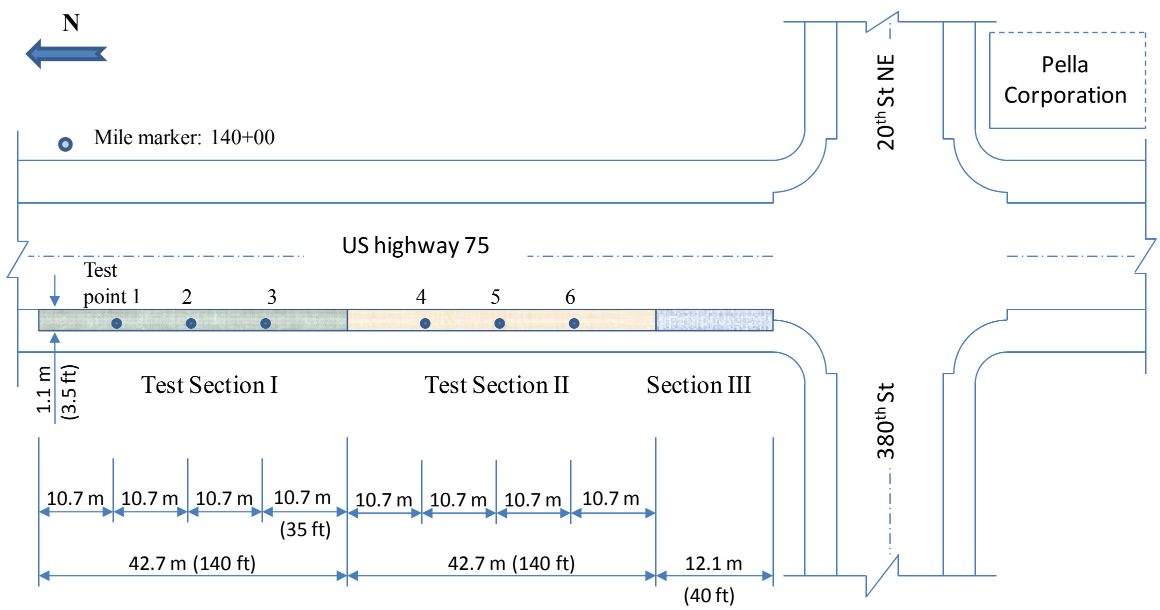
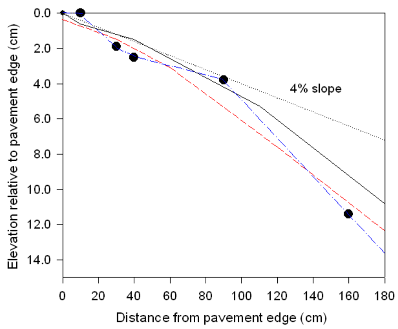


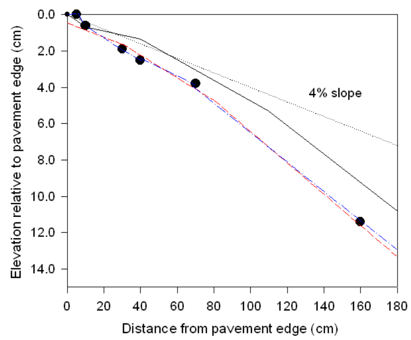
Figure 59. Test Area II on southbound shoulder of US 75 near Sioux Center, Iowa

Figure 60. Stabilization procedure of Test Area II on southbound shoulder of US 75 near Sioux Center, Iowa July 29, 2009

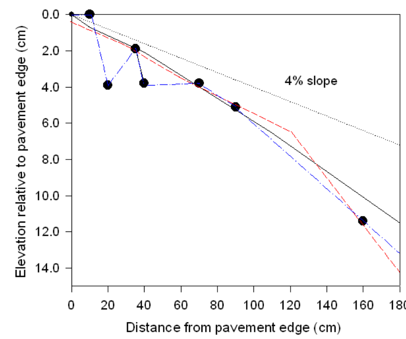
Elevation profiles of the shoulders in this test area were measured on August 6, 2009 (in solid lines), October 27, 2009 (in dashed red lines with dots showing measurement points), and June 8, 2010 (in dashed blue lined) (See Figure 61).



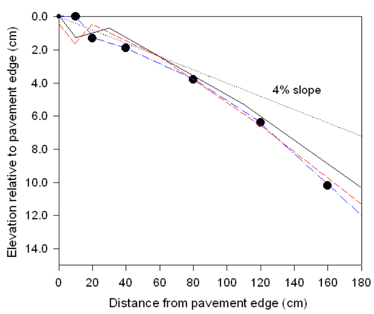
Point 1



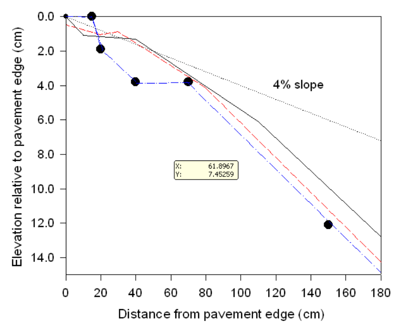
Point 2



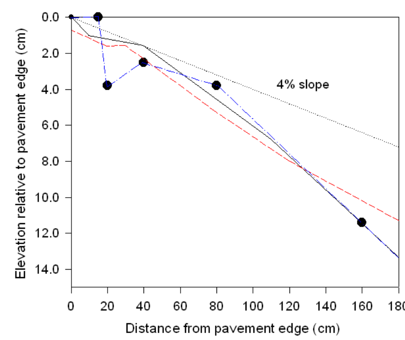
Point 3



Point 4



Point 5



Point 6

Figure 61. Elevation profiles of Test Area II on the southbound shoulder of US 75 near Sioux Center, Iowa

By October 27, 2009, some small areas of instability were evident (See Figure 62). The profiles show that shoulders generally lost elevation while in service and by June 2010 at some locations, the stabilized material had been removed from the edge of the road, resulting in small potholes (See Figure 63).

Figure 62. Stabilized shoulder surface October 27, 2009

Figure 63. Looking south at Test Area II from Test Point 2 June 8, 2010

A field investigation regarding shoulder stiffness was conducted with observations taken at the same time that elevation profiles were taken. The resulting CIV and CBR values indicated that the stiffness of the shoulder changed little with time (See Table 22). In general, the stiffness increased between the first and second readings and decreased between the second and third.

Table 22. CIV and CBR values for Test Area II

Test point	8/6/2009		10/27/2009		6/8/2010			
	CIV	CBR^1	CIV	CBR^2	CIV	CBR^3	Ratio*	Ratio**
1	16.2	23.9	15.4	22.1	10.6	12.6	0.9	0.5
2	18	28.3	17.2	26.3	13.0	17.0	0.9	0.6
3	11.6	14.3	15.7	22.7	10.3	12.1	1.6	0.8
4	9.1	10.1	11.9	14.9	6.0	6.0	1.5	0.6
5	9.5	10.8	10.3	12.1	10.3	12.1	1.1	1.1
6	12.4	15.8	12.6	16.2	9.0	10.0	1.0	0.6

* Ratio = CBR^2/CBR^1

** Ratio = CBR^3/CBR^1

Test Area III

Test Area III was divided into two sections, in which Section I was topically stabilized and Section II was stabilized using stabilization Procedure 4 (See Figure 64). Moderate rain started to fall after water was sprayed over the area, resulting in the stabilizing agent being washed away along with the sand that was to cover the DUSTLOCK (See Figure 65).

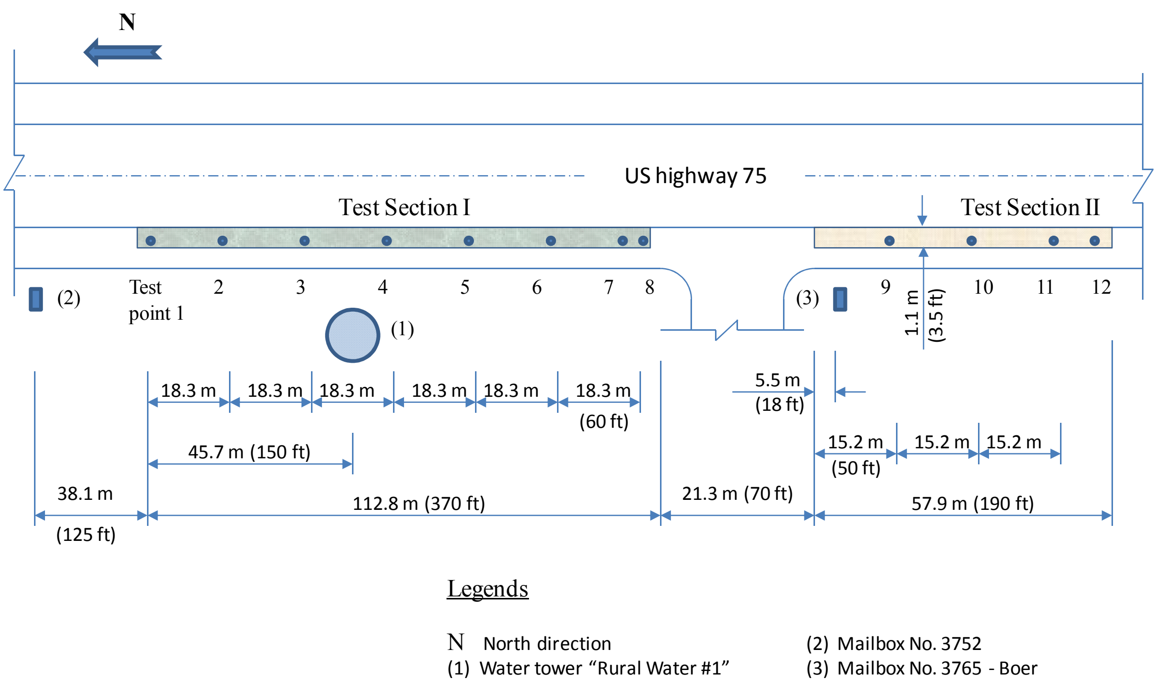


Figure 64. Test Area III on southbound shoulder of US 75 near Sioux Center, Iowa July 29, 2009

Figure 65. Stabilization procedure of Test Area III on southbound shoulder of US 75 near Sioux Center, Iowa July 29, 2009

Grain size distribution for the aggregate at Test Area 3, which was a mixture of RAP used for shoulder stabilization on US 75 southbound near Sioux Center, is shown in Figure 66. The aggregate was mechanically analyzed and classified as GW – well-graded gravel (USCS), or A-1-a (AASHTO).

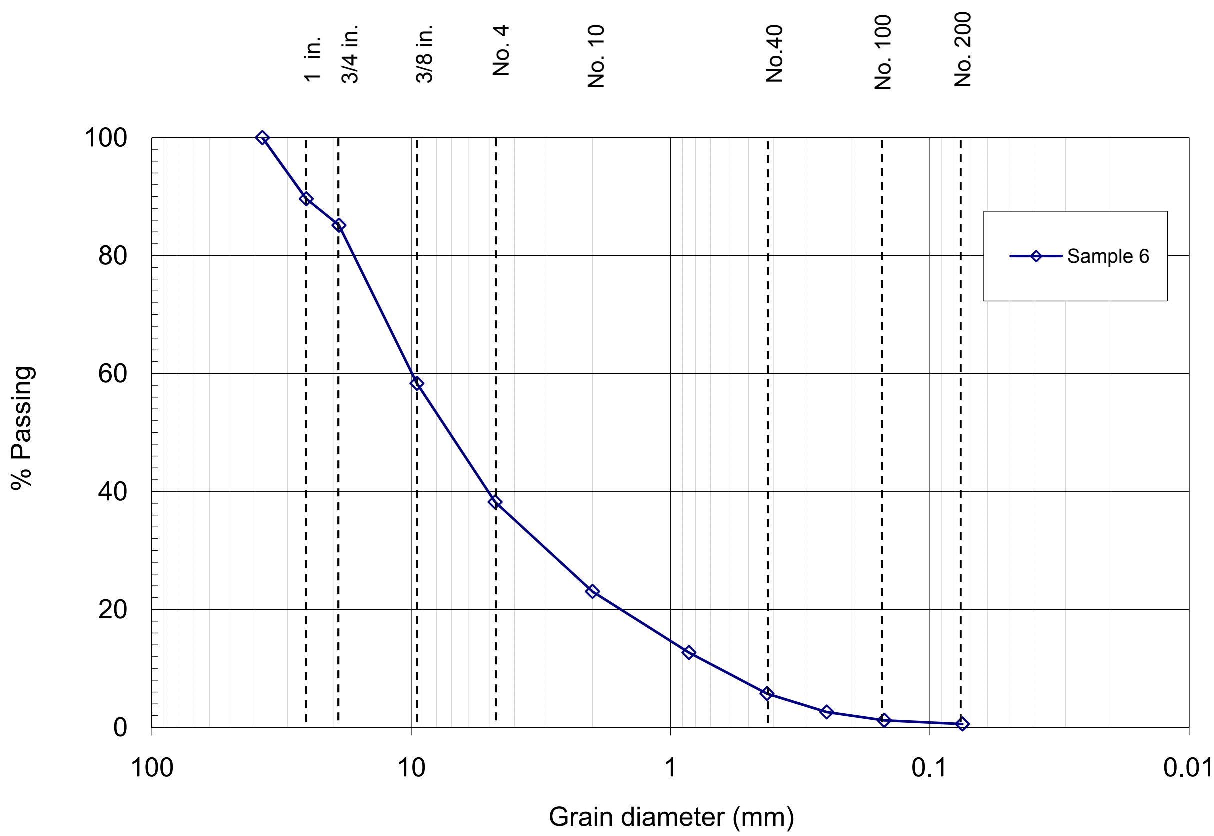
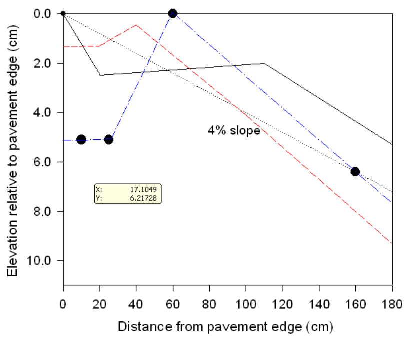


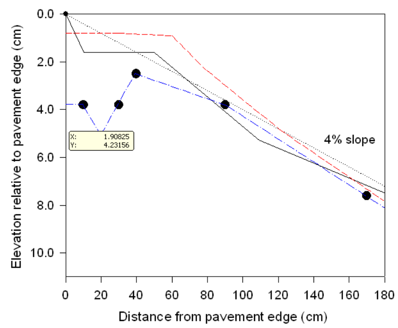
Figure 66. Grain size distribution of the RAC aggregates collected from the Iowa DOT stockpile in Rock Valley, Iowa

A post construction field investigation of the test areas on US 75 near Sioux Center was conducted August 6, 2009, October 27, 2009, and June 8, 2010. Shoulder stiffness measurements that were taken using the heavy Clegg impact hammer were tested at the assigned test points (See Figure 64). Elevation profiles were also taken; elevation profiles of the shoulder at specific test points were shown in solid lines (August 6, 2009), dashed red lines (October 27, 2009), and dashed blue lines with dots at measurement locations(June 8, 2010) (See Figure 67).

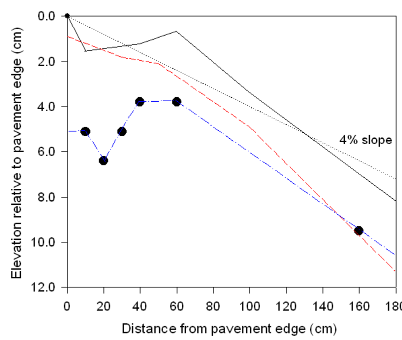
The elevation profiles showed that the elevation of the shoulder surface at the test points changed over several months. By October 2009, at some test points, the shoulder surface elevation had increased, while it decreased at the other points. The DUSTLOCK shoulder surface was observed to be damaged at several areas after about two months of construction.



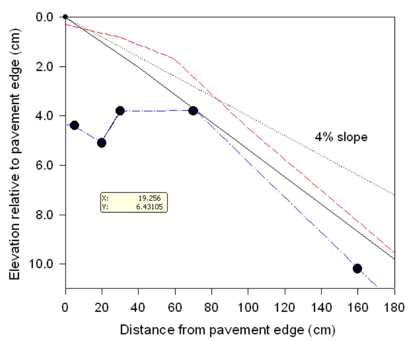
Point 1



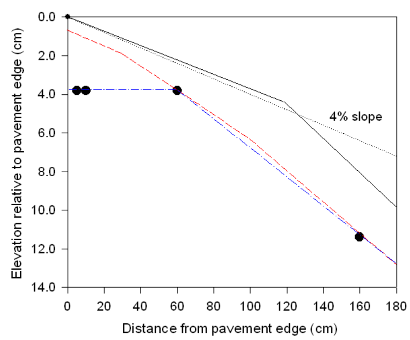
Point 2



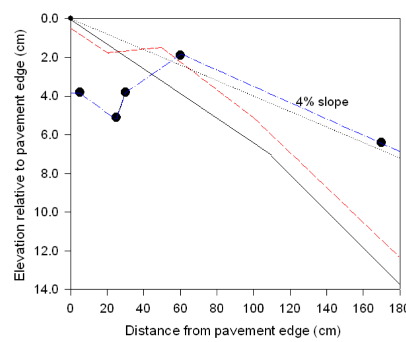
Point 3



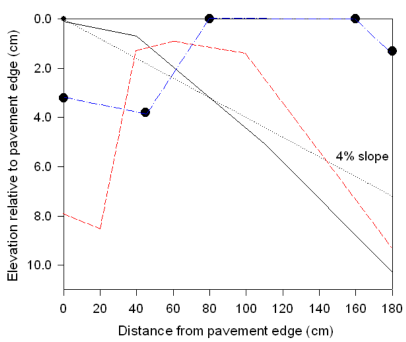
Point 4



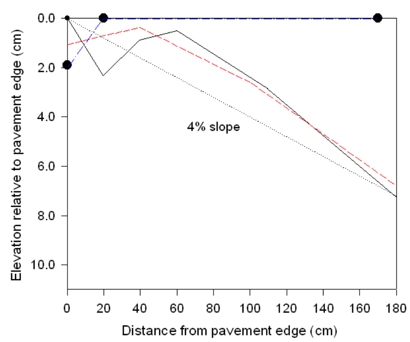
Point 5



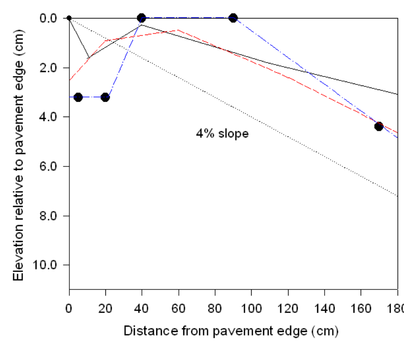
Point 6



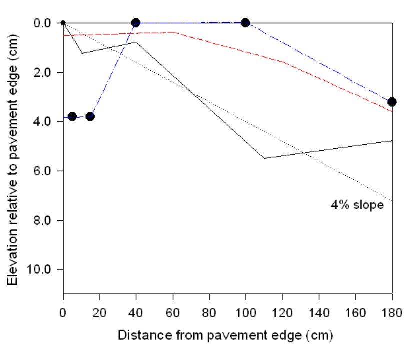
Point 7



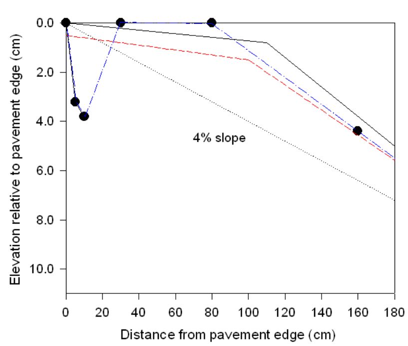
Point 8



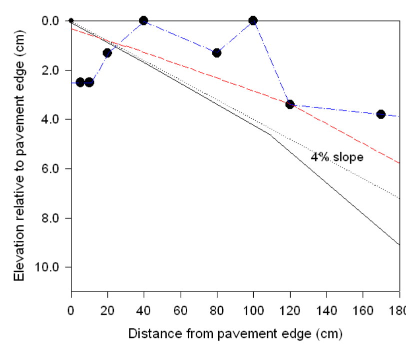
Point 9



Point 10



Point 11



Point 12

Figure 67. Elevation profiles of Test Area III on the southbound shoulder of US 75 near Sioux Center, Iowa

Figure 68. Shoulder condition of the Test Area III on the southbound shoulder of US 75 near Sioux Center, Iowa October 27, 2009

The damage was observed in particular at Test Point 7 (See Figures 67 and 68). By June 2010, the stabilized material had mostly disappeared from the entire area (See Figure 69).

Figure 69. Looking north and south from Test Point 5 Area III on June 8, 2010 (approximately the same location as the photos in Figure 68)

Results of the field tests using Clegg impact hammer tests conducted on August 6, 2009 (one week after construction), on October 27, 2009, and on June 8, 2010 showed that CIVs of the shoulder at points 2 through 4, 9, and 11 increased by from 10% to 290% (See Table 23). The CIVs at points 5 and 8 decreased by 30% and 70%. Stiffness at points 6 and 10 remained constant after about two and a half months in service. The June 8, 2010 readings were less variable and, in general, lower than the previous readings.

Table 23. CIV and CBR values for Test Area III

Test point	8/6/2009		10/27/2009		6/8/2010			
	CIV	CBR[1]	CIV	CBR[2]	CIV	CBR[3]	Ratio*	Ratio**
1	N/A	N/A	23.4	43.8	12.8	16.6	N/A	N/A
2	20.3	34.5	25.3	50.0	12.5	16.0	1.5	0.5
3	7.3	7.6	18.6	29.9	11.3	13.8	3.9	1.8
4	22.2	40.0	22.9	42.2	13.5	18.0	1.1	0.5
5	24.0	45.7	20.1	33.9	9.7	11.1	0.7	0.2
6	17.0	25.8	16.8	25.3	15.9	23.2	1.0	0.9
7	20.6	35.3	8.5	9.2	15.6	22.5	0.3	0.6
8	N/A	N/A	33.5	81.7	21.9	39.1	N/A	N/A
9	16.3	24.1	20.9	36.2	12.0	15.1	1.5	0.6
10	16.5	24.6	16.7	25.1	15.5	22.3	1.0	0.9
11	18.0	28.3	18.8	30.4	12.0	15.1	1.1	0.5
12	N/A	N/A	21.9	39.1	9.2	10.3	N/A	N/A

* Ratio = CBR^2/CBR^1

** Ratio = CBR^3/CBR^1

FIELD INVESTIGATION ON US 20 WESTBOUND NEAR JESUP, IOWA

Introduction

US 20 near Jesup, Iowa is a four-lane highway with an ADT of 9500, including 1,246 trucks and buses (2002 Volume of Traffic on the Primary Road System of Iowa). The route goes through a hilly area in Black Hawk County that borders Buchanan County. Test sections were constructed on the granular shoulder along the westbound lanes, from around milepost 245.25 to milepost 244.35 (See Figure 70).

Figure 70. Test sections (from A to B) on westbound shoulder of US 20 near Jesup, Iowa (photo courtesy of Google)

Soils within the test area are part of the Dinsdale-Klinger-Maxfield association. A sketch of typical relief and positions of soils within the association are shown in Figure 71. The test sections were on the Dinsdale silty clay loam with the topography of 2 to 5% slopes.

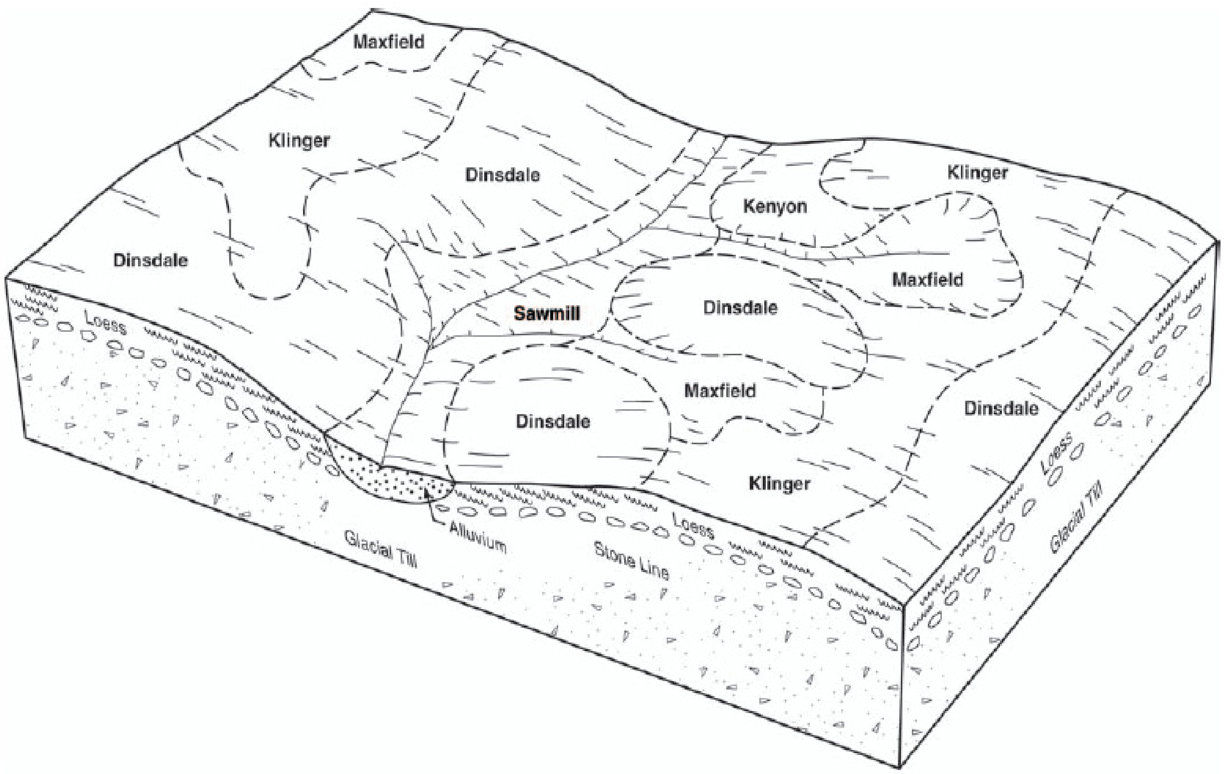


Figure 71. Typical pattern of soils and parent material in the Dinsdale-Klinger-Maxfield association (Black Hawk County, Iowa Soil Survey)

Construction of Test Sections

The granular shoulders of this highway developed edge ruts mostly from the bottom of a sag at the east end to the test area to a point midway up the crest of a hill marked by the Spring Creek Road overpass. Edge rutting was less problematic in the remaining areas. The edge rut was the deepest from mileposts 245.20 to 245.00, where the average rut width was 12 in. (300 mm), rut depth of 1.25 in. (32 mm), and bottom surface that was hardpan. The shoulder surface that was more than 12 in. (300 mm) from the pavement edge was covered with coarser floating aggregate. Fine finer particles were either eroded away or covered by the course particles (See Figure 72).

Figure 72. Shoulder conditions and edge ruts along the pavement slabs August 17, 2009

The shoulders were lightly graded on August 17, 2009 by a motor grader. This grading did little to affect the surface conditions of the granular shoulders, although it scraped loose aggregate away from hard areas that were higher than their surroundings. The edge ruts were changed little by this maintenance activity.

The test sections were constructed August 18, 2009 using DUSTLOCK. Six test sections were constructed by varying the construction procedures and application rates of the stabilizing agent and sand or existing granular shoulder material. A control section was placed at the crest of the hill, near the overpass of Spring Creek Road. The test section layout and details are shown in Figures 73 and 74.

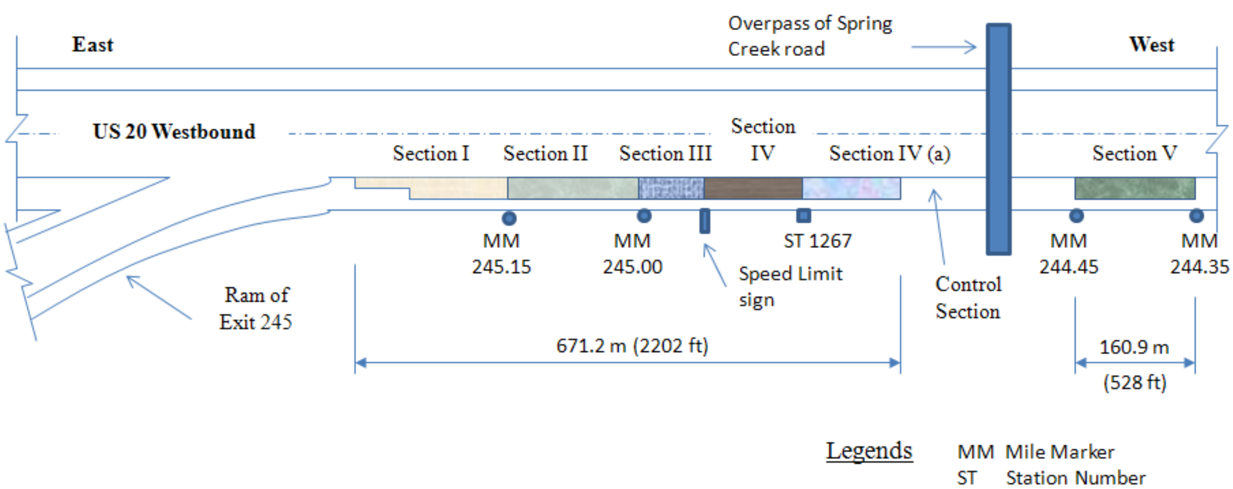


Figure 73. Test sections on westbound shoulder of US 20 near Jesup, Iowa (not to scale) August 18, 2009

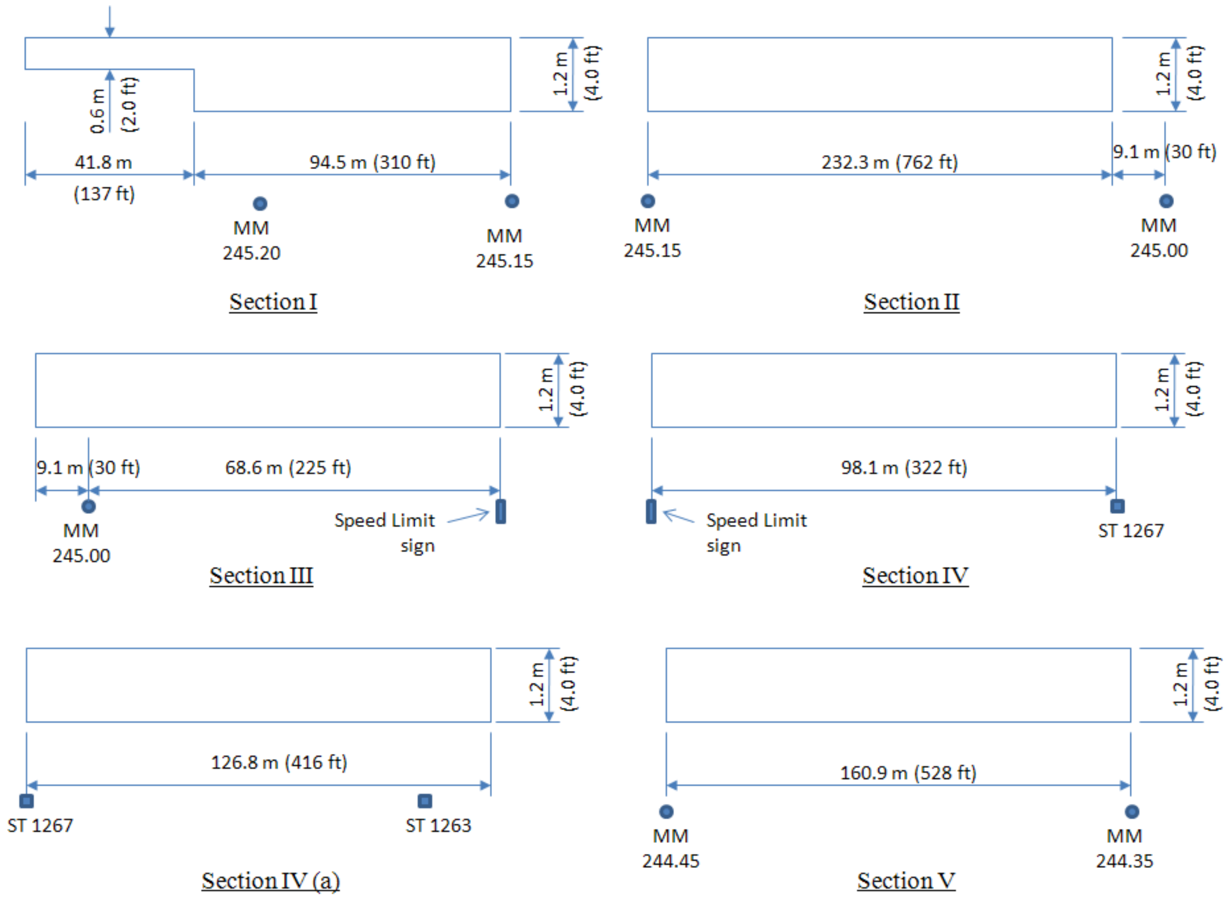


Figure 74. Details of test sections on westbound shoulder of US 20 (not to scale)

Test Section I

The grain size distribution for the granular shoulder material at Section I is shown in Figure 75. The stabilizing agent was topically applied to the section. DUSTLOCK was initially sprayed with one tip of the distributor, creating a strip that was 137 ft (41.8 m) long and 2 ft (0.6 m) wide. Two tips were used for the remainder of the test sections providing an average strip width of 4 ft (1.2 m) of DUSTLOCK (See Figure 76).

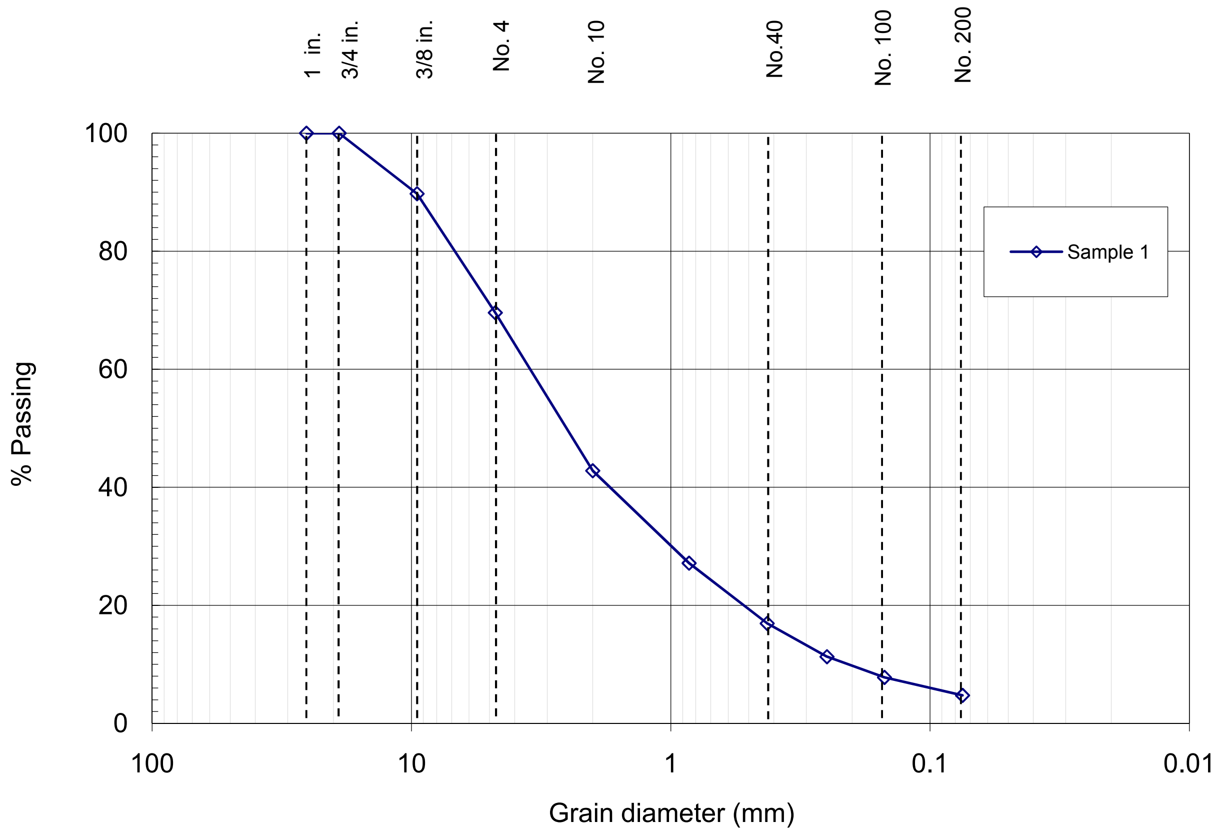


Figure 75. Grain size distribution of the aggregate collected from Section I August 18, 2009

Figure 76. Topical application of DUSTLOCK: a) 2 ft (0.6 m) strip (sprayed with one tip) and b) 4 ft (1.2 m) strip (sprayed with two tips) August 18, 2009

The shoulder surface was covered with sand provided by three passes of a dump truck with a sand spinner. The surface was then allowed to set for 15 minutes before being compacted by the roller. The construction period for this section, began at 9:34 a.m. and ended at 10:32 a.m., accounting for 58 minutes. The finished surface of the section is shown in Figure 77.

Figure 77. Section I after construction August 18, 2009

Test Section II

The grain size distribution for the granular shoulder materials at Test Section II is shown in Figure 78. The deepest edge rutting mostly occurred in this section. The shoulder surface was heavily graded by a motor grader on August 18, 2009. Loose aggregate was leveled to fill the edge rut along the pavement edge. This filled layer was from 1/2 to 1 in. (1.2 to 2.5 cm) thick, resulting in a surface that appeared to the researchers to be equivalent to a scarified surface. The loose surface was compacted with a pneumatic roller and then DUSTLOCK was topically applied (See Figure 79). Three passes of sand was broadcast on the surface. The roller was then used to compact the section.

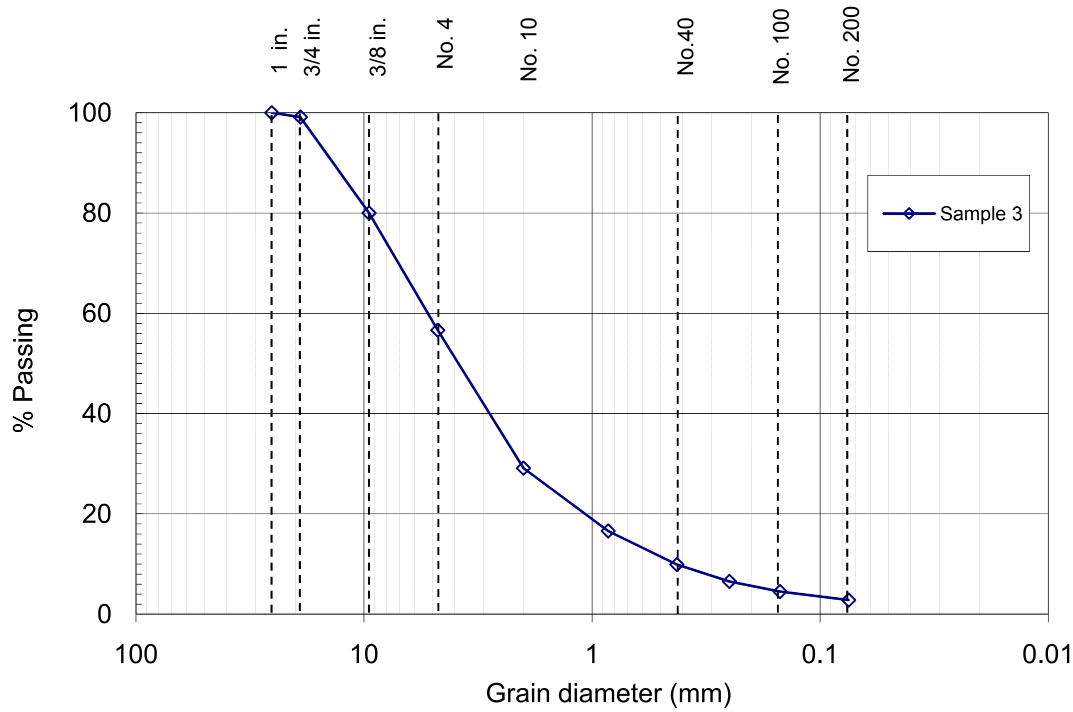


Figure 78. Grain size distribution of the aggregate collected from Section II

Figure 79. Section II: a) grading, b) filling and leveling, c) compaction, and d) application of DUSTLOCK August 18, 2009

The construction duration of the section was 1 hour 20 minutes, from 9:18 a.m. to 10:38 a.m. The completed section is shown in Figure 80 (c).

Figure 80. Section II: a) pavement cleaning, b) compaction, and c) finished surface August 18, 2009

Test Section III

The grain size distribution for the granular shoulder material at Test Section III is shown in Figure 81. The Test Section III shoulder surface was graded with a motor grader to constant cross slope of 3% toward the ditch. After grading, loose material on the shoulder surface next to the pavement edge was 1.2 in. (3.0 cm) lower than the pavement surface. However, the original hardpan surface of the edge ruts was still beneath the loose surface (See Figure 82).

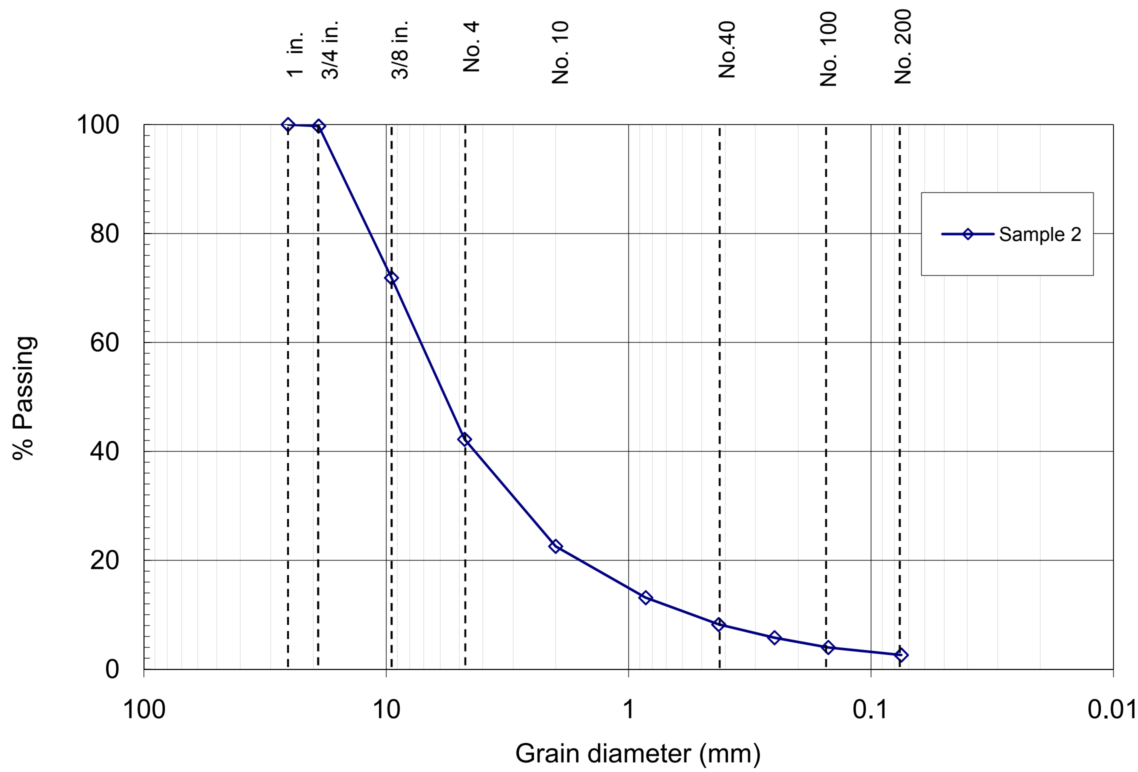


Figure 81. Grain size distribution of the aggregate collected from Section III

Figure 82. Section III: a) graded surface, b) side view of graded surface, and c) pavement edge drop off August 18, 2009

A skid steer mounted milling head was used to scarify the hardpan surface, creating a scarified strip of 4 ft (1.2 m) width and ½ in. (1.2 cm) depth. Three passes of overlapping scarification were required to provide the 4 ft (1.2 m) test section width. The scarified layer was then sprayed with water and compacted with six passes of the pneumatic roller. The motor grader was then struck off the compacted shoulder surface, providing a surface with a constant cross slope. DUSTLOCK was then topically applied to the shoulder surface before the application of five passes of sand from the sand spinner of a dump truck. The DUSTLOCK and sand were allowed to set for 15 minutes before they were compacted by the pneumatic roller (See Figure 83). Section III was constructed from 10:44 a.m. to 1:04 p.m. for a duration of 2 hours 22 minutes.

Figure 83. Section III: a) shoulder scarification, b) moisturizing, c) roller compaction, d) surface grading, e) DUSTLOCK application, f) sand spraying, and g) roller compaction August 18, 2009

Although the construction process included surface grading after the initial compaction, the shoulder surface after construction did not have a cross slope that was as constant as desired. The moist aggregate materials that were bound with the high-viscosity binder (DUSTLOCK) and the rubber wheels of the roller might have interacted to create an uneven surface. The shoulder surface along the pavement edge was still slightly lower than the surrounding area.

Test Section IV

The original shoulder surface of Test Section IV was struck off to a constant cross slope with a motor grader, resulting in a pavement drop-off depth of 1.2 in. (3.0 cm) and a cross slope of 3% toward the ditch. Water and DUSTLOCK were then topically applied to the shoulder surface. Six passes of sand from the dump truck spinner were applied to the shoulder surface. The finished surface of the section is shown in Figure 84.

Since the strike off process was accomplished at the same time for sections III, IV, and IV (a), the start time for the construction of Section IV was considered to be at 10:44 a.m. (the same as

Section III). The ending time was considered to be the end of the sanding process, which was 12:56 p.m. Therefore, the construction duration of section IV was 2 hour 12 minutes.

Figure 84. Stabilized shoulder surface of Sections II to IV (a) August 18, 2009

Test Section IV (a)

The shoulder surface for Test Section IV (a) was also struck off with a motor grader to create a constant cross slope of 3% toward the ditch, similar to Section IV. The edge drop off had a depth of 1.2 in. (3.0 cm).

Water and DUSTLOCK were then topically applied to the shoulder surface. Unlike section IV, where sand was applied, the existing shoulder aggregate materials that were cast toward the ditch by the motor grader were cast back on top of the DUSTLOCK surface with the motor grader. The material that was cast on top of the DUSTLOCK was fine and dusty. The finished surface of this section is shown in Figure 85. The starting time of the construction of section IV (a) was at 10:44 a.m. (which was about the same time as section IV). The ending time of construction for this section was at the end of the sanding process, at 12:16 p.m. Construction duration for section IV was 1 hour 32 minutes.

Test Section V

Test Section V was located at the bottom of a sag from milepost 244.45 to 244.35. This area was considered to be problematic to the maintenance crews. Aggregate shoulder for this section was struck off to a 3% cross slope by the motor grader. The struck surface was sprayed with water and then DUSTLOCK. To eliminate the use of sand, the struck-off aggregate materials were cast back by the motor grader to cover the DUSTLOCK. The test section was then compacted by six passes of the pneumatic roller (See Figure 60).

Figure 85. Construction process of Section V August 18, 2009

Redistribution of aggregate materials using the road grader reduced construction time and eliminated the use of sand. However, when the aggregate was cast back on top of the DUSTLOCK, the DUSTLOCK was rolled out of its original position. When the material was struck back away from the pavement, some of the mixture was unintentionally cast toward the ditch (See Figure 86). Nevertheless, this test section was constructed in a short period of time. The construction duration was only 34 minutes, starting at 1:15 p.m. and ending at 1:49 p.m..

Figure 86. Uneven mixed of DUSTLOCK due to grading process in Section V August 18, 2009

Results and Analysis

A field investigation was performed September 29, 2009 where elevation profiles were taken and Clegg impact hammer tests were conducted. The shoulder elevations were generally lower than those measured August 18, 2009. The surface of the stabilized shoulder was generally intact; however, it was damaged in places (See Figure 87).

Figure 87. Stabilized shoulder using DUSTLOCK on US 20 westbound September 29, 2009

A field check was undertaken November 7, 2009 to make visual observations and take photographs (See Figure 88 and 89). Course aggregates particles covered the stabilized surface in some areas. In other areas, an edge rut had developed.

On June 9, 2010, elevation profiles were taken and Clegg Impact Hammer tests were conducted. The condition of the stabilized sections ranged from being completely intact to only having remnants of the stabilized material. The locations of the worst damage corresponded to the locations with the most severe edge ruts before construction (See Figure 88). The blue dashed line (with dots for test points) was the June 9, 2010 surface; the solid line is the original post construction surface August 18, 2009; and the dashed red line is the September 29, 2009 surface.

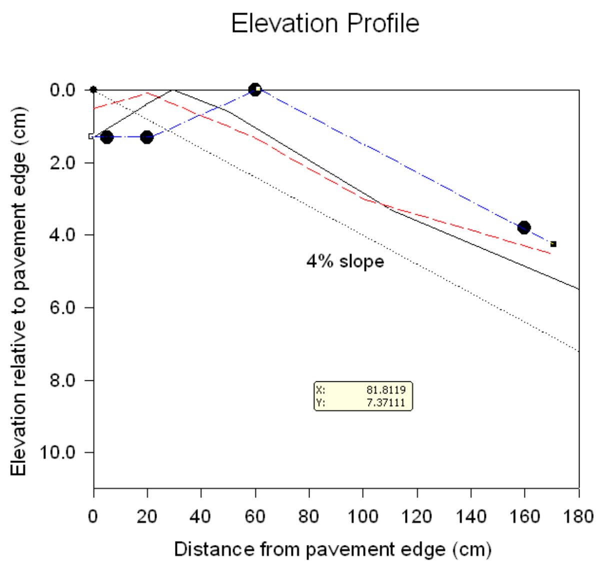


Figure 88. Elevation Profile of Section I Point 6 showing removal of DUSTLOCK from edge-rut area

Figure 89. Stabilized shoulder using DUSTLOCK on US 20 westbound covered with course aggregate beyond edge-rut area November 7, 2009

In some locations, the stabilized material was worn off in the edge-rut location, but still intact farther away from the pavement edge, often covered with course aggregate particles. It appeared that the hardpan in the edge rut was losing elevation more slowly than the stabilized material did, while it was being worn away (See Figures 90 and 91).

Figure 90. Looking west from Area II Test Point I milepost 245 June 9, 2010 (approximately same location as in Preconstruction Figure 72)

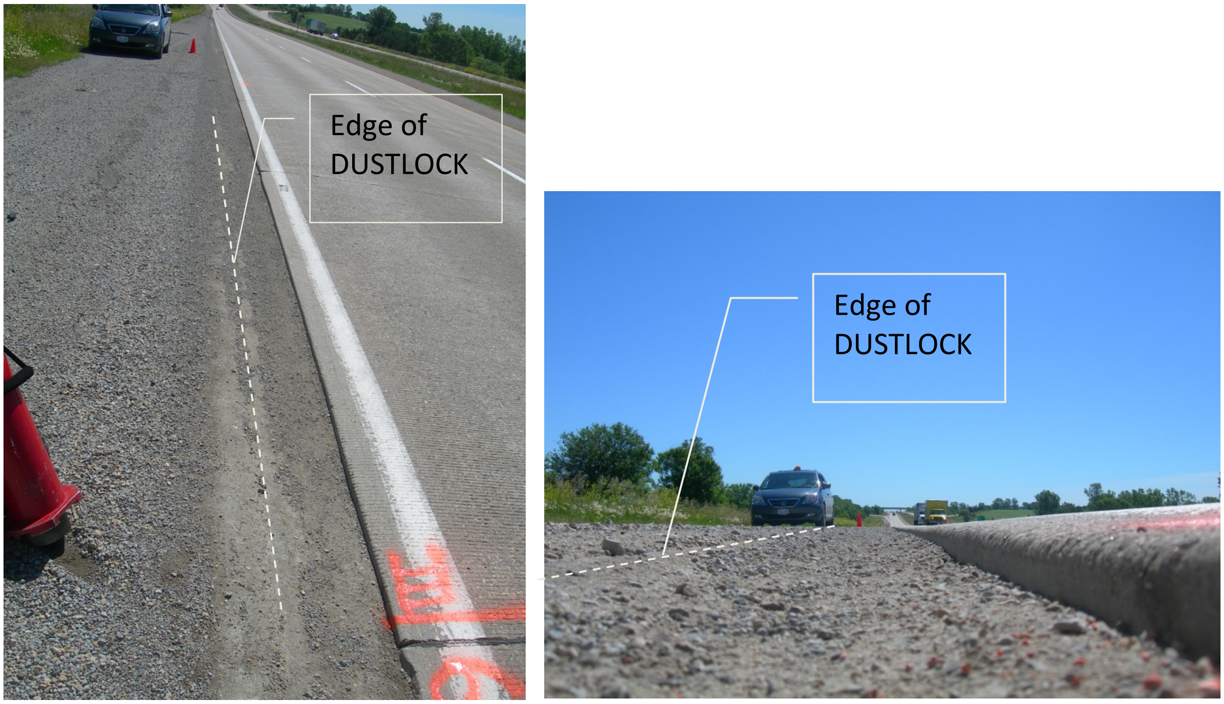


Figure 91. Removal of DUSTLOCK from edge rut area

Clegg impact hammer tests were conducted for the control section near milepost 244.45 (See Table 24) and all the stabilized sections (See Tables 25 through 30). The test locations were 1 ft (0.3 m) from the edge of the pavement.

Table 24. CIV and CBR values for the control section

Test point	Distance from MP 244.45 (ft)	9/29/2009	
		CIV	CBR
1	10	24.7	48.0
2	20	30.9	70.8
3	30	26.3	53.5
4	40	34.4	85.7
5	50	22.4	40.7
Average		**27.7**	**59.7**

Note: CIV readings were not taken 6/9/2010 because the battery ran out of charge

Control Section

Table 24 shows that the stiffness of the control section varied widely. The average values for CIV and CBR of this section were 27.7 and 59.7, respectively. CIV values measured on this section varied from 22.4 to 34.4. CBR values varied from 40.7 to 85.7. During the June 9, 2010 site visits, Clegg Hammer measurements were not taken because the Clegg Hammer battery had ran out of charge by the time the research team arrived at the location.

Test Section I

Field tests using the Clegg impact hammer on the Test Section I were conducted at 11 test points on both sides of the milepost 245.20 along the shoulder. The test points were separated into 10 ft (3.0 m) segments. Test points 1 through 5 were on the east side of milepost 245.20 while test points 7 through 11 were on the west side of it. The average CIV and CBR values for this section were 23.0 and 42.7, respectively. These values were lower than the stiffness values of the control section. On June 9, 2010, CIV results indicated that the shoulder was less stiff than it was in the previous Fall, but sufficiently stiff for the requirements of a shoulder.

Table 25. CIV and CBR values for Section I

Test point	Distance to MP 245.20 (ft)	9/29/2009		6/9/2010	
		CIV	CBR	CIV	CBR
1	-50	23.9	45.4	14.8	20.7
2	-40	22.2	40.0		
3	-30	22.1	39.7		
4	-20	23.5	44.1		
5	-10	22.6	41.3		
6	0 (at MP 245.20)	23.7	44.7	14.3	19.6
7	10	21.9	39.1		
8	20	23.4	43.8		
9	30	24.7	48.0		
10	40	24.4	47.0		
11	50	21.1	36.8	16.0	23.4
Average		**23.0**	**42.7**	**15.0**	**21.3**

Test Section II

The Clegg impact hammer tests were conducted at 10 points on the shoulder of Section II. The distance between two successive test points were 10 ft (3.0 m). The first test was conducted at test point 1, which was at 150 ft (45.7 m) to the west of milepost 245.15. The following test points were on the west side of test point 1. The average values of CIV and CBR were 24.7 and 48.2, respectively. The June 9, 2010 CIV values indicated some loss of stiffness since September 29, 2009; however, the loss was not enough to compromise the function of the shoulder.

Table 26. CIV and CBR values for Section II

Test point	Distance from Test Point 1* (ft)	9/29/2009		6/9/2010	
		CIV	CBR	CIV	CBR
1*	0	26.0	52.4	18.9	30.6
2	10	21.6	38.2		
3	20	24.2	46.3		
4	30	24.4	47.0		
5	40	25.5	50.7	15.6	22.5
6	50	25.0	49.0		
7	60	25.3	50.0		
8	70	22.6	41.3		
9	80	24.0	45.7		
10	90	28.5	61.5	20.2	34.2
Average		**24.7**	**48.2**	**18.2**	**29.1**

* Test point 1 is 150 ft west of milepost 245.15

Test Section III

The Clegg hammer tests were conducted at 11 test points, starting at point 1, which was 50 ft (15.2 m) on the west side of milepost 245.00. The following points were to the west. The stiffness of this section was comparable with the control section. The average CIV and CBR values were 27.0 and 56.3, respectively. As with the previous test section, some loss of stiffness was observed between October and June, but not enough to compromise the function of the shoulder.

Table 27. CIV and CBR values for Section III

Test point	Distance from Test Point 1* (ft)	9/29/2009		6/9/2010	
		CIV	CBR	CIV	CBR
1*	0	25.0	49.0	14.0	19.0
2	10	26.3	53.5		
3	20	30.4	68.8		
4	30	26.7	54.9		
5	40	23.2	43.1		
6	50	27.0	56.0	21.4	37.7
7	60	27.0	56.0		
8	70	29.1	63.7		
9	80	29.1	63.7		
10	90	28.5	61.5		
11	100	25.2	49.7	24.8	48.3
Average		**27.0**	**56.3**	**20.1**	**35.0**

* Test point 1 is 50 ft west of milepost 245

Test Section IV

Ten test points were used for Clegg impact hammer tests. The first test point (1) was at the speed limit sign. The following points were tested in the westbound direction. The average values of CIV and CBR were 25.7 and 52.4, respectively. Some reduction in stiffness was apparent between October and June.

Table 28. CIV and CBR values for Section IV

Test point	Distance from test point to speed limit sign (ft)	9/29/2009		6/9/2010	
		CIV	CBR	CIV	CBR
1	0	26.5	54.2	14.5	20.1
2	10	19.3	31.7		
3	20	19.6	32.5		
4	30	26.8	55.2		
5	40	23.9	45.4	15.8	23.0
6	50	28.8	62.6		
7	60	33.4	81.3		
8	70	28.5	61.5		
9	80	28.3	60.7		
10	90	21.8	38.8	17.7	27.5
Average		**25.7**	**52.4**	**16.0**	**23.5**

Test Section IV (a)

The first test point was selected at Survey Station 1266. The following test points were on the west side of test point 1. The average values of CIV and CBR were 26.1 and 52.9, respectively. Stiffness was reduced between October and June.

Table 29. CIV and CBR values for Section IV(a)

Test point	Distance from STA 1266 (ft)	9/29/2009		6/9/10	
		CIV	CBR	CIV	CBR
1	0	25.7	51.4	17.4	26.8
2	10	24.9	48.7		
3	20	25.3	50.0		
4	30	31.6	73.7		
5	40	28.5	61.5	18.2	28.8
6	50	26.2	53.1		
7	60	26.3	53.5		
8	70	24.0	45.7		
9	80	24.5	47.3		
10	90	23.5	44.1	20.4	34.8
Average		**26.1**	**52.9**	**18.7**	**30.1**

Test Section V

Clegg impact hammer tests were conducted at five test points. The average values of CIV and CBR were 27.6 and 58.2, respectively, in October 2009. Tests were not conducted in June 2010 because the Clegg impact hammer battery ran out of charge before the research team arrived at the location. The stiffness of this section was comparable with that of the control section.

Table 30. CIV and CBR values for Section V

Test point	Distance from MP 244.45 (ft)	9/29/2009		6/9/2010*	
		CIV	CBR	CIV	CBR
1	0 (at the MP 244.45)	28.5	61.5		
2	10	28.3	60.7		
3	20	29.8	66.5		
4	30	26.0	52.4		
5	40	25.3	50.0		
Average		**27.6**	**58.2**		

* CIV readings not taken (battery ran out of charge)

Final Field Check

A final field check was undertaken with the assistance of Brian Miller, a staff member of the Iowa DOT Waterloo Maintenance Garage. Information was obtained about typical shoulder maintenance practices and what effect the stabilized material had on them, as follows.

To maintain the shoulders, full traffic control is needed to close one lane. It takes one and a half days to maintain both inside and outside shoulders for one pass. If short sections need attention between maintenance trips, a dump truck with an underbody blade is usually sent out to blade granular shoulder material into the rut.

Since the stabilized test section was constructed, the shoulders have been maintained twice: once in the Fall and once in the Spring. There may have been an additional maintenance trip in the Spring. The stabilized areas were not maintained in the Fall because they did not require attention. In comparison to areas that were not stabilized, much lighter maintenance was performed in the Spring. Therefore, at least one maintenance cycle was saved by stabilizing the shoulder.

A comparison was made between one of the more challenging areas within the test sections (milepost 245 westbound) and two other similarly challenging areas outside the test section areas (milepost 242 eastbound and under the bridge for Exit 246 eastbound). Both of the ruts at the locations outside the test sections were 4.5 in. deep, while the rut inside the test section was 3 in. deep. The rut under the bridge is possibly a bit worse than the one westbound at milepost 245. If all locations were untreated, Miller would have expected that all of the ruts would have been the same depth.

FIELD INVESTIGATION ON US 218 NEAR NASHUA, IOWA

Introduction

The inside granular shoulders on US Highway 218 southbound near Nashua, Iowa were reconstructed in June 2006 as a result of severe rutting. Geogrid was selected to stabilize the shoulder section. An unstabilized control section was also provided. The stabilized sections were named after the names of the geogrid types. A field investigation was conducted to examine the performance of the test sections November 7, 2009 (See Figure 92). Elevation profiles were taken, and Clegg impact hammer and DCP tests were performed. The results are summarized in Appendix F.

Figure 92. Test sections on November 7, 2009

Test Results and Analysis

Control Section

The control section was 200 ft (61 m) long from mileposts 220.60 to 220.55. It was stable with no heavy rutting observed (See Figure 92). An edge rut was located within 8 in. (200 mm) of the pavement edge with an average depth of about 0.8 in. (20 mm). The elevation profiles showed that the maximum edge rut was about 1.8 in. (45 mm). The CIV values of the shoulder at various points 8 in. (200 mm) from the pavement edge ranged from 13.1 to 15.4 (See Table 31).

Table 31. CIV values for the control section

Distance from Pavement Edge, in. (cm)	CIV Values				
	MP 220.60	MP 220.60 -85ft	MP 220.60 -119ft	MP 220.60 -153ft	MP 220.60 -187ft
8 (20)	13.1	14.5	15.4	14.7	13.9
20 (50)	8.6				
39 (100)					9.3

Section BX 1200

This section was 328 ft (100 m) long, from milepost 220.55+64ft to milepost 220.50. The shoulder surface was observed to be in good condition. Edge ruts were observed in several areas with the maximum rut depth of 1.1 in. (27 mm). The CIV values at different points 8 in. (200 mm) from the pavement edge varied from 9.9 to 15.7 (See Table 32).

Table 32. CIV values for the BX 1200 section

	Distance from Pavement Edge, in. (cm)	
Test point	8 (20)	39 (100)
MP 220.60 - 221 ft	15.7	
MP 220.60 - 247 ft	11.7	9.6
MP 220.55	12.2	
MP 220.55 - 26 ft	14.0	
MP 220.55 - 51 ft	13.4	
MP 220.55 - 77 ft	14.5	
MP 220.55 - 102 ft	10.9	12.9
MP 220.55 - 128 ft	9.9	
MP 220.55 - 153 ft	12.6	
MP 220.55 - 179 ft	13.1	
MP 220.55 - 204 ft	14.2	
MP 220.55 - 230 ft	13.2	
MP 220.50	12.9	

Section BX 1100

This section was 246 ft (75 m) long, from mileposts 220.50 to 220.45. An edge rut that was 16 in. (400 mm wide) was present throughout the section with the maximum rut depth of 0.8 in. (20 mm). The CIV values of this section at different points of 8 in. (200 mm) from the pavement edge varied from 8.6 to 17.5 (See Table 33).

Table 33. CIV values for the BX 1100 section

	Distance from Pavement Edge, in. (cm)	
Milepost	**8 (20)**	**47 (120)**
MP 220.50 - 26 ft	13.9	
MP 220.50 - 51 ft	12.6	
MP 220.50 - 77 ft	8.6	
MP 220.50 - 102 ft	14.7	
MP 220.50 - 128 ft	16.5	10.4
MP 220.50 - 153 ft	17.5	
MP 220.50 - 179 ft	13.9	8
MP 220.50 - 204 ft	15.5	
MP 220.50 - 230 ft	16.5	

*Sections BX 4100 and BX 4100**

Granular aggregates particles were observed building up next to the pavement edge. An edge rut was observed within 8 in. (200 mm) from the edge with the maximum rut depth of 1.8 in. (20 mm). The surface stiffness ranged from 7.8 to 17.3 (See Table 34).

Table 34. CIV values for the BX 4100 and BX 4100* sections

		Distance from Pavement Edge, in. (cm)				
Section	**Test Point**	**8 (20)**	**31 (80)**	**39 (100)**	**47 (120)**	**71 (180)**
BX 4100	MP 220.50-255 ft	11.6				
	MP 220.45	14.7			13.2	
	MP 220.45-26 ft	11.6				
	MP 220.45-51 ft	11.9		6.2		
	MP 220.45-77 ft	7.8		7.8		
	MP 220.45-102 ft	9.6				
	MP 220.45-128 ft	11.1				
	MP 220.45-153 ft	16.7	9.1		13.2	
	MP 220.45-179 ft	11.9				
	MP 220.45-204 ft	11.3	8			10.6
	MP 220.45-230 ft	16.2			6.7	
BX 4100*	MP 220.45-255 ft	9.6	6.3			
	MP 220.40	12.9		5.7		
Unstabilized Area	MP 220.40-68 ft	9.0			7.3	
	MP 220.40-94 ft	16.5				
	MP 220.40-119 ft	17.3	5.8		5.2	3.2
	MP 220.375	14.4	5			

Notes: Section BX 4100 is 246 ft long, from MP 220.45+18ft toward MP 220.40
Section BX 4100* is from MP 220.45-230 ft to MP 220.40

FIELD INVESTIGATION ON US 34 NEAR BATAVIA, IOWA

Introduction

The granular shoulders on highway US 34 westbound near Batavia, Iowa, were constructed in September 2005. The base course of this shoulder consisted of a blend of 50% recycled asphalt pavement and 50% recycled concrete. The average thickness of the granular layer was 6 in. (150 mm). A field investigation was conducted to examine the performance of the test sections on November 12, 2009 (See Figure 93). Elevation profile, Clegg impact hammer, and DCP were performed at various mileposts. Results of these tests are summarized in Appendix G.

Figure 93. Test sections on November 12, 2009

Results of Field Investigation

The shoulder surface appeared to be stable with edge ruts 16 in. (400 mm) wide with a maximum rut depth of 2 in. (50 mm) (at milepost 206.75). At other places (such as at milepost 207.80), the shoulder surface was relatively high.

Clegg impact hammer tests were conducted at 3 ft (0.9 m) and 6 ft (1.8 m) from the pavement edge. Results showed that the shoulder surface within 3 ft from the pavement edge was stiff with an average CIV of 17.6. The CIV values within this distance from the pavement edge varied from 15.2 to 27.8. The average CIV of the shoulder with 6 ft (1.8 m) from the pavement edge was 14.1. CIV values of the shoulder within this distance varied from 13.2 to 15.0 (See Table 35).

Table 35. CIV values obtained from Clegg impact hammer

	Distance from Pavement Edge (ft)	
Milepost	3	6
MP 207.75	16	14.9
MP 207.75	27.8	13.1
MP 207.60	15.2	14.7
MP 207.25	20.1	14.4
MP 207.10	14.5	14.0
MP 206.75	14.4	13.2
MP 205.50	15.4	15.0
MP 205.05	17.2	13.7
Average:	**17.6**	**14.1**

SUMMARY

A multifaceted investigation was undertaken to develop recommendations for methods to stabilize the granular shoulder with the goal of mitigating edge ruts. Included was reconnaissance of problematic shoulder locations, a laboratory study to develop a method to test for changes in granular material stability when stabilizing agents are used, and the construction of three sets of test sections under traffic at locations with problematic granular shoulders.

Conclusions

Based on the results of the investigation, the following was concluded:

- Problematic shoulders are generally stiff enough to carry expected traffic loads for emergency pull-off and temporary parking. Material gradations are generally finer than specified for new construction and cross slopes are often steeper than called out on cross sections for new construction. However, such differences in what is expected for original construction are consistent with damage that would be expected during use and maintenance (degradation of size due to breakage and abrasion and loss of material through erosion and winter and summer maintenance).

  Therefore, it seems likely that edge ruts develop from a combination of vehicle off-tracking and time elapsed between maintenance cycles, rather than defects regarding original geometry and material gradation or from structural weakness.

  Some effort to renew cross slope and material gradation may be helpful in mitigating edge ruts. In addition, a shorter maintenance cycle would most likely be required to mitigate edge ruts.

- Calcium chloride, magnesium chloride, and Base One did not provide noticeable improvements on the US 20 shoulders. However, they were easily applied and have the potential to be applied with the Iowa DOT's own maintenance staff, using its own equipment that could be modified from winter use.

  These methods were attempted because it was hypothesized that an important failure mode was that fine particles near the pavement edge were being removed by wind erosion, leaving only large particles that are easily displaced by off-tracking vehicles.

  These products bind fine particles, mechanically with Base One and by attracting moisture with calcium chloride and magnesium chloride. Apparently, some other mechanism causes the edge ruts, despite the presence of fine particles near the pavement edge.

- If full-depth reclamation is used to incorporate stabilizers, the Iowa DOT does not currently own and operate the necessary equipment to compact and stabilize the reclaimed material. To provide the needed compaction effort, heavier equipment would have to be purchased or rented.

  In particular, it would be necessary to have a pneumatic compactor that could operate bi-directionally. Typically-available, pull-behind compactors do not allow enough passes to be made quickly enough when consideration is given to the time required to safely turn the units, especially on limited access highways.

- DUSTLOCK appears to wear well in locations where the shoulder material provides a stable base and vehicles do not off-track to the extent that they do on the US 20 test section. In areas of heavy off-tracking, preliminary indications are that stabilizing the shoulders reduces the number of maintenance cycles to half of what they would be without the stabilizer.

- The laboratory test method for investigating stabilizer performance appeared to be a reasonable effort that provided some information about stabilized material behavior in confined situations. However, the method would have to be combined with a test similar to an asphalt rut test to detect instability for unconfined circumstances.

Recommendations

- Consider using DUSTLOCK for shoulders with stable material for roads with moderate traffic (about as much as on US 18 near Garner, which is 6,000 to 6,500 Annual Average Daily Traffic/AADT).

- For problematic areas with unstable materials, consider paving 2 to 4 ft strips next to the pavement. It might be possible to develop construction contracts similar to patching contracts to facilitate such improvements. Also, it may be possible to include such an improvement with a patching contract.

- Consider experimenting further with the topical applications calcium chloride and magnesium chloride to moisten shoulder material, so it is easier to grade and compact properly in dry weather.

- Continue the use of geogrid and flyash where necessary to stabilize soft subgrades beneath the shoulder material (in situations where such soft subgrades are problematic).

- Consider experimenting further with Base One where shoulder stiffness is insufficient.

- Limit scarification to light scarification that is only slightly deeper than edge ruts that are being repaired.

- Consider greater use of bi-directional rollers when shoulder repairs and maintenance require heavy compaction. The Iowa DOT's current self-propelled pneumatic rollers will likely be satisfactory for many such applications.

- Consider the development of lightly-paved shoulders for areas beyond rumble strips. Consider providing deep, lightly-bound bases using various stabilizing agents.

- Consider increasing the frequency of adding new shoulder material in areas with steep cross slopes and overly fine gradations of existing granular shoulder material.

- Consider developing methods to redistribute shoulder material from areas that have low cross slope to areas that have high cross slope. Such a system might include laser scanning or Light Detection and Ranging (LiDAR) to establish the location of materials, and trimming equipment to strike off areas with low cross slope.

REFERENCES

AASHTO Roadside Design Guide (2002). American Association of State Highway and Transportation Officials, Washington, DC.

AASHTO Strategic Safety Plan (1998). American Association of State Highway and Transportation Officials, Washington, DC.

Armour, M. (1984). Relationship between Shoulder Design and Accident Rates on Rural Highway. Proceedings-Conference of the Australian Road Research Board, Vol. 12, No. 5, pp 49-62.

Jahren, C. T., Smith, D. E., Johnson, G and White, D.J. "Economics of Upgrading an Aggregate Road," Final report 2005-09 of Minnesota Local Road Research Board Project # 769 for Minnesota Department of Transportation, January, 2005.

Souleyrette, R., McDonald, T., Hans, Z., Kamyab, A., Welch, T. and Storm, B. (2001). Paved Shoulders on Primary Highways in Iowa: An Analysis of Shoulder Surface Criteria, Cost and Benefits. Center for Transportation Research and Education, Iowa State University.

White, D. J., Mekkawy, M., Jahren, C. T., Smith, D. E., and Muhannad, S., "Effective Shoulder Design and Maintenance," Final Report of Iowa Highway Research Board Project TR-531 for the Iowa Department of Transportation, June 2007.

Volume of Traffic on The Primary Road System of Iowa (2002). Iowa Department of Transportation, Ames, Iowa.