Pilot Construction Project for Granular Shoulder Stabilization

Final Report
September 2013




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16. Abstract

Granular shoulders need to be maintained on a regular basis because edge ruts and potholes develop, posing a safety hazard to motorists. The successful mitigation of edge-rut issues for granular shoulders would increase safety and reduce the number of procedures currently required to maintain granular shoulders in Iowa. In addition, better performance of granular shoulders reduces the urgency to pave granular shoulders. Delaying or permanently avoiding paving shoulders where possible allows more flexibility in making investments in the road network.

To stabilize shoulders and reduce the number of maintenance cycles necessary per season, one possible stabilizing agent—acidulated soybean oil soapstock—was investigated in this research. A pilot testing project was conducted for selected problematic shoulders in northern and northeastern Iowa. Soapstock was applied on granular shoulders and monitored during application and pre- and post-application. Application techniques were documented and the percentage of application success was calculated for each treated shoulder section.

As a result of this research, it was concluded that soybean oil soapstock can be an effective stabilizer for granular shoulders under certain conditions. The researchers also developed draft specifications that could possibly be used to engage a contractor to perform the work using a maintenance-type construction contract. The documented application techniques from this project could be used as guidance for those who want to apply soapstock for stabilizing granular shoulders but might not be familiar with this technique.

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EXECUTIVE SUMMARY

Problem Statement

Edge rutting on granular shoulders, as shown in Figure 1, is a serious traffic safety issue because it can cause vehicles to run off the road, which can lead to loss of control and even loss of life (Jahren et al. 2011). Edge rutting is caused by three factors: wind and air currents, vehicle off-tracking, and drainage.

Figure 1. Edge rutting on granular shoulder (Jahren et al. 2011)

Over time, wind and air currents from large vehicles blow fine material away from the shoulder, exposing large particles on the shoulder surface, which are removed more easily by vehicle off-tracking. Off-tracking refers to the situation where rear tires run a different path from front tires during vehicle turning movements. Pavement drainage accumulates along the pavement edge and makes shoulder materials unstable.

Background

A shoulder edge-rut mitigation research project identified applications of acidulated soapstock, which is a soybean oil by-product, as a possible strategy to mitigate the development of edge ruts on roadways with granular shoulders (Jahren et al. 2011).

Evidence indicates that this strategy has the potential to reduce the number of required maintenance cycles on high-speed high-traffic roads (such as US Highway 20 near Jessup, Iowa with 9,000 vehicles per day/vpd annual average daily traffic/AADT and a speed limit of 65 mph) and last up to five years on moderate-speed medium-traffic roads (such as US 18 near Garner, Iowa with 6,000 AADT and a speed limit of 45 mph).

Objective

The objective of the proposed research project was to assist the Iowa DOT in mitigating edge ruts on granular shoulders cost-effectively by pilot testing the use of soybean oil soapstock in a full-scale maintenance setting.

Pilot testing the material on roads with various AADT levels and shoulder conditions would provide an opportunity to better define situations where soybean oil soapstock and similar materials would be useful. The following questions would be answered:

- What level of AADT can the treatment tolerate?
- What amount of vehicle off-tracking can the treatment tolerate?
- How must the shoulder material be prepared prior to application given that developing a sufficiently solid surface for the base of the application was found to be a challenging task in areas that were rutted just prior to construction?
- Can the treatment be maintained to extend its life?
- How can the treatment be repaired efficiently when points of incipient failure develop?
- How can the Iowa Department of Transportation (DOT) purchase the material?
- What specifications are required so that the material be applied as part of a construction or maintenance contract?
- What other alternative strategies should be explored?

Research Description

Granular shoulders need to be maintained on a regular basis because edge ruts and potholes develop, posing a safety hazard to motorists. To stabilize shoulders and reduce the number of maintenance cycles necessary per season, one possible stabilizing agent—acidulated soybean oil soapstock—was investigated in this research.

A pilot testing project was conducted for selected problematic shoulders in northern and northeastern Iowa. Soapstock was applied on granular shoulders and monitored during application and pre- and post-application. Application techniques were documented and the percentage of application success was calculated for each treated shoulder section.

Researchers also developed draft specifications that could possibly be used to engage a contractor to perform the work using a maintenance-type construction contract.

Key Findings

Conclusions

By the end of the study, researchers were able to determine whether and under what conditions this soapstock could be effective in mitigating edge rutting and potholes for granular shoulders. Most shoulders had good performance. Of the 20 test sections, 14 had 100 percent good performance, meaning no edge ruts or potholes were identified and the soapstock stayed firmly in place on the treated shoulders.

Two locations had the worst performance with 0 percent successful application. Although no edge ruts were observed for these two sections, most of the soapstock applied on the shoulder surface was not in place when post-construction observations were made. At these locations, the soapstock was applied during rain showers and the wet conditions during application are the likely cause of poor performance.

At two other locations, new edge ruts developed in a few places, but the application was mostly successful with 98.3 and 95.7 percent successful application. Edge rutting at one location was not severe, only 1/2 in. deep, and, at the other, one 3/4 in. deep pothole was observed nearby.

Two other locations had a few places where the soapstock did not survive intact before post-construction observations were made. One location has heavier than recommended traffic volumes for soapstock use and shoulders that had unusually unstable surface aggregate.

The major causes for observed failed application were poor aggregate gradation and stability, severe vehicle off-tracking, high-volume traffic, presence of a relatively sharp curve, runoff from the road profile uphill of the failure location, and occurrence of rain during soapstock application. In addition, there was insufficient aggregate to maintain the design shoulder cross slope and fill to the interface between the pavement edge and the shoulder in a few study locations.

In fact, application results could be affected by many factors not only limited to what is listed above. Possible influence factors include cross-slope of the shoulder, stiffness of shoulder materials, gradation distribution of aggregates, preparation of shoulders (particularly compaction), weather during application, moisture content of shoulder materials, soapstock thickness and viscosity, soapstock application rate, compaction after application, and thickness of covering sand.

Recommendations

- Before soapstock application, shoulders should be prepared with proper regrading work and compaction. Aggregate materials applied during regrading should have a gradation complying with the DOT specification.

- During the soapstock application, rain should be avoided because too much moisture can prevent soapstock from staying firmly on the shoulder. Too much or too little moisture compromises the effectiveness of the application. If the shoulder is too dry, water should be applied to add more moisture. If the shoulder is too wet, soapstock application should be delayed until it is dry enough.
- Soapstock should be distributed evenly on the shoulder, which might require the operator to recirculate the soapstock in the tank to obtain its uniform viscosity.
- After the shoulder is treated, consider using compaction provided by a pneumatic roller to enhance the ability of the soapstock to bind with the aggregate materials.
- If potholes or edge ruts develop after soapstock application, consider filling them using a pothole patcher.
- More advanced research could be performed in the future to further determine the effects of the various possible influence factors on unpaved shoulder soapstock application.
- Developing an expedient method to stabilize and stiffen the underlying aggregate in areas of pre-existing edge ruts, pot holes, and water erosion gullies should be considered because, if successful, such a method would likely increase the success of soapstock application.

Implementation Readiness and Benefits

As a result of this research, it was concluded that soybean oil soapstock can be an effective stabilizer for granular shoulders under certain conditions.

The results of this study are intended to allow maintenance personnel to improve the performance of granular shoulders with regard to edge ruts, by applying a soapstock-stabilizing agent on problematic shoulders (Figure 2).

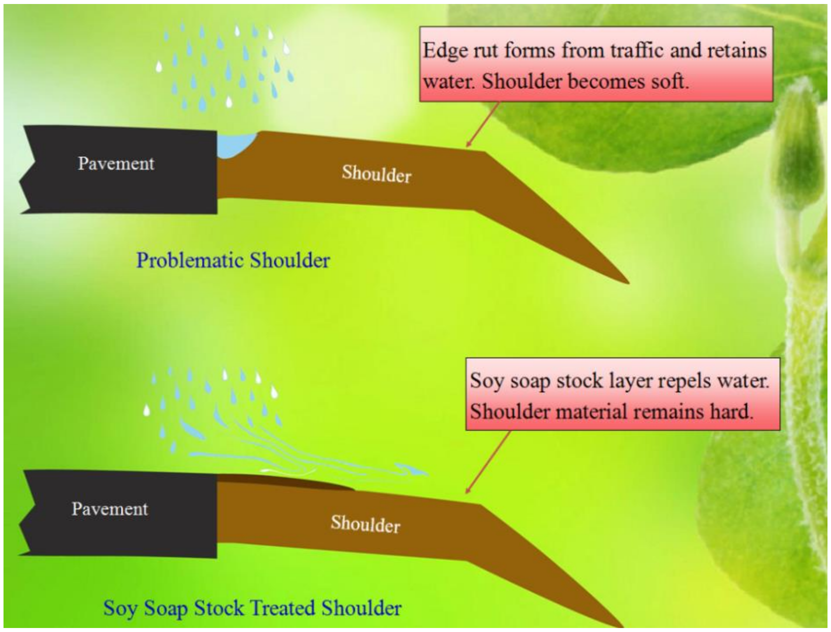


Figure 2. Stabilization of granular shoulders with soybean oil soapstock

The successful mitigation of edge-rut issues for granular shoulders would increase safety and reduce the number of procedures currently required to maintain granular shoulders in Iowa. In addition, better performance of granular shoulders reduces the urgency to pave granular shoulders. Delaying or permanently avoiding paving shoulders where possible allows more flexibility in making investments in the road network.

The documented application techniques from this project could be used as guidance for those who want to apply soapstock for stabilizing granular shoulders but might not be familiar with this technique.

CHAPTER 1. INTRODUCTION

Background

Among several approaches to shoulder stabilization and maintenance improvement, using a proprietary formulation of soybean oil soapstock appears to be a promising stabilization technique.

The question about how to specify or purchase soapstock and products like it are especially important, because it is a proprietary material that cannot be purchased routinely in large quantities by the Iowa Department of Transportation (DOT) and local jurisdictions.

During a previous phase of this project, researchers used similar materials, which clogged the spray nozzles of an Iowa DOT distributor truck (White et al. 2007). It may be extremely challenging to develop an open specification for this product, therefore making it necessary to develop a public interest finding that will allow the Iowa DOT to purchase soapstock as a proprietary product.

Using this material is attractive because it is nontoxic, can be applied at ambient temperatures with distributor trucks, and fits the equipment and labor skill set that is available with the Iowa DOT and many local jurisdictions. If the strategy of applying soapstock is adopted, past experience indicates that maintaining the integrity of the membrane can be challenging and that, when the membrane is breached, repairs must be made promptly to avoid failure. The proposal stated that construction and maintenance of such shoulders could also be tested as part of the project.

This project had two aspects:

- Pilot test the use of soapstock on a larger scale to assess its efficacy more definitively
- Develop specifications or assisting with crafting a public interest finding for soapstock and similar materials

Objective

The objective of the research project was to assist the Iowa DOT in cost effectively mitigating edge ruts on granular shoulders by pilot testing the use of DUSTLOCK in a full-scale maintenance setting. Researchers would also develop standard specifications for a class of products that might have similar effectiveness and use of other stabilizing strategies or paving short sections of shoulders.

Work Location Map

Based on recommendations by Iowa DOT garage supervisors for possible shoulder paving projects, test locations were selected on road sections that suffered from severe edge rut problems. In northern Iowa, a group of locations were selected near Algona, Garner, and Leland, with another group near Allison, Shell Rock, Waverly, and Denver. In northeastern Iowa, a group of test locations were selected near West Union, Elkader, and Elgin (Figure 3).

Figure 3. General testing areas in Iowa

Generally, the traffic volumes were within 6,000 vehicles per day (vpd) as recommended by Jahren et al. 2011 for those locations, except for Denver, Iowa, where the traffic volume varied from 6,500 to 8,000 vpd.

Research Tasks

In mid-June 2011, a technical advisory committee (TAC) was established to assist in the effort to execute this research project. The had been determined in the project proposal. The level of effort for each task was discussed in consultation with the chair and other members of the TAC. The total effort would remain within the scope of the budget unless authorized in advance by the Iowa DOT. The intention was to provide flexibility to meet unforeseen challenges and to take advantage of unexpected opportunities. The detailed tasks were listed basically as follows.

Task 1: Plan DUSTLOCK Full-Scale Pilot Test Construction. Researchers should collaborate with the TAC and designated Iowa DOT personnel to plan construction for full-scale pilot testing of DUSTLOCK shoulder stabilization for edge-rut mitigation. Researchers should conduct the pre-construction tests and measurements.

Task 2: Execute DUSTLOCK Pilot Construction. The construction should be executed in accordance with the plan developed in Task 1, to the extent reasonably possible. Researchers need to observe construction procedures and provide technical support.

Task 3: Monitor DUSTLOCK Pilot Construction. Researchers should make post-construction observations one week to one month after construction, before freeze up in Fall 2011, after thaw in Spring 2012, and at times that the Iowa DOT notices critical changes in performance.

Task 4: Develop a Purchasing Strategy for DUSTLOCK and Similar Materials. Researchers should propose a list of performance indicators and present them to the TAC and other experts that the Iowa DOT and the researchers might nominate. Objective measurements should be developed to characterize the level of performance for each indicator. If an acceptable set of measurements are found, researchers will develop a draft specification or materials acceptance policy and assist the TAC and/or the Iowa DOT in presenting it to relevant decision makers.

Task 5: Develop a Plan to Test Alternative Strategies. The research team should review the results of previous studies (White et al. 2007 and Jahren et al. 2011) and, in consultation with the TAC and vendor representatives, develop a plan to place test sections for granular shoulder stabilization. The test plan will include both laboratory and field components. The laboratory phase will allow researchers to test a broad range of strategies with relatively low effort.

Task 6: Execute Test Plan for Alternative Strategies. Researchers should execute the laboratory portion of the test plan and purchase samples of stabilizers as necessary. At the end of the laboratory phase, researchers will analyze the results and recommend strategies for field testing. The actual selection of strategies for field testing will be accomplished in consultation with the TAC. Researchers will conduct preconstruction observations, measurements, and tests.

Task 7: Post-Construction Observations for Alternative Strategies. Researchers will perform post-construction observations for the field tests.

Task 8: Data Synthesis. The research team will review the documentation of the construction operations and the results of the post-construction observations, and rate the success of the various strategies.

This report is organized along the lines of these research tasks, with each chapter describing the actual work done to complete each task. Some changes occurred according to the actual work situation and budget. In particular, Tasks 4, 5, and 6 were intended to be accomplished by a volunteer student who received limited funding from this project. This student’s accomplishments were limited to completing Task 4, only leaving Tasks 5 and 6 uncompleted.

CHAPTER 2. LITERATURE REVIEW

Shoulder Edge Rutting and Edge Drop-Off

Pavement/shoulder edge drop-off is a critical safety concern for highways and roads that have granular shoulders. “The pavement/shoulder drop-off is created by a difference in elevation between two surfaces of the roadway” (Glennon 2005). When a driver leaves the roadway and encounters the shoulder edge drop-off, the resulting outcome depends on “the driver’s steering and braking response, steer angle, vehicle size, vehicle speed, severity of the vehicle’s departure and return angles, and the magnitude and geometry of the drop-off.”

The possible undesirable outcomes include crossing to an adjacent lane, encroaching on the far side of the roadway, or skidding on shoulders or roadways, which would cause potential collision or rollover (Hallmark et al. 2006). If the pavement/shoulder edge drops off two inches or more, the vehicle could easily lose control (Glennon 2005).

In a study done by Berthelot and Carpentier (2003), vehicle off-tracking was the major cause of gravel loss adjacent to the pavement edge, and loss of gravel could lead to the edge drop-off. Vehicle off-tracking occurs more frequently for roads with high traffic speeds and high traffic volumes. During the study, it was observed that heavy trucks caused a large amount of aggregate particles to break down during the dry season. In addition, heavy trucks always leave clear wheel paths on the surface of the roadway or shoulders, and gravel on the surface could easily be removed or broken down by several truck passes.

When wheel paths are developed, the water infiltration rate on the tracked portion would be decreased and the surface runoff would be increased, which results in greater water erosion. If edge rutting has already existed in shoulders, the pooled water would soften the surface and increase the tendency to rut (Berthelot and Carpentier 2003).

Wagner and Kim (2004) found shoulder edge drop-offs occur more frequently on the inside of horizontal curves. Thus, granular shoulders need to be maintained periodically to prevent edge ruts and their attend to their safety issues (NYSDOT 1990).

Dust emission is another factor facilitating shoulder edge rutting and shoulder degradation. Loss of fine materials causes a reduction of particle cohesion on unpaved surfaces, thus increasing loss of gravel and the required frequency of maintenance (Jones et al. 2001). Fine materials are blown away easily by traffic abrasion in the form of dust during the dry season (Hanley-Wood Inc. 1995). Dust emission is not only a traffic safety concern but also a concern for human health and air quality (Brookman and Drehmel 1981).

Another process, the addition of asphalt overlays, can increase shoulder edge drop-off. Sometimes, new layers of asphalt are added to resurface the roadway, but no effort is made to raise the elevation of the granular shoulders adjacent to the roadway (Humphreys and Parham 1994).

Shoulder Stabilization

Soil stabilization can be achieved by either mechanical stabilization or by using a stabilizing agent.

So-called mechanical stabilization refers to a process where new aggregate is added to increase the internal friction angle of the granular shoulder material. For granular shoulders, mechanical stabilization could be used to densely grade the aggregate surface, which helps prevent excessive moisture infiltrating the subbase (Hanley-Wood Inc. 1995).

The proper use of stabilizers could contribute to provide a granular shoulder with good performance and a long life cycle (Mekkawy et al. 2010). In terms of using stabilizers, it is important to select the right stabilizer for different conditions and types of soil (Hanley-Wood Inc. 1995). With the proper use of stabilizers on unpaved shoulders, the loss of fine materials could be reduced greatly, a tighter bond could be formed between aggregates, and blading maintenance frequency could be reduced (Skorseth 2000). Generally. stabilizing agents provide light surfacing, dust control, and stabilization. One example of each agent follows.

Light Surfacing (Otta Seal)

According to Johnson (2003), "An Otta seal is an asphalt surface treatment constructed by placing a graded cover aggregate on top of a thick application of a relatively soft bituminous binding agent." This treatment method works well on low traffic volume roads. Otta sealing helps prevent excessive moisture infiltration into the base material. However, an Otta seal does not improve the structural capacity; it requires that the road base/subbase be strong enough to support the expected traffic loads. Usually, a double coat is recommended to achieve the best performance (Johnson 2003).

In 1963, Otta seal developed by Norway was sprayed in the field for the first time and has been used in Nordic countries and developing countries since then. The service life of Otta seal is expected to range between 8 and 15 years (NPRA 1999).

Dust Control (Polymers)

Polymer emulsions have been used widely for dust control. Soil-Sement and Soiltac are examples of these products, which have a milky-white appearance. According to a study done by Bushman et al. (2004) on the stabilization of unpaved roads, Soil-Sement polymer (PH varying from 4 to 9.5) could penetrate into the soil and create a tight bond between particles, thus producing a solid and durable road surface that could support high-volume traffic and survive extreme weather.

The Soiltac manufacturer claims that Soiltac, as a polymer-based emulsion, could provide a protective barrier with a stable and rigid base when applying it on unpaved surfaces (Soiltac 2012). In terms of costs, Soil-Sement polymer costs around $8 per gallon and Soiltac polymer costs around $5 per gallon, neither of which includes the shipping and application costs (White et al. 2007). In addition, maintenance needs to be done every two or three years with a new coat placed on the top surface (NAVFAC 1998).

Stabilization (Calcium Chloride and Magnesium Chloride)

Calcium chloride and magnesium chloride are two common stabilizers for granular roads. Calcium chloride is made from underground natural brine deposits, which could reserve moisture in unpaved surfaces and prevent dust and small particles from blowing away. It also protects granular material from frost heave in winter. Calcium chloride works well on granular surfaces with well-graded aggregates and percentage of fines from 12 to 18% (Kirchner and Gall 1991).

Magnesium chloride is a salt, which could be used as a chemical stabilizer for granular surfaces. Magnesium chloride works similar to calcium chloride in terms of stabilizing granular surfaces, but it does not work well when the temperature is higher than 71°F and the relative humidity is lower than 31% (Kirchner and Gall 1991).

In the research test sections documented by Jahren et al. (2011), calcium chloride and magnesium chloride did not mitigate edge ruts noticeably.

Soybean Oil Soapstock

Soybean oil soapstock is a biodegradable that shares many of the characteristics of light petroleum-based oil (Skorseth 2000). The DUSTLOCK manufacturer claims that it can be used effectively under various conditions (e.g., unpaved roads, driveways, airports, mining sites, parking lots, and construction sites) (EDC 2011a).

The most common use of soapstock is for dust control. Product literature claims that the soapstock penetrates well into the road surface and forms a tight bond with soil, establishing a biodegradable surface (EDC 2011a). Other claimed benefits of using soapstock include that it is environmentally-friendly, non-flammable, and relatively safe to use, and it is purported to be suitable for a wide range of soil types (Gauteng 2005). However, soapstock leaves an aldehyde odor after it is applied. Because this odor can be undesirable, producers were reportedly trying to mitigate the odor without reducing its effectiveness (Lohnes and Coree 2002).

This soapstock is produced from the degumming process of crude soybean oil. The crude soybean oil is mixed with the proper amount of water and then separated using a centrifugal method. By performing this separation, the proportion of oil contents, free fatty acids, lecithin, and fatty acids, can be refined. According to Guerra's interview with Susana Goggi (2012), for this soapstock, the proportion of oil content varies from 30 to 36%, which is a common range for any products made from soybean oil.

Lecithin is also an important agent because it provides a part of the physical properties of soapstock and helps develop the surface coating (Ambuja 2006).

The first reported use of soapstock as a shoulder stabilizer that was found under this research effort was sponsored by Minnesota DOT (MnDOT). According to Han and Marti (1996), soapstock worked well on the surface with an AADT volume less than 100 and was preferentially applied in normal or dry weather. The fine particles on the surface were preferentially controlled within a range of 5 to 20%.

Because the penetration rate decreases with decreasing temperature, warmer temperatures are preferable when soapstock is being applied. Usually, it takes 4 to 6 hours for the soapstock to penetrate a road surface, but it could also take as long as a day to a week depending on variations in aggregate gradations and weather conditions.

The equipment for spraying soapstock can be a typical distributor of the type that is used for asphalt products or other dust control products such as calcium chloride or magnesium chloride solutions. Before application, the road surface should be lightly graded. For the initial application, the recommended spraying rate is 1.13 liters/m^2 (0.25 gal/yd^2) and heavy traffic should be avoided. Based on the observation, the surrounding grass will turn brown but will recover after about two weeks of the initial spray.

According to the tips for storage of soapstock provided by MnDOT, stainless steel or iron tanks should be used, the length of storage should not exceed a year, and heat tape should be used to warm the material during winter storage.

Important properties of soapstock are that it repels water and does not evaporate easily. It has medium to high viscosity, which prevents it from being washed out. Considering the performance of soapstock, it worked well on granular shoulders, embankments, and low-volume roads, but presented some problems on curves, which are subjected to many turning movements.

Due to the limited production of soapstock, its market price increased, from $1.07 per gallon in 1991 to $1.12 to $1.50 per gallon in 1995. In August 2011, the Iowa DOT purchased soapstock for $3.00 per gallon.

The Iowa DOT District 2 conducted its first soapstock trial on granular shoulders on a section of US 18 near Garner, Iowa in July 2000 (unpublished process improvement team notes provided by Mark Black, Iowa DOT District 2 Maintenance). The shoulders were stabilized, but the work was neither published nor repeated. An obstacle to its continued use was that this product was proprietary and therefore difficult for the Iowa DOT to purchase (Jahren et.al. 2011).

In 2007, researchers started investigating the use of soapstock and tried a product that was different from the one used in 2000 on the inside shoulder of westbound US 18 near Rudd, Iowa at a super-elevated curve. The edge drop-off was 4 in. before the treatment and became 2 in. after two months of treatment. However, there were problems associated with the procedures and equipment for the treatment.

Unfortunately, the soapstock clogged the spray nozzles during the operation and the maintenance crew spent considerable effort unplugging nozzles. Later, the researchers identified the vendor for the product used in 2000 and purchased the product from it. Researchers further investigated newly-purchased soapstock with desirable results (White et al. 2007).

The previous field investigations and study reported by Jahren et al. (2011) indicated likely benefits for using soapstock to stabilize granular shoulders under the right conditions. Based on the documented benefits and local availability of soapstock, this research was focused specifically on the application of soapstock on granular shoulders in selected locations around Iowa.

It was determined that pilot testing at a full scale would be useful to further ascertain the efficacy of soapstock for mitigating edge-rutting issues and stabilizing granular shoulders in Iowa. If the results are positive, researchers could provide guidance on appropriate locations and conditions for applying soapstock effectively. More importantly, the documented application techniques could be used as the guidance for those who want to apply soapstock for stabilizing granular shoulders but might not be familiar with this technique.

CHAPTER 3. PLAN SOAPSTOCK PILOT CONSTRUCTION

Location Selection

Before the test sections could be constructed, locations needed to be selected for application. Originally, the Iowa DOT was planning to pave shoulders identified with edge-rutting problems around Iowa, but garage supervisors reported many more locations than the budget could address. So, many problematic shoulders could not be paved due to lack of budget.

From the shoulders being left unpaved, the researchers selected locations with a moderate traffic volume (less than 6,000 vpd) as suggested by Jahren et al. (2011). In northern Iowa, a group of locations were selected near Algona, Garner, and Leland, with another group near Allison, Shell Rock, Waverly, and Denver. In northeastern Iowa, a group of locations were selected near West Union, Elkader, and Elgin. For most locations, the traffic volume varied from 1,000 to 6,000 vpd. The one exception was near Denver, Iowa, which is a four-lane divided highway with both inside and outside shoulders and AADT of 6,500 per lane northbound (NB) and 8,000 per lane southbound (SB). Each location is described in Table 1.

Basically, for locations where the edge rut was the only concern, soapstock could be sprayed at a width of 4 ft. For locations where gullies due to water erosion were identified near the grass line, soapstock would be applied for the full width of the shoulder.

Table 1. Selected work locations by garage supervisors from Iowa DOT District 2

Garage	Work Location
Area I: Algona and Garner	US 18
	1.01. MP 161.6 to 161.9 both sides – around Garner
	US 69
	1.02. MP 210.8 to 211.4 both sides – north of Leland
	1.03. MP 209 to 209.4 SB – south of Leland
	US 169
	1.04. MP 195.5 to 196 SB – south of Algona
	1.05. MP 194.8 to 195.5 SB – south of Algona
Area II: Waverly and Allison	IA 3
	2.01. MP 226.2 to 226.6 both sides – east of Waverly
	US 63
	2.02. MP 174.6 to 177 outside and inside, both sides – Denver
	IA 3
	2.03. MP 220 to 220 WB – Waverly
	2.04. MP 215 to 216 both sides – Shell Rock
	2.05. MP 205.1 to 205.7 both sides – east of Allison
Area III: West Union and Elkader	US 18
	3.01. MP 264.5 to 265 both sides – east of West Union
	3.02. MP 269.8 to 271 both sides – west of Clermont
	IA 13
	3.03. MP 75 to 75.7 NB – Elkader
	3.04. MP 75 to 75.2 SB – Elkader
	3.05. MP 72.4 to 74 NB – south of Elkader
	3.06. MP 70 to 70.1 NB – south of Elkader
	3.07. MP 69.3 to 69.6 SB – south of Elkader
	W-51 (measured from intersection of W-51 and 215th Street)
	3.08. 3,600 to 4,460 ft south NB – south of Elgin
	3.09. 70 to 1,050 ft south NB – south of Elgin
	3.10. 1,760 to 4,000 ft south SB – south of Elgin

Mapping of Work Locations

For selected work locations, general information such as the route and milepost (MP) number was included in the document received from Iowa DOT personnel. With this general information, the latitude and longitude for all work locations were determined using the Iowa linear referencing system (LRS), which could be accessed from the Iowa DOT website. As a geospatial system, the Iowa LRS database includes global positioning system (GPS) locations for all US, interstate, and Iowa state routes with designated mileposts (Iowa DOT 2011). Then, the latitude and longitude for work locations were input manually into the handheld GPS unit by researchers as waypoints, and also used to generate electronic maps using Google Map.

Pre-Construction Field Tests and Measurements

On the first set of field trips, researchers brought the printed Google maps for general guidance. After the researchers arrived at the local maintenance garage, the garage supervisor led them to the problematic shoulder sections and indicated the beginning and endpoints, at which the researchers marked with wood lath. In addition, the handheld GPS unit was used to locate the endpoints electronically. After the initial locations were determined with the help of the garage supervisor, researchers then returned to each location and conducted field tests and measurements. Digital photos were taken to document the condition of each site.

Dynamic Cone Penetrometer (DCP) Tests

Dynamic cone penetrometer (DCP) tests were conducted to assess the stiffness and stability of the shoulder material. The test procedure was performed according to the "Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications" (ASTM D 6951/D 6951M - 09). Figure 4 (bottom left) shows researchers doing a standard DCP test.

Figure 4. Profile test (top left), Clegg hammer test (top right), DCP test (bottom left), and aggregate samples (bottom right)

With collected DCP data, California bearing ratio (CBR) plots could be developed for each location. CBR value of shoulder subgrade could be estimated from the average penetration rate. For post construction observations, DCP tests were replaced with Clegg hammer tests to reduce field time requirements.

Clegg Hammer Tests

Clegg hammer tests were also used to measure shoulder material stiffness. The test procedure was conducted according to the "Standard Test Method for Determination of the Impact Value (IV) of a Soil" (ASTM D 5874 – 02 (2007)). Figure 4 (top right) shows researchers performing a standard Clegg hammer test.

Both DCP tests and Clegg hammer tests were conducted to obtain the stiffness of shoulder materials along the work section, basically at or close to start- and endpoints, as well as at the midpoint. Although results from DCP tests might be more accurate, the accuracy level of the Clegg hammer tests were considered to be sufficient for the purposes of this investigation. Therefore, the Clegg hammer was used more often because of its convenience and shorter time cycle. At the same location where DCP and Clegg hammer tests were conducted, elevation profiles were measured and aggregate samples were taken.

Elevation Profile Measurements

Elevation profile measurements were conducted to document the slope of the shoulder surface and the depth of the edge rut. An angle iron was placed above the shoulder surface with one end set on the pavement edge and another end attached to a G-shaped clamp. To make sure the angle iron was level, a torpedo level was set at the midpoint of the angle iron and the G-shaped clamp was adjusted accordingly.

After the initial leveling process was completed, the vertical distance from the shoulder surface to the bottom edge of angle iron was measured by placing a ruler perpendicular to the angle edge, as shown in Figure 4 (top left). For each location, measurements were taken at a horizontal distance of 2 in. (5 cm), 6 in. (15 cm), 12 in. (30 cm), 18 in. (46 cm), 24 in. (61 cm), 36 in. (91 cm), and 48 in. (122 cm) from the pavement edge. If the shoulder was quite wide, additional measurements were taken at 60 in. (152 cm) and 72 in. (183 cm) where applicable.

In addition, the following procedure was followed to validate the accuracy of this type of measurement. A 3.75 in. tall metal shelf was set on the flat ground. One end of the angle iron was placed on top of the shelf, and the other end was adjusted to make sure the angle iron was level, assisted with a torpedo level. At 72 in. away from the object horizontally, the elevation of the bottom surface of the angel iron was read from a ruler. After this process was repeated 10 times, it was found that the error of this measurement was within 1/4 in. in elevation difference over a 6 ft horizontal distance.

Gradation Tests

For each location, an aggregate sample was collected by excavating the granular shoulder material, as shown in Figure 4 (bottom right). An additional sample was taken in places where fresh aggregate had been recently spread on the shoulder. The samples were used for conducting further gradation tests following the "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates" (ASTM C 136-01 (2001)). In addition, Atterberg limits tests were conducted following ASTM D 4318-10 to measure the plasticity and liquid limit of aggregate samples.

Equipment Selection

After the preconstruction observations and tests, researchers began to plan for soapstock application. Some questions had been raised, such as which equipment can be used for application, how should the equipment be arranged for a smooth and safe operation, and what amount of oil and sand will be needed every day? Possible solutions about the equipment issue were discussed with Iowa DOT personnel and garage supervisors, and the final decisions were made by garage supervisors based on available resources and their previous experience with maintenance operations.

The water truck and sand trucks were owned by the Iowa DOT (bottom of Figure 5).

Figure 5. Road grader (top left), soapstock truck (top right), water truck (bottom left), and sand truck (bottom right)

In previous projects, a “spinner,” which was usually used to spread deicing salt on the road in winter, was used on the sand truck to spread sand on the shoulder. Using the spinner, for more than one pass was needed to obtain required coverage, which caused the sand application process to become the controlling process that slowed progress for the entire operation.

For this research project, it was found that the spinner could be replaced with a chip spreader attached to the back of a dump truck; this unit was originally used for spreading chips for chip-seal maintenance. With a chip spreader, one pass would be enough to obtain the required coverage. Maintenance personnel modified the chip spreader by placing a wood plate across the opening of the dump gate to adjust the open width. The wood plate could be removed easily.

The semi-truck with the soapstock spray rig (Figure 5 top right) was provided by Boer and Sons Incorporated, which also provided the soapstock, and Jerry Boer assisted with the application process.

Update of Google Map and New Diagrams

The map was updated with the start- and endpoint for each work location marked on a GPS unit during the first trip. By drawing a line that was snapped to the road between the two endpoints on the map, the length of work was calculated automatically. The amount of soapstock and sand needed were estimated with the calculated length of work and expected spraying width and application rate. Then, researchers made a diagram (Figure 6) to show the general route, the length of work, and the amount of soapstock and sand needed for each location, which was intended to help garage supervisor and equipment operators make more effective decisions using this information.

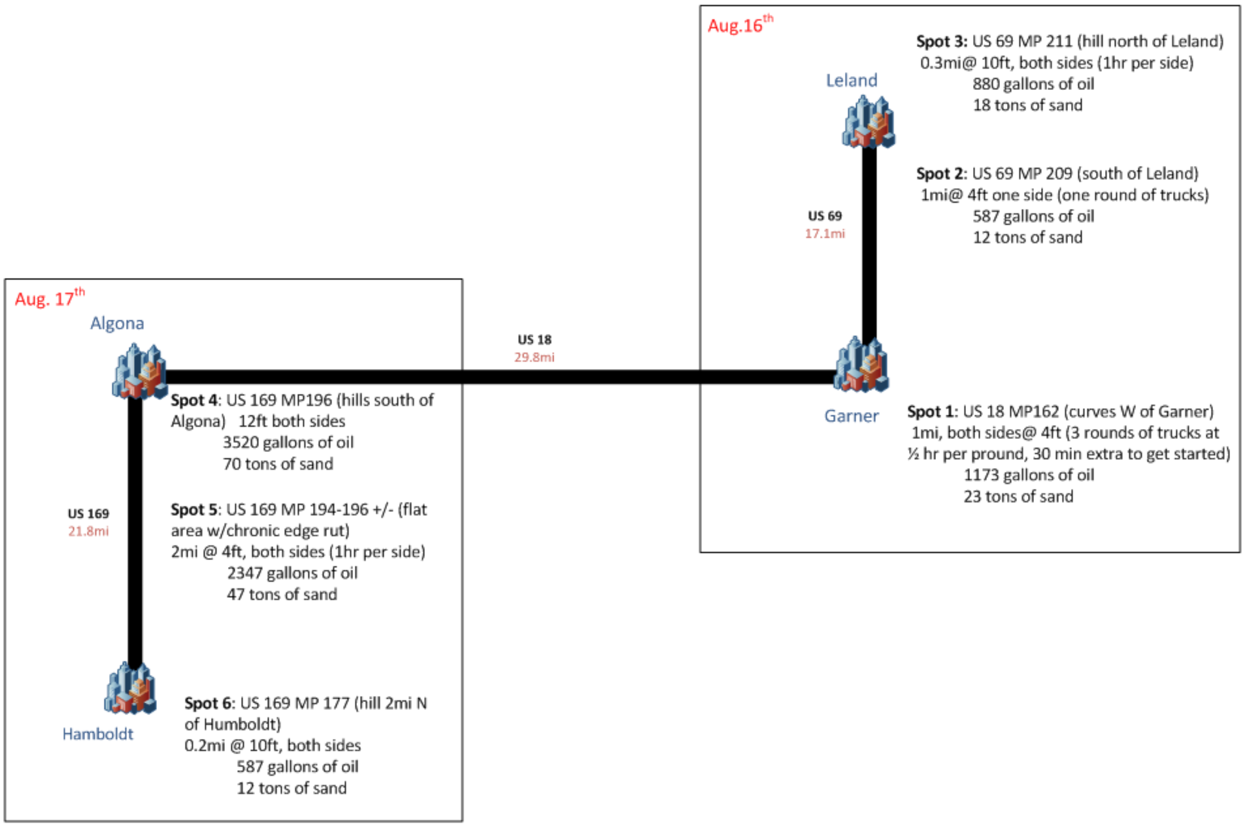


Figure 6. Sample spraying route for Algona and Garner, Iowa

CHAPTER 4. EXECUTE SOAPSTOCK PILOT CONSTRUCTION

Construction activities were conducted at the three test areas selected during the planning stage from August 16 through September 2, 2011. The dates for each area are listed in Table 2.

Table 2. General schedule for pilot testing project

Phases	Date	Work Locations
Pre-Construction Measurements	08/02/11	Humboldt*, Algona, Britt*, and Leland
	08/03/11-08/04/11	Waverly, Shell Rock, Allison, and Denver
	08/10/11-08/11/11	Elgin, Wadena, S. of Elkader, and E. of West Union
Pilot Construction Activities	08/16/11-08/17/11	Algona, Garner, and Leland
	08/18/11-08/19/11	Waverly, Shell Rock, Allison, and Denver
	08/30/11-08/31/11**	Waverly and Denver
	09/01/11-09/02/11	Elgin, Wadena, S. of Elkader and E. of West Union
Post-Construction Observations	10/13/11-06/21/12	Algona, Garner, and Leland
	10/29/11-06/21/12	Waverly, Shell Rock, Allison, and Denver
	10/28/11-06/21/12	Elgin, Wadena, S. of Elkader and E. of West Union

*Not sprayed during construction
**Second time spraying soapstock

Two of the locations visited during the initial pre-construction measurements did not have any process any soapstock applied (the soapstock supply ran out while applying to higher priority locations), while some of the shoulders near Waverly and Denver had a second coat applied.

For the soapstock application process, the work train included a water truck, soapstock distributing truck, and sand truck, which would be operating in the order with the time lags indicated right to left in Figure 7.

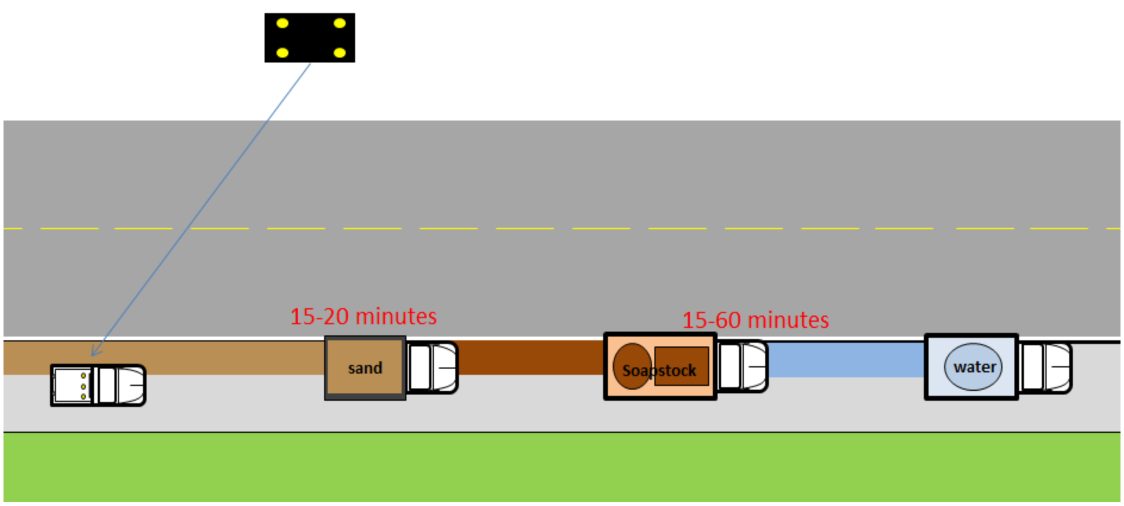


Figure 7. Basic work train setup for soapstock application

The detailed construction activities are explained in the following sections for each of the three geographic areas.

Area I: Algona and Garner

This area includes five test sections serviced by the Algona and Garner Garages under the supervision of Scott Loge. A description of spraying locations, actual work length, and spraying width is shown in Table 3.

Table 3. Spraying work location description for Area I: Algona and Garner

Sec. No.	Location	Route	Start MP	End MP	Shoulder	Actual length (ft)	Sprayed width (ft)	Sprayed area (yd^2)
1.01	Garner	US 18	161.6	161.9	Both	3,024	4	448
1.02	North of Leland	US 69	210.8	211.4	NB	2,112	10	782.22
					SB	2,112	6.5	508.44
1.03	South of Leland	US 69	209	209.4	SB	1,584	4	234.67
1.04	South of Algona	US 169	195.5	196	SB outside	5,786	8.5-12 varies	/
1.05	South of Algona	US 169	194.8	195.5	Both	5,238	4	776

On August 16 and August 17, 2011, the weather was cool and dry on the construction sites. The general construction activities for each location were performed in following steps.

1. The shoulder was first properly bladed a few days ahead of construction. For most shoulders, no new aggregate was added, except for the northbound (NB) shoulder near north Leland. This was done to correct water erosion ruts near the grassline. The surface was lightly compacted to increase the stability of the surface.

2. On the day of construction, traffic control was set up. A traffic sign was attached to a pick-up truck with an amber flashing light and it moved slowly behind the operating equipment.

3. The water truck went ahead to spray water on the shoulder. (Sufficient moisture is required for a successful application of the soapstock. Insufficient moisture could block the soapstock from penetrating into the shoulder.) Maintenance personnel used their experience to select the appropriate amount of water to spray and observed the drying process to decide when the soapstock could be applied. A trial and error approach was adopted to find the right amount of water and timing.

4. After the water had soaked in for about half an hour, the soapstock was sprayed on the moist shoulder by the soapstock distributor. A worker rode on the back of the spray rig to control the number of operating nozzles and ensure the soapstock was distributed evenly on the shoulder at the proper width. This process is shown in Figure 8.

Figure 8. Soapstock application process

Usually, the width of sprayed soapstock was 4 ft, which required two nozzles working simultaneously. North of Leland, soapstock was applied at full width going up to the hill, because gullies caused by water erosion tended to developed near the grass line (they had been filled in with new compacted aggregate before soapstock application commenced). The result of this application is shown in Figure 9.

Figure 9. Soapstock applied on the shoulder of US 69 up the hill near Leland, Iowa

5. After the soapstock was applied for 15 minutes to 20 minutes, two sand trucks with the modified chip spreader started to spread a thin layer of sand over the treated surface. The thickness of sand was about 1/2 in., and the width of sand was adjusted based on the width of soapstock applied on the shoulder. A second/ back-up sand truck was waiting. When the sand in one truck ran out, the back-up truck would run forward and the empty one would go back for more sand. The result of this application is shown in Figure 10.

Figure 10. Sand applied on the shoulder of US 18 near Garner, Iowa

Section 1.05 south of Algona required a considerable amount of soapstock because of its length and width (full width because the road is on a hill and the shoulders are subjected to considerable water erosion). Part of the work was accomplished on the first day of construction, and the remainder was accomplished on the second day.

During the soapstock application operation on August 17, 2011, the soapstock was found to have not-properly penetrated into the shoulder due to an overly-dry surface, so the spraying work was stopped and the water truck had to complete one more pass to increase the moisture content of the shoulder to the desired level. Around 11a.m. on that day, one of the sand trucks had a mechanical problem, which caused a delay. This made the whole operation slower than expected.

In addition, the operator of the soapstock truck tried two methods to obtain a heavier coverage at Section 1.05. One way was to run a second pass on the southbound (SB) shoulder. The other way was to drive slowly on the NB shoulder. Both methods worked well in terms of achieving heavier coverage.

In one place, recycled asphalt paving material was newly spread on the shoulder. After the soapstock and sand was applied to it, the mixed material looked much like dense-graded aggregate, with a noticeably greater amount of fine particles (Figure 11).

Figure 11. Soapstock and sand applied to recycled asphalt paving materials

Area II: Waverly and Allison

This area includes five test sections within the area served by the Waverly and Allison Garages and under the supervision of Russell Frisch. A description of application locations, actual work length, and spraying width are shown in Table 4.

Table 4. Spraying work location description for Area II: Waverly and Allison

Sec. No.	Location	Route	Start MP	End MP	Shoulder	Actual length (ft)	Sprayed width (ft)	Sprayed area (yd^2)
2.01	East of Waverly	IA 3	226.2	226.6	Both	3,122	4	462.52
		IA 3	226.4	226.6	Both	1,561*	4	231.26
2.02	Denver	US 63	174.6	177	SB outside	7,755	4	1,148.89
					SB inside	9,063	4	1,342.67
					NB outside	7,461	4	1,105.33
					NB inside	9,305	4	1,378.52
			176.5	177	SB outside	1,584*	4	234.67
			176	176.5	NB outside	3,168*	4	469.33
2.03	West of Waverly	IA 3	220	220	WB	1,491	4	220.89
2.04	Shell Rock	IA 3	215	216	Both	11,170	4	1,654.81
2.05	East of Allison	US 63	205.1	205.7	Both	8,280	4	1,226.67

*Second time spraying soapstock

The general construction activities were performed following the same procedures described for Area I.

On August 18, 2011, rain occurred during the time that the application process was executed around Allison and Shell Rock. Figure 12 shows the result of the soapstock application on the westbound (WB) shoulder of IA 3 nearby and east of Allison during the rain.

Figure 12. Spraying in the rain on IA 3 near Allison, Iowa

The rain became heavy in the afternoon, so work was suspended until the next day. Apparently, the rain did have some negative effect on the treatment, because many of the locations where soapstock was applied during the rain performed poorly compared to other work locations in post observations.

On August 30 and August 31, 2011, the second coat was applied on the shoulders at Section 2.01 east of Waverly and Section 2.02 near Denver. The weather on August 30 was cloudy with very light rain, and the weather on August 31 was cool and cloudy. On the morning of August 30, the soapstock was applied in the normal manner, except that watering was not necessary because of the light rain.

Section 2.02 was located on curves of US 63 near Denver. This highway is a four-lane divided highway with a traffic level (6,000 ADT) heavier than the targeted study level. Soapstock was applied on both outside and inside shoulders and adjacent to both SB and NB lanes. The result of one section of the treated shoulder is shown in Figure 13.

Figure 13. Soapstock and sand applied on the shoulder of US 63 near Denver, Iowa

In the same location, Section 2.02, one action observed by researchers might be meaningful for a successful application. This was near the Janesville exit on US 63 near Denver, and the treated surface was rolled after the sand application. The result of this is shown in Figure 14.

Figure 14. Surface rolled after sand application for the shoulder of US 63 near Denver, Iowa

Area III: West Union and Elkader

This area includes 10 test sections within the areas of responsibility for the West Union and Elkader Maintenance Garages under the supervision of Roger Burns. A description of spraying locations, actual work length, and spraying width is shown in Table 5.

Table 5. Spraying work location description for Area III: West Union and Elkader

Sec. No.	Location	Route	Start MP	End MP	Shoulder	Actual length (ft)	Sprayed width (ft)	Sprayed area (yd^2)
3.01	East of West Union	US 18	264.5	265	Both	3,048	4	451.56
3.02	West of Clermont	US 18	269.8	271	Both	8,900	4	1,318.52
3.03	Elkader	IA 13	75	75.7	NB	3,090	12	1,373.33
3.04	Elkader	IA 13	75	75.2	SB	1,330	12	591.11
3.05	South of Elkader	IA 13	72.4	74	NB	4,890	4	724.44
3.06	South of Elkader	IA 13	70	70.1	NB	740	10	274.07
3.07	South of Elkader	IA 13	69.3	69.6	NB	1,315	10	487.04
3.08	South of Elgin	W 51	3,600 ft*	4,460 ft*	NB	860	2	63.70
3.09	South of Elgin	W 51	70 ft*	1,050 ft*	NB	980	2	72.59
3.10	South of Elgin	W 51	1,760 ft*	4,000 ft*	SB	2,240	2	165.93

*Distances south of W-51 and 215 Street intersection

On September 1, 2011, the weather was sunny and dry in Elkader. On September 2, 2011, the weather was cool and cloudy with intermittent rain in some places. The general construction activities were performed following the same procedures described for Area I. For Section 3.03-3.04 near Elkader, soapstock was applied at a 12 ft width because of the gullies were developing near the grass line, as shown in Figure 15. The resulting condition of one of the sections just after sand was spread is shown in Figure 16.

For Section 3.08-3.10 south of Elgin, the shoulders were much narrower than the ones in other places. Thus, soapstock was sprayed at a 2 ft width there. The road was closed temporarily during the application. This road is under the jurisdiction of Fayette County.

Figure 15. 12 ft wide soapstock applied on the shoulder of IA 13 east of Elkader, Iowa

Figure 16. Sand applied on the shoulder of IA 13 east of Elkader, Iowa

One action drew researchers' attention when Boer used the plastic pipe and pump to recirculate soapstock from the bottom to the top of the storage tank (Figure 17). The day before this action, the treatment showed inconsistent results between the morning and afternoon work session, which was believed to be a consequence of soapstock segregation. According to Boer, material with low viscosity tends to settle to the bottom, while material with high viscosity tends to flow to the top. After the soapstock was circulated, its viscosity was more consistent, so it could be distributed evenly and provide better performance.

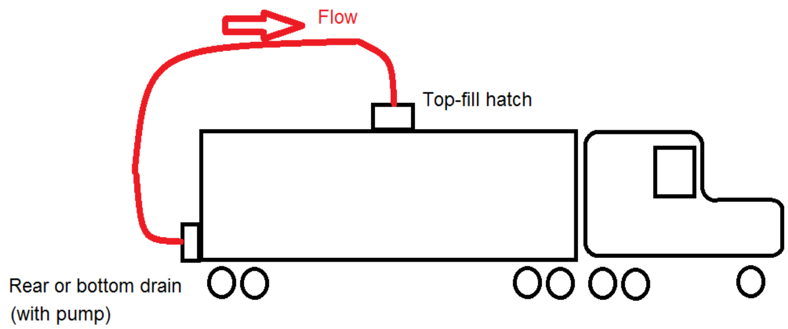


Figure 17. Recirculating soapstock to provide more consistent density (Harris 2011)

While applying soapstock onto Fayette County Road (CR) W-51, the county maintenance crew developed an alternate method for placing sand over the soapstock. A county truck placed sand on the white line by using an edge rut chute. Then, the motor grader bladed sand over the surface on which the soapstock was applied (Figure 18).

Figure 18. Grader bladed over the shoulder applied with sand

This procedure worked well for places where the shoulder surface was lower than the pavement, but not for places where the shoulder surface was higher than the pavement. The newly-applied soapstock on higher shoulder surfaces was scraped off the shoulder by the motor grader blade.

Application Rate and Overall Productivity

The water truck ran at a speed of 3 to 5 mph (5 to 8 km/hr), which could spray 1/4 gal water over 1 yd^2 of shoulder. The soapstock spray rig moved at a speed of 2 to 3 mph (3 to 5 km/hr) when spraying soapstock on the moist shoulder with an average application rate of 1/4 gal water over 1 yd^2. A sand truck with a chip spreader spread sand on the treated shoulders at a speed of 3 to 5 mph (5-8km/hr), which could achieve an average application rate of 10 lb per yd^2.

Based on observations, the maximum productivity for the "work train" (water truck, soapstock spray rig, and sand truck) was two lane-miles per hr. After considering the allowance for start and stop times, refilling tanks and sand trucks, and other miscellaneous time, the maximum daily productivity could be 8 to 10 lane-miles (13 to 16 lane-km).

During the whole construction period, there was one time that the daily productivity was up to 12 lane-miles, which was the highest observed during the application process. This was because personnel were already quite familiar with all application techniques and there were no interruptions that occurred during the operation.

More often, the daily productivity remained approximately 6 lane-miles. Time and effort were needed for trial and error in application techniques and subsequent adjustments. At times, personnel needed to make decisions or adjustments according to actual site conditions or unexpected events. Also, in some cases, the soapstock was applied at the full with of the shoulder; such a process required more tips back to the supply tanker for the spray rig in comparison to a process for applying to a four foot width.

CHAPTER 5. MONITOR SOAPSTOCK AFTER PILOT CONSTRUCTION

After soapstock was applied on all test sections, post-construction observations and measurements were made to evaluate results. Trips for the full set of measurements and observations were scheduled in late October 2011and June 2012. Between these official trips, researchers sometimes drove to the field to visually monitor the shoulder performance and obtain updated photos.

Guidance of Google Map and GPS Hand Unit

Before starting each trip, researchers printed the Google maps showing the location of the soapstock application work. The maps served to provide general guidance, while exact locations were determined with the aid of a GPS hand unit. All waypoints were recorded by a GPS hand unit during the preconstruction measurements phase, so the researchers could find the beginning and end of each test location by searching for corresponding waypoints.

Update of Photos

During each trip, photos were taken to document the performance of treated shoulders. If there were any new edge-rutting problems or places where soapstock was removed, researchers made a closer examination and tried to find what caused those problems. In addition, photos were taken when tests or measurements were taken at a certain place.

Tests and Measurements

The post-construction tests and measurements were similar to the preconstruction tests and measurements. Clegg hammer tests and elevation profiles were taken for each shoulder section. Instead of taking both DCP tests and Clegg hammer tests, only Clegg hammer tests were taken to improve time and cost efficiency. Data from Clegg hammer tests were judged to be sufficient for the purposes of this investigation and gave researchers an immediate indication of the stiffness of shoulder materials.

For places where the road had a noticeable slope, the slope of road profile was also taken by using the differential leveling method (Caltrans 2006). The equipment researchers used for this measurement was AT-22A automatic levels (Topcon Corporation) shown in Figure 19, which was usually set some distance from the top of the slope.

Another researcher would stand uphill from the level, holding a leveling rod with its bottom on the ground. The elevation difference could be obtained from the readings on the leveling rod, and the horizontal distances could be measured by a measuring wheel. The ratio of the elevation difference and horizontal distance is the slope of the road.

Figure 19. Level for measuring the road profile

Data Analysis

Percentage of Successful Application Length

During the summer of 2012, researchers visited all test locations to check shoulder conditions to ascertain whether the soapstock application had survived the winter. Researchers measured the length of treated sections with newly-developed edge ruts using a measuring wheel. The error of this measurement was ±0.6%, which was obtained after averaging the results from 13 measurements for the same 100 ft distance in a flat parking lot.

The percentage of successful application could be obtained by dividing the length of shoulders with good performance by the total length of the test section. The results were considered to be an indication of whether soapstock was effective in mitigating edge-rutting problems and stabilizing shoulders. The results are shown in the next chapter titled Data Synthesis.

CBR

Clegg hammer data were collected from several locations along each shoulder section before and after soapstock application. Readings directly from the Clegg hammer represent Clegg impact values (CIVs), which could be then converted to CBR values to measure the stiffness of shoulder materials. For this investigation, the equation applied to make the conversion was as follows (CLEGG 1986):

$$CBR = (0.24 \times CIV + 1)^2$$

This equation proved to be appropriate for general case. Then, individual CBR values were averaged to get the average CBR for a whole shoulder section.

Shoulder Cross Slope

Elevation profiles were taken from several locations along each shoulder section before and after soapstock application. Collected data were graphed using SigmaPlot 12 (by Systat Software Inc.) to show the approximate cross slope of each shoulder. In addition, the slope was calculated by dividing the elevation difference of 6 in. and 48 in. away from the pavement edge by their horizontal distance (42 in.). The average cross slopes of shoulders were obtained to allow a rough comparison between different shoulder sections.

Slope of Road Profile

For every observed location where the road profile had a noticeable slope, the slope was measured by applying the differential leveling method (Caltrans 2006), which calculated the ratio of the elevation difference between two spots and their horizontal distance. The horizontal distance between two selected spots on the hill was at least 100 ft, obtained by using a measuring wheel.

Gradation Distribution

The classification of shoulder materials were done by following the Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) standard.

For granular shoulders in Iowa, either type A or type B gravel is used. Type A refers to a crushed stone or a gravel-limestone mixture. Type B refers to a uniform mixture of coarse and fine aggregates produced from crushing limestone, dolomite, or quartzite (Iowa DOT Standard Specifications 2005). For both type A and B gravels, the maximum size is 3/4 in. By comparing to the Iowa DOT Class A/B Aggregate Specification, the percentage above upper fine limit at #4 sieves was calculated for each material sample. The detailed gradation graphs for all shoulder material samples were generated using GEOSYSTEM version 2.1 (by GEOSYSTEM Software) and are included in Appendix A.

Traffic Level

The traffic level for each shoulder section was obtained from 2010 vehicle traffic movement maps on the Iowa DOT website. These maps provide traffic volumes expressed as AADT for the major roads and highways between cities.

Research Limitations

During the construction process, the application rate was not recorded for every shoulder section. The average application rate was taken for several shoulder locations. After the application was made to a few locations, the soapstock spray rig was weighed so the amount of material used could be calculated where actual operation time was recorded.

Some shoulder samples were taken after the soapstock was applied, including Sections 1.01, 2.02 (inside shoulders), 3.05-3.07, and 3.08-3.10. Therefore, gradation results for those places might not represent the shoulder properties exactly before the soapstock application.

Slopes of shoulders were taken at several locations along one shoulder and then averaged to obtain an average value. This average value roughly represents the general cross slope for a shoulder section; however, the actual shoulder slope could vary a lot at various places within the section.

CHAPTER 6. DATA SYNTHESIS

The research team made observations and measurements during each post-construction field trip. The latest observation was made in late June 2012 (10 months after the initial soapstock application). Researchers found that most shoulders performed well with soapstock staying firmly on the surface. In a few places, new edge ruts or potholes had developed. In a few other places, soapstock had been removed by traffic although there were no present edge ruts. Results are shown and discussed further for each of the three areas.

Key to Specific Locations Listed in Tables

Generally, the following abbreviations appear in the tables for specific locations that were identified and monitored:

E: Elkader
EN: Elgin NB
ES: Elgin SB
GW: Garner West
SVA: South of Algona (but possibly not true in some cases)
UN: West Union
UNC: West Union (County Road)
WV: Waverly

Generally, taking GW01A, for example, GW refers to the town (Garner West), 01 means the first work session in this area, and A/B/C/D refers to the specific location/spot in this test section.

Area I

Observed Performance

All newly-developed edge ruts or potholes up until June 21, 2012 are identified and listed in Table 6 for the five sections in Area I. Problems occurred in Sections 1.01 and 1.05, where Section 1.01 contained one rut and one pothole and Section 1.05 had two ruts.

Table 6. New problematic spots identified in Area I

Sec No.	Location	Route	Specific Location	Problematic Length (ft)	Width (in.)	Depth (in.)	Notes
1.01	Garner	US 18	0.15 mi east of GW01A EB	45	6	0.5	rut
1.01	Garner	US 18	90 ft east of GW01A WB	5	13	0.75	pothole
1.05	South of Algona	US 169	0.13 mi south of AF01 SB	157	10	1.5	rut
1.05	South of Algona	US 169	0.23 mi north of AF01 SB	69	17	2.5	rut

Table 7 lists the calculated percentage of success for each treated shoulder section and the overall area. The total problematic length was 276 ft out of 1,9856 ft, so the total percentage of successful application was 98.61% for Area I.

Table 7. Percentage of successful application for Area I

Sec No.	Location	Route	Successful Length (ft)	Problematic Length (ft)	Total Length (ft)	Percentage of Success
1.01	Garner	US 18	2,974	50	3,024	98.3%
1.02	North of Leland	US 69	4,224	0	4,224	100.0%
1.03	South of Leland	US 69	1,584	0	1,584	100.0%
1.04	South of Algona	US 169	5,786	0	5,786	100.0%
1.05	South of Algona	US 169	5,012	226	5,238	95.7%
Total			19,580	276	19,856	98.6%

Figure 20 provides an example of good shoulder performance for this area. This shows a section of the US 169 shoulder adjacent to the SB lane just south of Algona, where a thin layer of soapstock remained firmly on the shoulder. Another example is shown in Figure 21. The shoulder section was on US 18 near Garner with a thicker layer of soapstock on surface.

Figure 20. Southbound shoulder of US 169 south of Algona, Iowa

Figure 21. Eastbound shoulder of US 18 near Garner, Iowa

Figure 22 shows an example of newly-developed edge ruts. The shoulder section was on US 169 just south of Algona. The photo was taken right after a brief rainfall in Algona, and a small water pond was observed.

The possible reason for this failure might be water erosion. There is an uphill grade adjacent to this location, which results in water runoff that erodes the edge drop off area.

Figure 22. Edge rut developed south of Algona, Iowa

Figure 23 shows an example of a comparison of an untreated shoulder edge and the untreated one.

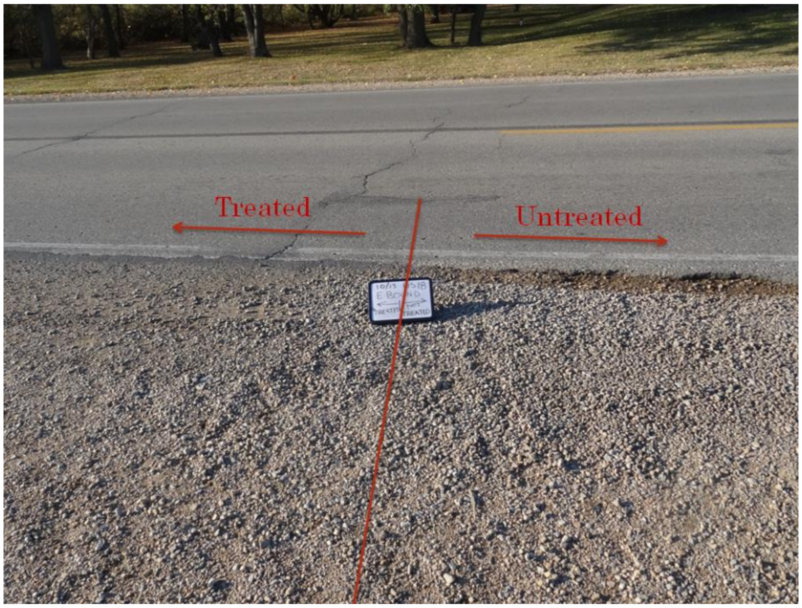


Figure 23. Results compared for treated and untreated shoulder edge

The photo was taken October 13, 2011, about two months after soapstock application on US 18 shoulders near Garner. On the right side of the dividing line, a small amount of edge rutting was observed where soapstock was not sprayed. On the left side, the original edge rut was more severe than the one on the right, but it had been filled with granular material and covered with soapstock.

California Bearing Ratio (CBR)

CBR results before and after soapstock applications are listed for each Area I shoulder section in Table 8. Clegg hammer data were collected August 3, 2011 and June 21, 2012. More detailed CIV data for selected locations along each section and the conversion of CIV to CBR are included in Appendix A.

Table 8. CBR values of shoulder materials in Area I

Sec No.	Location	Route	Average CBR	
			pre-app	post-app
1.01	Garner	US 18	/	75.9
1.02	North of Leland	US 69	12.6	36
1.03	South of Leland	US 69	83.5	44.8
1.04	South of Algona	US 169	55.3	76.4
1.05	South of Algona	US169	/	54.1

From this table, original shoulder materials were sufficiently stiff with CBR values greater than 10. Except for Section 1.03, CBR values increased after the soapstock was applied.

Shoulder Cross Slope

For each shoulder section, elevation profiles were taken before and after soapstock application. The average cross slope for each shoulder section was calculated and is listed in Table 9.

Table 9. Average cross slopes of shoulder sections in Area I

Sec No.	Location	Route	Average Slope (%) Aug. 2011	Oct. 2011	June 2012
1.01	Garner	US 18	/	5.7	3.3
1.02	North of Leland	US 69	6.3	7.4	8
1.03	South of Leland	US 69	3.9	6.5	6
1.04	South of Algona	US 169	5.5	5.4	3.6
1.05	South of Algona	US 169	/	7.1	8

Elevation profile data were collected in August and October 2011 and June 2012. The shoulder cross slopes varied a lot from one place to another. More detailed data and plotted graphs are included in Appendix A.

Grade of Road Profiles

The grade of one road profile was measured for Section 1.02 near north Leland with a grade of 3.6%. The grade of three road profiles were measured just south of Algona, two of which were in Section 1.04, with grades of 3.6 and 3.3%, and one of which was in Section 1.05, with a grade of 1.5%. The detailed results are listed in Table 10.

Table 10. Grades of road profiles in Area I

Sec No.	Location	Length (ft)	Elevation difference (ft)	Slope (%)
1.02	0.11 mi north of SVA07B NB	183	6.55	3.6%
1.04	0.19 mi north of SVA04B SB	257	9.3	3.6%
1.04	0.15 mi south of SVA04A SB	150	4.95	3.3%
1.05	0.12 mi south of AF01 SB	150	2.3	1.5%

Gradation Sample Results

The classification for each shoulder material sample is listed in Table 11 along with the percentage of material above the #4 sieve rates. Based on the Iowa DOT Class A/B aggregate specification, the fine limit at #4 sieves is supposed to range between 30 and 55%. The detailed gradation graphs for all shoulder material samples are included in Appendix A.

Table 11. Gradation results for shoulder materials in Area I

Sec No.	Location	Route	Specific Location	USCS	AASHTO	% above fine limit for Class A gradation @#4
1.01	Garner	US 18	0.15 mi east of GW01A EB	SM	A-1-b	13.7
1.02	North of Leland	US 69	SVA07A NB	SM	A-1-b	20.6
			SVA07A SB	SM	A-1-b	21.6
1.03	South of Leland	US 69	200 ft south of SVA06A SB	SP-SM	A-1-a	12.3
1.04-1.05	South of Algona	US 169	0.62 mi south of SVA04A NB	SW-SM	A-1-a	7.4

Original shoulder materials were all finer than the upper limit of Class A aggregate (55%). The shoulder section north of Leland (Section 1.02) had the finest materials with 20.6% above the fine limit NB and 21.6% above the fine limit SB. The gradations at #4 sieves for Sections 1.04 and 1.05 are relatively close to the specification with 7.4% above the fine limit. From Atterberg limits tests, all materials were determined to be non-plastic.

Traffic

The traffic levels listed in Table 12 were obtained from the traffic map on the Iowa DOT website (Iowa DOT 2010).

Table 12. Traffic levels for Area I test sections

Sec No.	Location	Start MP	End MP	Route	AADT
1.01	Garner	161.6	161.9	US 18	5800
1.02	North of Leland	210.8	211.4	US 69	2250
1.03	South of Leland	209	209.4	US 69	3640
1.04	South of Algona	195.5	196	US 169	2750
1.05	South of Algona	194.8	196	US 169	2750

Area II

Observed Performance

All identified problematic locations up until June 21, 2012 are identified and listed in Table 13 for the five sections in Area II.

Table 13. New problematic spots in Area II

Sec No.	Location	Route	Specific Location	Problematic Length (ft)	Notes
2.01	East of Waverly	IA 3	WV01A	230	Soapstock missing, elevation of pavement raised by new layers of asphalt
2.02	Denver	US 63	330 ft south of WV02A SB	35	No edge ruts, but soapstock had been removed
2.04	Shell Rock	IA 3	Entire section	11,170	
2.05	East of Allison	IA 3	Entire section	8,280	

Most of the problems for this area resulted from the removal of the soapstock by traffic rather than edge ruts or potholes.

Table 14 lists the calculated percentage of success for each treated shoulder section and the overall area. The total problematic length was 19,715 ft of 63,960 ft, so the total percentage of successful application was 69.2% for Area II.

Table 14. Percentage of successful application for Area II

Sec No.	Location	Route	Successful Length (ft)	Problematic Length (ft)	Total Length (ft)	Percentage of Success
2.01	East of Waverly	IA 3	4,453	230	4,683	95.1%
2.02	Denver	US 63	38,301	35	38,336	99.9%
2.03	Waverly	IA 3	1,491	0	1,491	100.0%
2.04	Shell Rock	IA 3	0	11,170	11,170	0.0%
2.05	East of Allison	IA 3	0	8,280	8,280	0.0%
Total			44,245	19,715	63,960	69.2%

Figure 24 provides an example of good shoulder performance for this area. This shows a shoulder section of IA 3 on adjacent to the EB lanes just east of Waverly, where a thick layer of soapstock remained firmly on the shoulder. Another example is shown in Figure 25. This shoulder section was on US 63 near Denver, where soapstock had penetrated into the shoulder and could not be seen easily.

Figure 24. Eastbound shoulder of IA 3 east of Waverly, Iowa

Figure 25. Southbound outside shoulder of US 63 near Denver, Iowa

Figure 26 shows one example of an undesired situation where most soapstock was abraded away by traffic, although neither edge ruts or potholes developed. This was part of the shoulder of IA 3 EB east of Allison. However, an edge drop-off did exist because there was not enough shoulder aggregate in this area to maintain the designed cross slope and fill flush to the pavement edge.

Figure 26. Soapstock missing east of Allison, Iowa

Figure 27 shows another undesired situation where the soapstock was not remaining on the inside shoulder of US 63 NB near Denver. Part of the shoulder materials had been displaced by traffic. Researchers observed that the inside shoulder material was less stable in comparison to the outside shoulder material and was easily prone to displacement.

Figure 27. Northbound inside shoulder of US 63 near Denver, Iowa

California Bearing Ratio (CBR)

For each Area II shoulder section, CBR results before and after soapstock applications are listed in Table 15.

Table 15. CBR values of shoulder materials in Area II

Sec. No.	Location	Route	Average CBR	
			pre-app	post-app
2.01	East of Waverly	IA 3	36.6	30.9
2.02	Denver	US 63	14.5	18
2.03	Waverly	IA 3	24.6	43.2
2.04	Shell Rock	IA 3	48.6	70.2
2.05	East of Allison	IA 3	42.8	73.6

Clegg hammer data were collected on August 4, 2011 and June 21, 2012. Detailed data with CIV for selected spots along each section and conversion of CIV to CBR are included in Appendix A.

From this table, original shoulder materials were stiff enough with CBR values greater than 10. After soapstock was applied on shoulders, CBR values increased for all sections except Section 2.01 east of Waverly. Shoulders near Waverly, Shell Rock, and east of Allison showed a large increase in CBR values, which indicates a large increase in stiffness.

Shoulder Cross Slope

For each shoulder section, elevation profiles were taken before and after soapstock application. The average cross slope for each shoulder section was calculated and is listed in Table 16.

Table 16. Average cross slopes of shoulder sections in Area II

Sec. No.	Location	Route	Average Slope (%)		
			Aug. 2011	Oct. 2011	June 2012
2.01	East of Waverly	IA 3	7.7	6.5	5.4
2.02	Denver	US 63	5.7	6.8	8.3
2.03	Waverly	IA 3	10.4	8.6	7.7
2.04	Shell Rock	IA 3	5.1	5.7	4.2
2.05	East of Allison	IA 3	7.4	6.8	7.1

Elevation profiles data were collected in August and October 2011 and June 2012. More detailed data and plotted graphs are included in Appendix A.

Grade of Road Profiles

For Sections 2.01, 2.02, and 2.03, one grade was identified for each section with noticeable grades of 1.6, 1.4, and 1.6%, respectively. From these calculated grades, the grades were relatively gentle. The detailed results are listed in Table 17.

Table 17. Road profile grades in Area II

Sec. No.	Location	Length (ft)	Elevation Difference (ft)	Slope (%)
2.01	250 ft west of WV01C EB	179	2.9	1.6
2.02	0.25 mi south of WV02A SB	150	2.1	1.4
2.03	400 ft west of WV03B WB	177	2.9	1.6

Gradation Sample Results

The classification for each shoulder material sample is listed in Table 18 along with the percentage above fine limit at #4 sieves listed.

Table 18. Gradation results for shoulder materials in Area II

Sec. No.	Location	Route	Specific Location	USCS	AASHTO	% above fine limit for Class A gradation @#4
2.01	East of Waverly	IA 3	100 ft west of WV01C EB	SM	A-1-a	6.9
2.02	Denver	US 63	100 ft north of WV02A SB outside	SP-SM	A-1-b	17.1
			100 ft south of WV02D NB outside	SP-SM	A-1-b	18.6
			WV02A NB inside	SP-SM	A-1-b	15.7
			WV02A SB inside	GP-GM	A-1-a	0
2.03	Waverly	IA 3	200 ft west of WV03B WB	GP-GM	A-1-a	0.1
2.04	Shell Rock	IA 3	100 ft east of WV04B WB	SM	A-1-b	13.3
2.05	East of Allison	IA 3	50 ft west of WV05C EB	SP-SM	A-1-a	0.9

Based on the Iowa DOT Class A/B aggregate specification, the fine limit at #4 sieves should range between 30 and 55%. Detailed gradation graphs for the shoulder material samples are included in Appendix A.

From this table, original shoulder materials were all finer than the upper limit of Class A aggregate (55%). The outside shoulder near Denver (Section 2.02) had the most fine materials with 18.6% above the fine limit NB and 17.1% above the fine limit SB. For Section 2.05, the gradation almost met the specification with 0.9% above the fine limit. From Atterberg limits tests, all materials were non-plastic.

Traffic

The traffic levels listed in Table 19 were obtained from the map on the Iowa DOT website (Iowa DOT 2010).

Table 19. Traffic levels for Area II test sections

Sec No.	Location	Start MP	End MP	Road	AADT
2.01	East of Waverly	226.2	226.6	IA 3	3,400
2.02	Denver	174.6	177	US 63	6,500-8,000
2.03	Waverly	220	220	IA 3	5,600
2.04	Shell Rock	215	216	IA 3	3,890
2.05	East of Allison	205.1	205.7	IA 3	2,430

Area III

Observed Performance

For Area III, the situation was different than for Area I or Area II. The decision was made to not retain the soapstock application by maintenance garage supervisor Burns since late November 2011. According to Burns in 2012, the soapstock worked well the time of application until the harvest season. During the harvest season, a large amount of heavy farm equipment drove slowly on the shoulders every day in this area. The lugged tires of this equipment broke up the soapstock in many places. Under the circumstances, Burns decided to add new gravel and regrade all shoulders. Unfortunately, researchers did not have the chance to observe that process or take any measurements before the regrading work. Therefore, the percentage of success is not available for Area III. Table 20 shows the total length of the sections for Area III.

Table 20. Area III application sections, which could not be measured

Sec No.	Location	Route	Total Length (ft)
3.01	East of West Union	US 18	3,048
3.02	West of Clermont	US 18	8,900
3.03-3.04	Elkader	IA 13	4,420
3.05-3.07	South of Elkader	IA 13	6,945
3.08-3.10	South of Elgin	W 51	4,080
Total			27,393

Figure 28 shows one shoulder section of US 18 EB east of West Union. Although the shoulder had been regraded, the hard surface resulting from the soapstock could still be observed. Another example is shown in Figure 29. The shoulder was also along US 18, west of Clermont, where the whole section was regraded with new gravel.

Figure 28. Shoulder of US 18 eastbound east of West Union, Iowa

Figure 29. Shoulder of US 18 on eastbound west of Clermont, Iowa

California Bearing Ratio (CBR)

For each shoulder section of Area III, CBR results before and after soapstock application are listed in Table 21.

Table 21. CBR values of shoulder materials in Area III

Sec No.	Location	Route	Average CBR	
			pre-app	post-app
3.01	East of West Union	US 18	50.8	53.2
3.02	West of Clermont	US 18	59.2	61.9
3.03-3.04	Elkader	IA 13	/	46.7
3.05-3.07	South of Elkader	IA 13	58	35.5
3.08-3.10	South of Elgin	W 51	39.1	35.5

Clegg hammer data were collected on August 10, 2011 and June 21, 2012. More detailed CIV data for selected locations along each section and the conversion of CIV to CBR are included in Appendix A.

From this table, original shoulder materials were sufficiently stiff with CBR values greater than 10. Except for places where Clegg hammer data were not taken and Section 1.03, CBR values increased in some cases and decreased in others after the soapstock was applied.

Shoulder Cross Slope

For each shoulder section, elevation profiles were taken before and after soapstock application. The average cross slope for each shoulder section was calculated and is listed in Table 22.

Table 22. Average cross slopes of shoulder sections in Area III

Sec. No.	Location	Route	Average Slope (%)		
			Aug. 2011	Oct. 2011	June 2012
3.01	East of West Union	US 18	5.7	8.5	8.3
3.02	West of Clermont	US 18	10	8.6	6
3.03-3.04	Elkader	IA 13	8.3	10.1	8.3
3.05-3.07	South of Elkader	IA 13	2.8	5.1	5.8
3.08-3.10	South of Elgin	W 51	3.6	9.2	6

Elevation profile data were collected in August and October 2011 and June 2012. More detailed data and plotted graphs are included in Appendix A.

Grade of Road Profiles

For Sections 3.01, 3.02, 3.03-3.04, and 3.08-3.10, one profile grade was identified for each. The steepest grade was in Section 3.08-3.10 just south of Elgin with a grade of 9.7%. Sections 3.01 and 3.03-3.04 had grades of 3.6 and 3.7%, respectively. The mildest grade was on Section 3.02 at 1.9%. The results are listed in Table 23.

Table 23. Slopes of hills in Area III

Sec. No.	Location	Length (ft)	Elevation difference (ft)	Slope (%)
3.01	490 ft east of UN01A EB	150	5.4	3.6
3.02	UN02A EB	150	2.9	1.9
3.03-3.04	330 ft north of E01A NB	100	3.7	3.7
3.08-3.10	340 ft north of EN02A NB	100	9.7	9.7

Gradation Sample Results

The classification for each shoulder material sample is listed in Table 24 along with the percentage above the fine limit at the #4 sieve.

Table 24. Gradation results for shoulder materials in Area III

Sec. No.	Location	Route	Location	USCS	AASHTO	% above fine limit for Class A gradation @#4
3.01	East of West Union	US 18	300 ft east of UN01A EB	SM	A-1-a	5.8
3.02	West of Clermont	US 18	90 ft west of UN02B EB	SP-SM	A-1-a	9.5
			0.28 mi west of UN03B WB	SM	A-1-b	30
3.03-3.04	Elkader	IA 13	330 ft north of E01A NB	SM	A-1-a	2.8
3.05-3.07	South of Elkader	IA 13	0.5 mi south of UN04C NB	SM	A-1-b	11.2
3.08-3.10	South of Elgin	W 51	35 ft north of UNC01AM NB	SM	A-1-b	14.2

Based on the Iowa DOT Class A/B aggregate specification, the fine limit at #4 sieves is supposed to be range from 30 to 55%. Detailed gradation graphs for the shoulder material samples are included in Appendix A.

From this table, original shoulder materials were all finer than the upper limit of Class A aggregate (55%). The shoulders west of Clermont (Section 3.02) had the finest materials with 30% above fine limit WB. The gradations at #4 sieves for Sections 3.03-3.04 and 3.01 are relatively close to the specification with 2.8 and 5.8% above the fine limit, respectively. From Atterberg limits tests, all materials were non-plastic.

Traffic

The traffic levels listed in Table 25 were obtained from the map on the Iowa DOT website (Iowa DOT 2010). For CR W-51, the most recent traffic data available on the DOT website was for 2009 (Iowa DOT 2009).

Table 25. Traffic levels for Area III test sections

Sec. No.	Location	Start MP	End MP	Route	AADT
3.01	East of West Union	264.5	265	US 18	2660
3.02	West of Clermont	269.8	271	US 18	2660
3.03-3.04	Elkader	75	75.7	IA 13	2150
3.05-3.07	South of Elkader	69.3	74	IA 13	2150
3.08-3.10	South of Elgin	70 ft*	4,460 ft*	W 51	610

*Distance south of W-51 and 215th Street intersection

Summary Results for All Locations

Observations were made on 20 treated granular shoulder sections around northern and northeastern Iowa. For each shoulder test section, various tests were conducted to investigate shoulder properties including aggregate gradation, shoulder stiffness, percent grade of the road profile, and cross slope of the shoulder. In addition, traffic levels were identified using the Iowa DOT database (Iowa DOT 2010). The final percentage of successful applications with regard to length was used as an indicator of the effectiveness of the soapstock application on granular shoulders. Results are summarized in Table 26.

Table 26. Summary results for all tested sections (1.01-3.10)

Sec No.	Location	Route	Success (%)	AADT	% above fine limit for Class A gradation @#4	Max Slope of Hill (%)	Average CBR		Average Shoulder Cross Slope (%)		
							Aug. 2011	June 2012	Aug. 2011	Oct. 2011	June 2012
1.01	Garner	US 18	98.3%	5,800	13.7	/	/	75.9	/	5.7	3.3
1.02	North of Leland	US 69	100.0%	2,250	21.1	3.6	12.6	36	6.3	7.4	8
1.03	South of Leland	US 69	100.0%	3,640	12.3	3.6	83.5	44.8	3.9	6.5	6
1.04	South of Algona	US 169	100.0%	2,750	7.4	3.3	55.3	76.4	5.5	5.4	3.6
1.05	South of Algona	US 169	95.7%	2,750	7.4	1.5	/	54.1	/	7.1	8
2.01	East of Waverly	IA3	95.1%	3,400	6.9	1.6	36.6	30.9	7.7	6.5	5.4
2.02	Denver	US 63	99.9%	6,500-8,000	12.9	1.4	14.5	18	5.7	6.8	8.3
2.03	Waverly	IA3	100.0%	5,600	0.1	1.6	24.6	43.2	10.4	8.6	7.7
2.04	Shell Rock	IA3	0.0%	3,890	13.3	/	48.6	70.2	5.1	5.7	4.2
2.05	East of Allison	IA3	0.0%	2,430	0.9	/	42.8	73.6	7.4	6.8	7.1
3.01	East of West Union	US 18	NA	2,660	5.8	3.6	50.8	53.2	5.7	8.5	8.3
3.02	West of Clermont	US 18	NA	2,660	19.8	1.9	59.2	61.9	10	8.6	6
3.03-3.04	Elkader	IA13	NA	2,150	2.8	3.7	/	46.7	8.3	10.1	8.3
3.05-3.07	South of Elkader	IA13	NA	2,150	11.2	/	58	35.5	2.8	5.1	5.8
3.08-3.10	South of Elgin	W 51	NA	610	14.2	9.7	39.1	35.5	3.6	9.2	6

Normally, the shoulder material would become more fine with age so, although the material is finer than what was originally specified, it would be expected that the material would break down to a finer gradation.

In reviewing the data in this table, it is apparent that most shoulders had good performance. Fourteen of 20 sections had 100% good performance, which means no edge ruts of potholes were identified and soapstock stayed firmly in place on the treated shoulders. On the other hand, problems occurred at several places.

At Shell Rock and east of Allison, shoulder Sections 2.04 and 2.05 had the worst performance with 0% successful application. No edge ruts were observed for these two sections, but most soapstock applied on the shoulder surface had been removed. Traffic levels were well below the upper limit of 6,000 AADT suggested by Jahren (2011) with 3,890 AADT in Shell Rock and 2,430 AADT east of Waverly. No noticeable profile grades existed within these sections, and shoulder cross slopes were not steep. Shoulder materials were sufficiently stiff with CBR values greater than 10.

For both locations, it rained during soapstock application. It is not recommended that soapstock be applied during rain or when the shoulders are completely saturated with moisture, because soapstock will not penetrate into the shoulder materials under those conditions. In addition, some of the soapstock could have been washed away during the rain. The poor performance of shoulder test sections at both locations appears to confirm the negative effect that precipitation and excessive moisture during application has on the performance of soapstock.

At Garner and south of Algona, new edge ruts developed in shoulder test Sections 1.01 and 1.05, even though the applications were mostly successful with 98.3 and 95.7% success, respectively.

The edge rut in Garner was not severe at only 1/2 in. deep. There was also one 3/4 in. deep pothole identified nearby. The highway near Garner had relatively high traffic volume (5,800 AADT), which might contribute to the development of the new edge ruts and pothole.

The edge ruts just south of Algona were somewhat deeper, one of which was 1.5 in deep and the other that was 2.5 in. deep. One rut developed near the bottom of a hill, and runoff from above might have contributed to its failure.

East of Waverly and Denver, shoulder Sections 2.01 and 2.02 had a few spots where soapstock had been removed. For the shoulder east of Waverly, the causes of failure were not clear. The defect was more of an edge drop-off than an edge rut, because there was not a depression that would hold water next to the pavement edge. Apparently, there was not enough shoulder aggregate in this area to maintain the designed cross slope and fill flush to the pavement edge.

For shoulders near Denver, the traffic level varied from 6,500 to 8,000 AADT, which was higher than the recommended 6,000 AADT. Therefore, the higher traffic volume might be one cause for the soapstock failure. In addition, the granular material on the inside shoulder appeared to be less stable compared to other shoulders, and that may have also contributed to the failure.

In West Union, Elkader, and Elgin, the soapstock had been abandoned after the harvest season of 2011. According to Burns in 2012, the soapstock worked well the time of application until the harvest season. During the harvest season, a large amount of heavy farm equipment drove slowly on the shoulders every day in this area. The lugged tires of this equipment broke up the soapstock in many places.

For some test sections, like the ones south of Leland and east of West Union, potholes were identified before the soapstock was applied. South of Leland, maintenance personnel used pothole patcher to place alternate layers of aggregate and asphalt emulsion to fill the holes. This combination use of soapstock and pothole patcher seemed to be effective in addressing these potholes. Such a repair was not attempted at the location east of West Union.

Multiple Regression Model for Rut Mitigation

Based on the data obtained from the research, the original shoulder properties (shoulder cross slope, CBR, % gravel, and % sand), road traffic volume, and change of rut depth after the application are shown in Table 27.

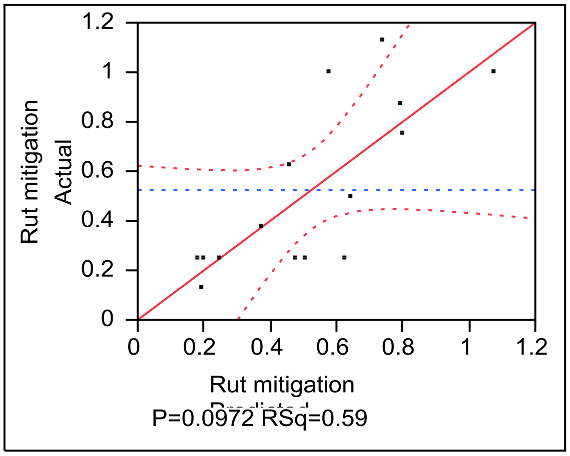
Table 27. Data set for rut mitigation model

Location	Rut Mitigation (in.)	Slope (%)	CBR	Gravel (%)	Sand (%)	Traffic
100 ft south of WV02A SB	0.25	1.05	20.9	27.9	63.2	6,500
0.5 mi south of WV02A SB	0.25	5.58	21	27.9	63.2	6,500
0.5 mi south of WV02A SB inside	1	6.65	5.3	27.9	63.2	6,500
100 ft north of WV02D NB	0.625	5.02	19.7	26.4	67.4	8,000
200 ft west of WV03B WB	1	8.37	30.3	44.9	43.2	5,600
100 ft east of WV04B WB	0.375	6.69	83.9	31.7	48.8	3,890
200 ft south of SVA04A SB	0.25	4.07	55.3	35.9	56.9	2,750
200 ft south of SVA06A SB	0.75	2.85	2.8	32.7	56.4	3,640
200 ft south of SVA07A SB	0.875	4.1	3.9	23.4	58.7	2,250
200 ft south of SVA07A NB	0.5	5.43	5.3	24.4	60.4	2,250
UN01A EB	1.125	2.78	57	39.2	46.5	2,660
215 ft west of UN01B WB	0.25	10.58	54.2	39.2	46.5	2,660
275 ft east of UN03A EB	0.125	7	67.6	15	68.6	2,660
200 ft west of UN03B WB	0.25	6.77	62.6	15	68.6	2,660
0.28 mi west of UN03B WB	0.25	14.7	40	15	68.6	2,660

With this data set, a statistical analysis was performed to identify the relationship and significance of various factors or attributes that affect rut mitigation. A multiple regression model was developed using the JMP Pro 10 statistical software package (SAS Institute Inc. 2012) to find the influences of shoulder cross slope, material stiffness (CBR), traffic volume (AADT), percentage of gravel, and percentage of sand to the rut mitigation depth.

A multiple regression model assumes a linear relationship between independent variables and dependent variables keeping other independent variables constant. The equation below shows the regression model along with its estimates for each independent variable. A 95% confidence interval is used to determine the significance of variables on rut mitigation. The strength of prediction from a multiple regression equation is measured using the square of the multiple correlation coefficient, R^2, also known as the coefficient of determination. R^2 measures the proportional reduction in variability about the mean resulting from the fitting of the multiple regression models. The analysis of the regression model is shown below.

Response Rut mitigation
Whole Model Y=$\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5$
Actual by Predicted Plot



Summary of Fit

RSquare	0.59491
RSquare Adj	0.36986
Root Mean Square Error	0.270966
Mean of Response	0.525
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	0.9704467	0.194089	2.6435
Error	9	0.6608033	0.073423	**Prob > F**
C. Total	14	1.6312500		0.0972

The final model is as follows:
$Y = (-2.192) + (-0.033) X_1 + (-0.009) X_2 + (3.7 \times 10^{-5}) X_3 + 15.988 X_4 + 140.247 X_5$

Parameter Estimates

	Term	t Ratio	Prob>|t|
β_0	Intercept	-1.44	0.1824
X_1	% slope	-1.19	0.2651
X_2	CBR	-2.56	0.0309*
X_3	traffic	0.78	0.4556
X_4	%gravel^(-1)	1.28	0.2342
X_5	%sand^(-1)	2.28	0.0489*

From the JMP analysis data fit for this model, R square equals 0.595, which means 60% of the data fit for this developed model. Based on the column Prob>t, the conclusions can be given as the CBR value and percentage of sand are the most significant factors for mitigating the edge rut. About 97% of the time, the CBR would have an influence on rut mitigation depth and, about 95% of the time, the percentage of sand would have an influence on the mitigation result. Other factors such as the shoulder cross slope, traffic, and percentage of gravel do not have a significant impact on the rut mitigation result.

Although the study locations were selected based on the traffic volume within 6,000 AADT, the traffic volume did not have a direct impact as indicated in this analysis. Vehicles normally do not drive on the shoulders except when pulling off the road for emergencies and various other reasons. The case where the traffic really makes a difference is during the harvest season when the heavy farm equipment is driving slowly on the shoulders. In addition, vehicle off-tracking and accidentally leaving the road for a short time are possible reasons why vehicles drive on the shoulder.

The number of data sets available for developing a multiple regression model is limited due to the difficulty of taking all measurements at the exact same place before and after the application. If a larger data set were to be incorporated, the model might produce a better prediction model.

On the other hand, the result of the application could be affected by many factors in addition to those mentioned above, such as the preparation of shoulders (especially compaction), weather during application, moisture content of shoulder materials, thickness and viscosity of soapstock, application rate of soapstock, compaction after application, and having an even thickness of covering sand. Many of these factors are difficult to quantify, measure, and present.

For example, the proper preparation of shoulders and effective compaction after soapstock application could help enhance the performance of treated shoulders and help to retain soapstock longer on shoulders. However, it is not easy to quantify how effective the preconstruction preparation and post-application compaction was for each shoulder section.

CHAPTER 7. SPECIFICATION DEVELOPMENT

A draft specification for the application of soybean soapstock was developed as part of this investigation. The content of the specification was selected for inclusion based on literature review, interviews with subject matter experts, and experience from this and related investigations.

A review was also undertaken by the Iowa DOT Office of Specifications. This draft specification is provided in Appendix B.

A commentary on the draft specification was also developed and is included in Appendix C; it gives a narrative background regarding the specification including references to the literature, interviews, and experience from this and related research projects.

It is recommended that the Iowa DOT consider possible adoption of these specification documents using their usual procedure for adopting specifications and other guidance material.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Most of the shoulders that were tested had good performance in Area I and II where the soapstock stayed firmly on the shoulders after one year's application. For Area III, the shoulders where the soapstock was applied was not maintained as a soapstock surface after the harvest season of the year in which the soapstock was applied, because the tires of the heavy farm equipment had disrupted the soapstock in many places. For places where soapstock was observed to work well during the latest observation, a hard crust was formed on shoulder surfaces after the application, and it could support the traffic loads as well as survive from the freezing and thawing process.

There were a few places in Area I and II that soapstock was not applied successfully. In Shell Rock and east of Allison, where rain was encountered during application, shoulder Sections 2.04 and 2.05 had the worst performance with 0% successful application. No edge ruts were observed for these two sections, but none of the soapstock that was applied on shoulder surfaces was visible. In Garner and south of Algona, shoulder Sections 1.01 and 1.05 experienced small percentages, 1.7% and 4.3%, respectively, of failure. The edge rut in the section near Garner was not severe, (only 0.5 in. deep). There was also one 0.75 in. deep pothole identified east of Waverly and near Denver. Shoulder Sections 2.01 and 2.02 had a few places where soapstock was no longer visible.

The problematic shoulders generally had a strong base, which could support the expected traffic loads, as indicated by average CBRs greater than 12, which is recommended by Mekkawy et al. (2010). The aggregate gradation is generally finer than that specified by the Iowa DOT, as indicated by percentages above the upper fine limit of the Iowa DOT Class A aggregate at #4 sieves. Most shoulder sections exceeded the Iowa DOT specified 4% for cross slope, but there were a few places with shoulder slopes less than 4%, which may increase the potential of water erosion by not allowing water from the shoulder to drain quickly into the ditch.

The application of soapstock took place on 20 test sections over 10 counties of Iowa. The soapstock worked effectively despite situations where aggregate gradation was finer than the originally-specified range for new shoulder material.

The likely causes of failure include rain or saturated moisture conditions during application and high traffic volume (especially heavy farm equipment with luggged tires) during the test period. For one place that developed a pothole, the failure was corrected with a pothole patcher.

The method of application used for this investigation appeared to be adequate. No special techniques or skills beyond those that Iowa DOT maintenance operators normally have were required to run the equipment. The general application process includes shoulder preparation by conducting maintenance grading shortly before application, spraying water on shoulders to provide an appropriate amount of moisture, applying soapstock on moist shoulders at a 0.25

gal/yd^2 target rate, and spreading a layer of sand 1/4 to 1/2 in. thick over the soapstock. In most cases, one pass per truck was sufficient.

For this research, certain limitations existed. The application was tested only on crushed limestone, which is the typical material used for granular shoulders in Iowa in the region of the test sections. The investigation for the soapstock itself was limited, because the product specifications are proprietary. The tests were done only in Iowa so the results would be most applicable to locations with similar climate and operational characteristics.

Because of time and equipment limitations, the application rate was not recorded for each location, so, although overall application rates are known, some details of specific application rates for specific areas are not known. In addition, the shoulders were not compacted fully and systematically before application. Despite these limitations, this investigation provides evidence that the concept of applying soapstock to shoulders is sufficiently successful that an effort should be made to further develop and refine the process.

Recommendations

Given the number of successful applications, it seems reasonable to continue the use of soapstock to stabilize granular shoulders that have a stiff subbase. However, it may be best to avoid locations that experience considerate traffic from agricultural vehicles with aggressive and lugged tires.

The use of soapstock could also be considered for stiff granular shoulders in other locations that have similar climate, construction materials, and operational characteristics.

In planning soapstock application, rain should be avoided because excessive moisture apparently prevents good performance of soapstock as a granular shoulder stabilizer. Too much or too little moisture does not lead to a successful application. If the shoulder is too dry, water should be sprayed to add more moisture. If the shoulder is too wet, soapstock application should be delayed until the excessive moisture has evaporated.

It is also recommended that the draft specification in Appendix B and the accompanying commentary in Appendix C be considered for adoption as appropriate by the Iowa DOT.

Additional advanced investigations could be performed to further determine the effects of influence factors (cross slope of the shoulder, stiffness of shoulder materials, gradation distribution of aggregates, traffic level, preparation of shoulders (especially compaction), weather during application, moisture content of shoulder materials, thickness and viscosity of soapstock, application rate of soapstock, compaction after application, and thickness of covering sand) on soapstock application for unpaved shoulders.

Some construction techniques observed during this investigation improved the results of the application and may be worthy of further study. For example, the recirculation of soapstock in the tank might help soapstock viscosity to remain consistent so it can be distributed more evenly on the shoulder. Compaction of the shoulder before and after application might enhance soapstock performance. For places with a relatively high traffic volume, adding a second coat of soapstock might help to better stabilize the granular shoulders.

The statistical model presented in this report is likely to be more helpful if more data are included. The target number of observations should probably be more than 30. Then, this model or the modified model could be tested again to provide a comparison for the results reported herein.

In addition, for each shoulder section, the level of effort expended on preparation before the application and on compaction after the application might be documented in a straight-forward manner. For example, selecting between sufficient/insufficient/no efforts may facilitate the development of a statistical model that allows researchers to infer the level of compaction effort required to ensure effective application results.

Researchers might also consider documenting the application rate for each section. Meanwhile, lab tests might be considered to evaluate to what extent the soapstock penetrates the shoulder material at various moisture contents and efficacy for various shoulder materials with various properties (especially porosity and density).

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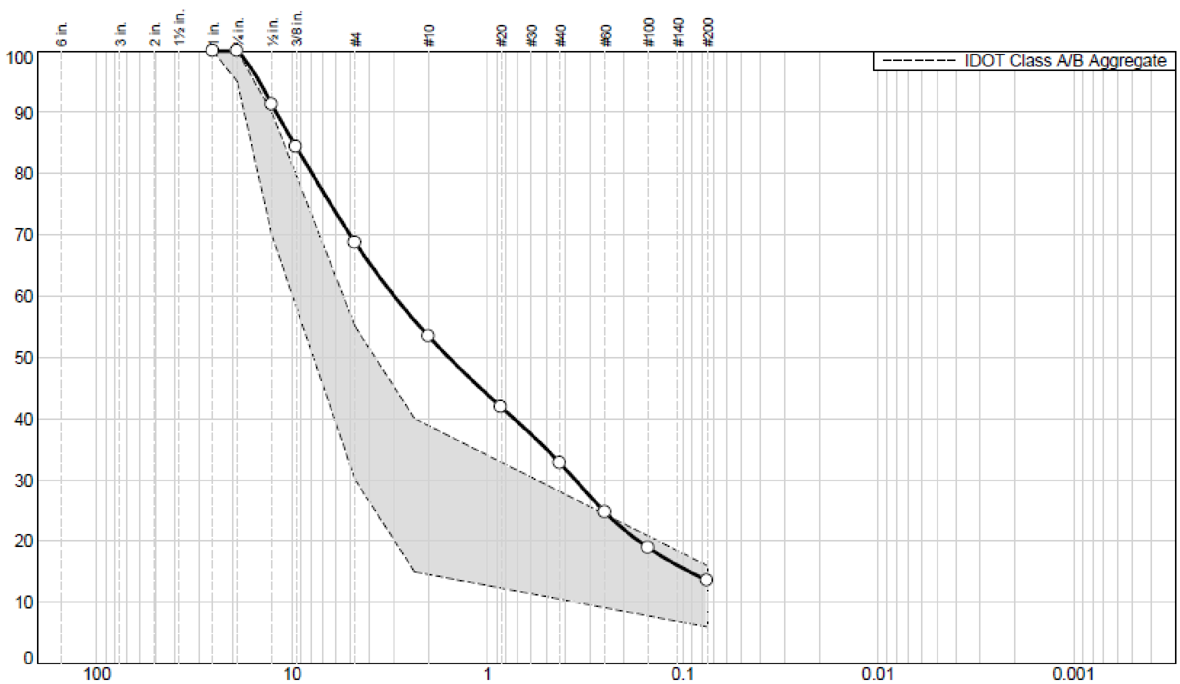
APPENDIX A. FIELD MEASUREMENT AND FIELD RESULTS

Area I Section 1.01 MP 161.6-161.9

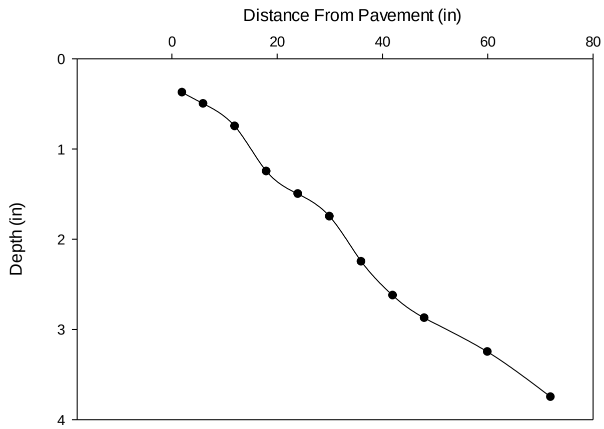
Description: US 18, Garner, shoulders on both sides, sprayed 3,024 ft long and 4 ft wide

GPS: West end: N 43 06.299, W 93 37.316
East end: N 43 06.336, W 93 36.975

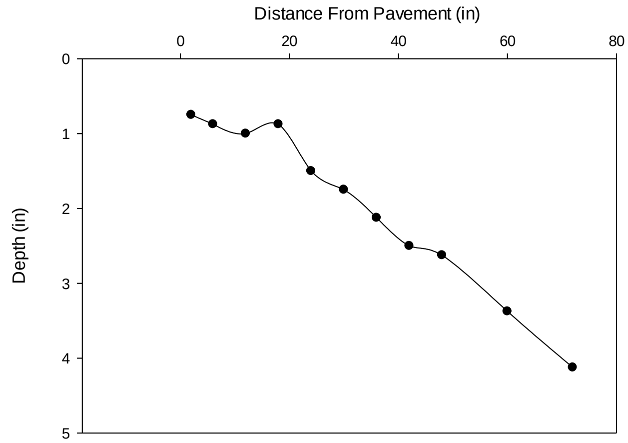
Gradation Distribution



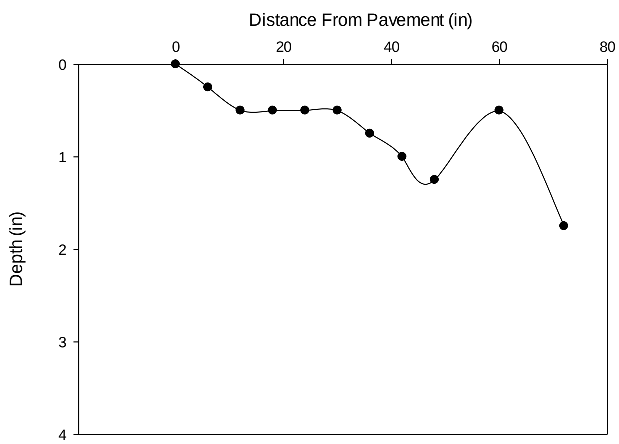
Elevation Profiles



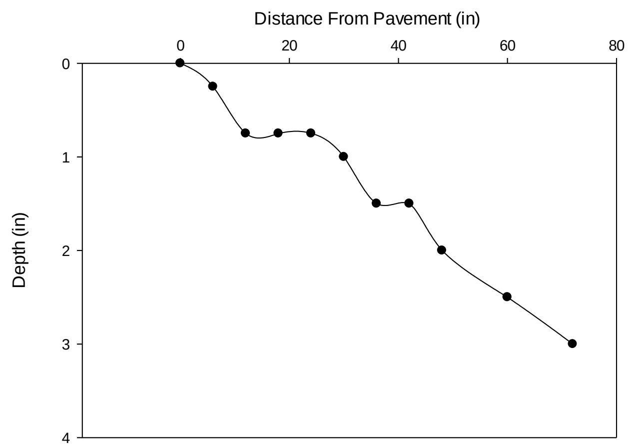
30ft East of GW01A



250ft East of GW01C, WB



0.11mi E of GW01A, EB



90ft E of GW01A, WB

CBR Values

Table 28. Clegg hammer data for Section 1.01

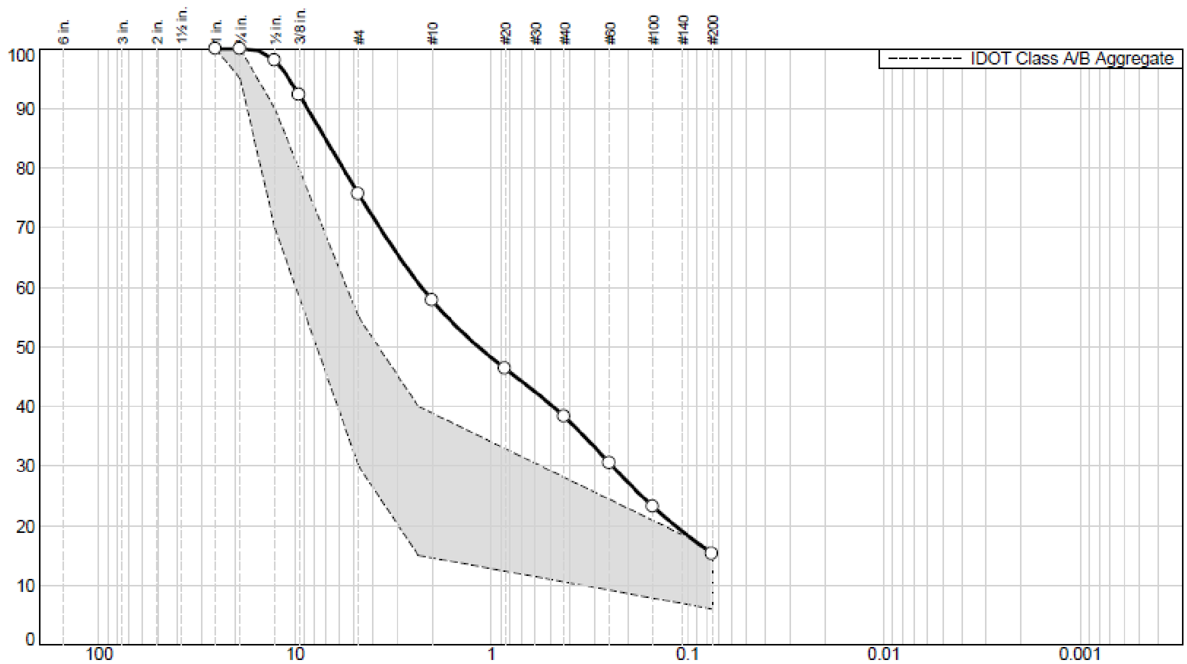
Date	Location	CIV	CBR	Average CBR	
	1.01			EB	WB
June 2012	30 ft east of GW01A EB	30.8	70.4	81.1	
	0.11 mi east of GW01A EB	33.7	82.6		
	155 ft west of GW01B EB	35.4	90.2		
	155 ft west of GW01B WB	32.4	77.0		70.6
	250 ft west of GW01A WB	32.6	77.9		
	90 ft east of GW01A WB	27.3	57.0		

Area I Section 1.02 MP 210.8-211.4

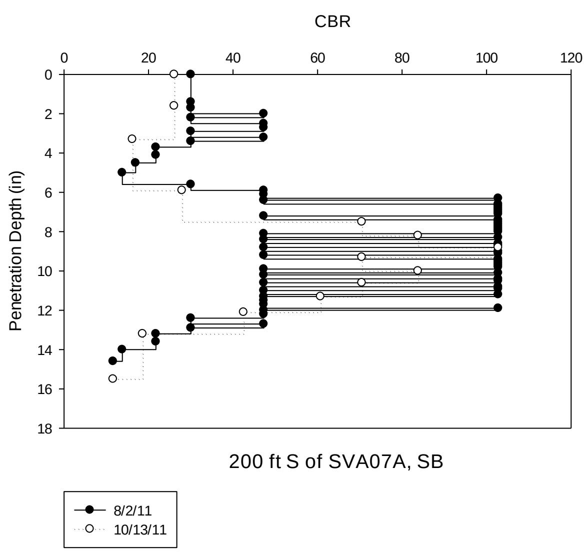
Description: US 69, north of Leland, shoulders on both sides, sprayed 2,112 ft long and 10 ft wide on northbound, 2,112 ft long and 6.5 ft wide on southbound

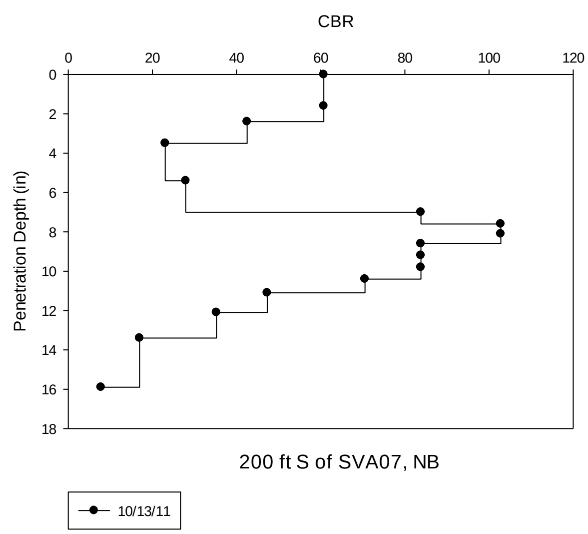
GPS: South end: N 43 21.062, W 93 38.207
North end: N 43 21.411, W 93 38.212

Gradation Distribution

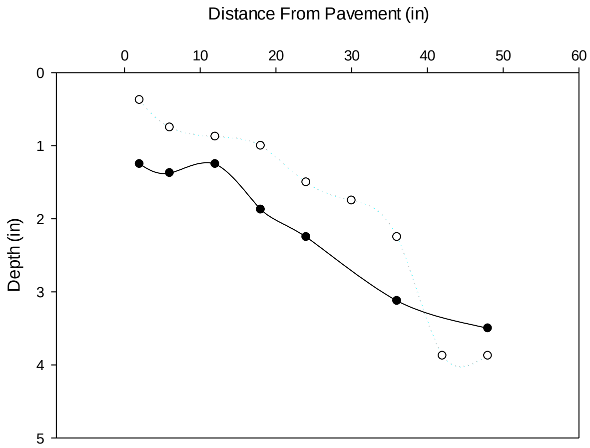


DCP Plots

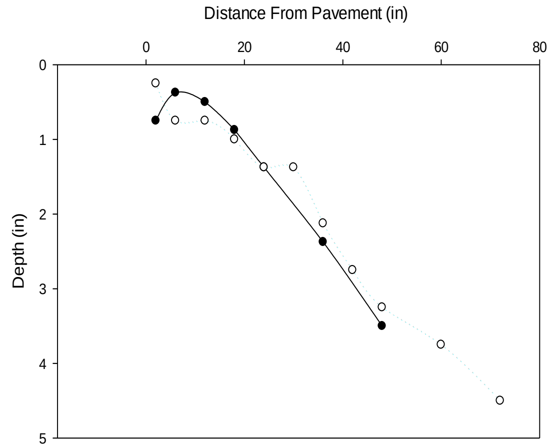




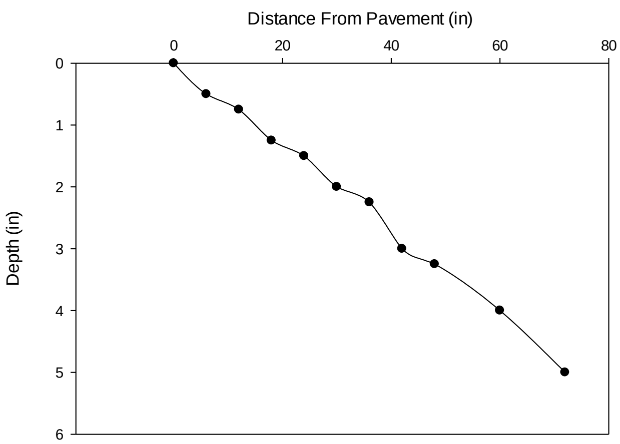
Elevation Profiles



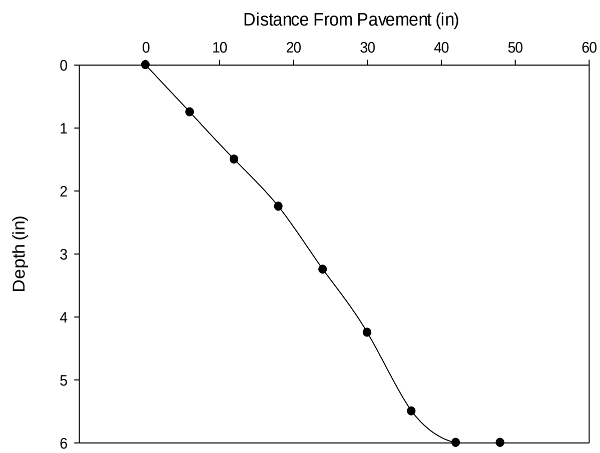
200ft S of SVA07A, SB



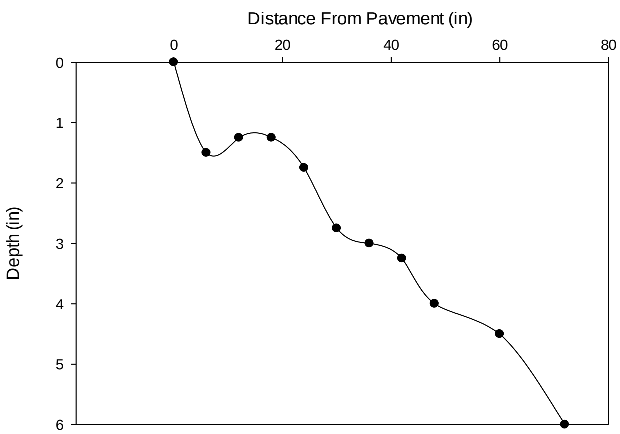
200ft S of SVA07A, NB



400ft N of SVA07B, NB



370ft N of SVA07A, SB



370ft N of SVA07A, NB

CBR Values

Table 29. Clegg hammer data for Section 1.02

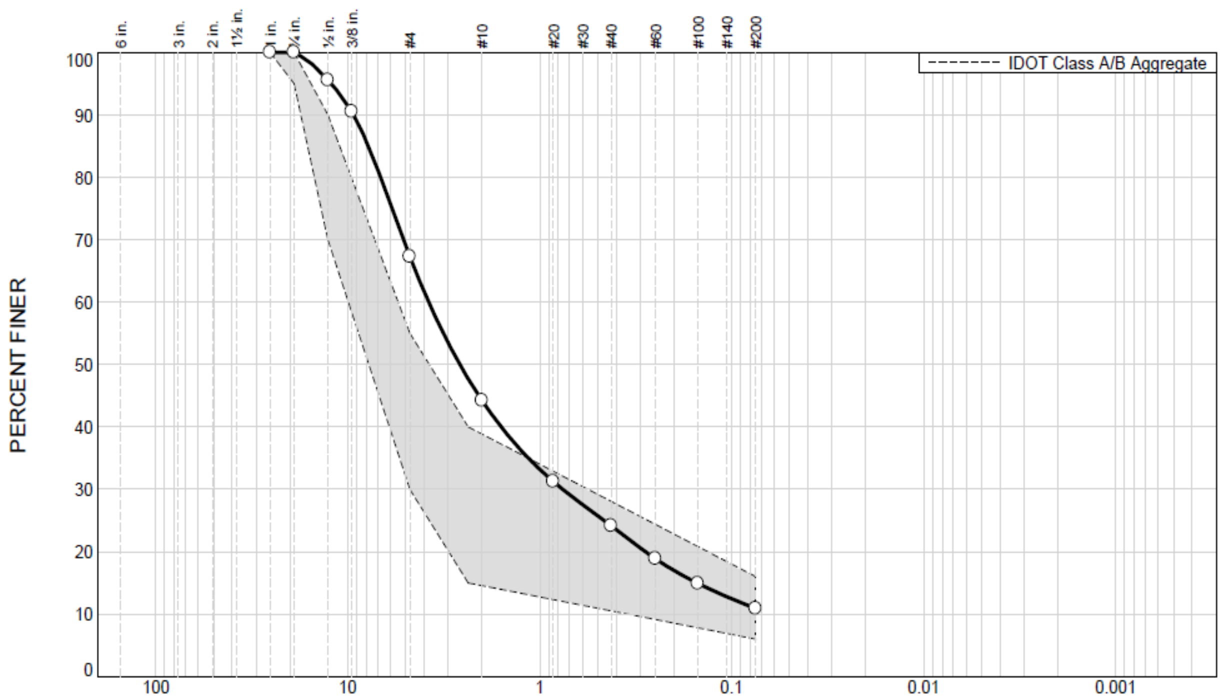
Date	Location	CIV	CBR	Average CBR		
	1.02			SB	NB	Overall
Aug. 2011	200 ft south of SVA07A SB	10.3	12.1	12.1		12.6
	200 ft south of SVA07A NB	10.9	13.1		13.1	
June 2012	400 ft north of SVA07B NB	21.8	38.8		39.5	36.0
	200 ft south of SVA07A NB	23.6	44.4			
	370 ft north of SVA07A NB	20.6	35.3			
	370 ft north of SVA07A SB	21	36.5	32.5		
	350 ft south of SVA07A SB	18.1	28.6			

Area I Section 1.03 MP 209-209.4

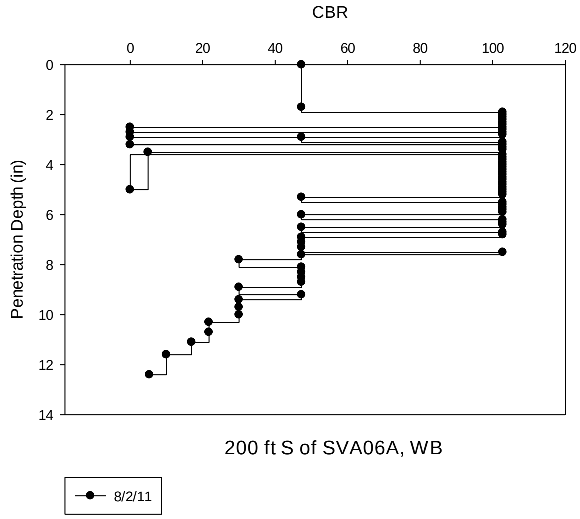
Description: US 69, south of Leland, shoulder on southbound, sprayed 1,584 ft long and 4 ft wide

GPS: South end: N 43 19.307, W 93 38.196
North end: N 43 19.553, W 93 38.214

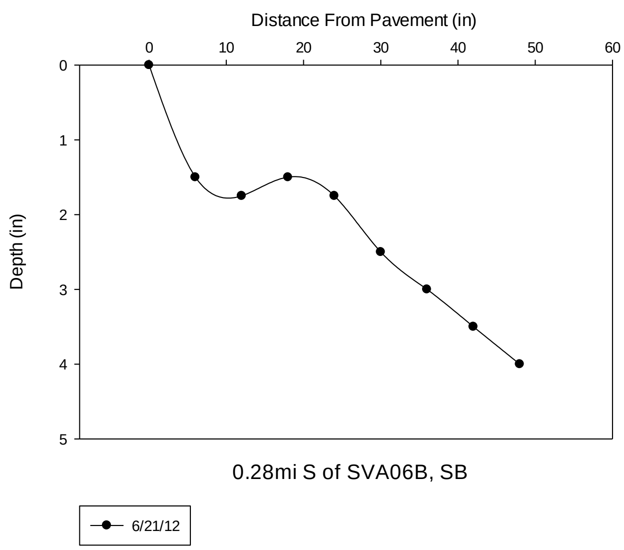
Gradation Distribution

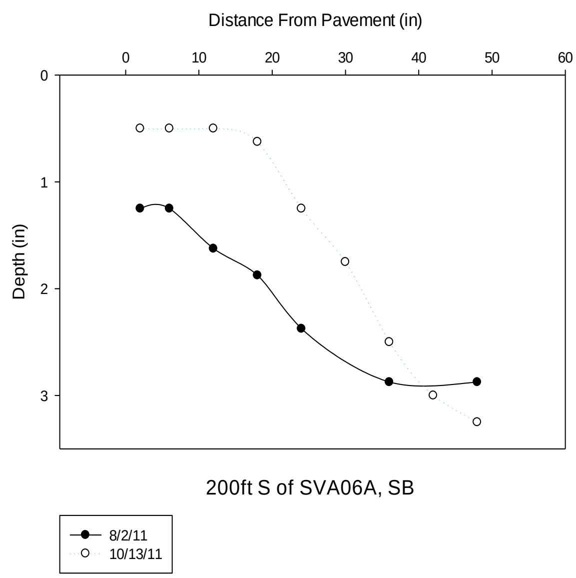


DCP Plots



Elevation Profiles





CBR Values

Table 30. Clegg hammer data for Section 1.03

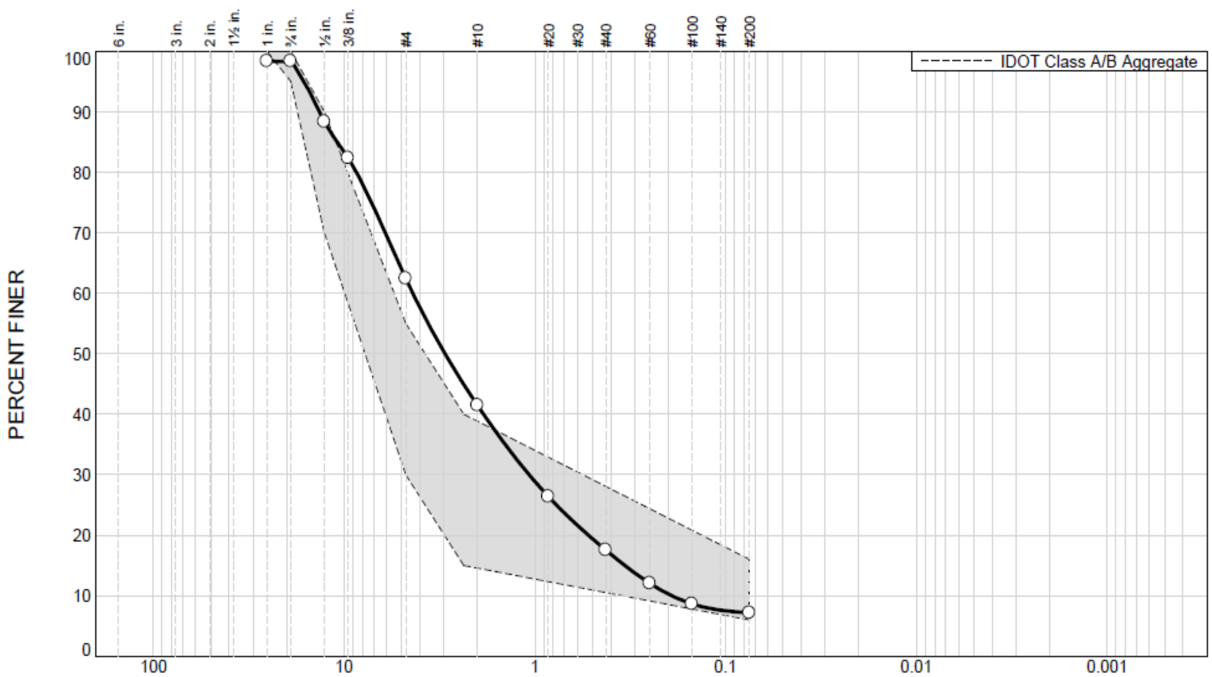
Date	**Location**	**CIV**	**CBR**	**Average CBR**
	1.03			SB
Aug. 2011	200 ft south of SVA06A SB	33.9	83.5	83.5
June 2012	0.28 mi south of SVA06B SB	20.7	35.6	44.8
	310 ft north of SVA06B SB	27	56.0	
	0.35 mi north of SVA06B SB	23.1	42.8	

Area I Section 1.04 MP 195.5-196

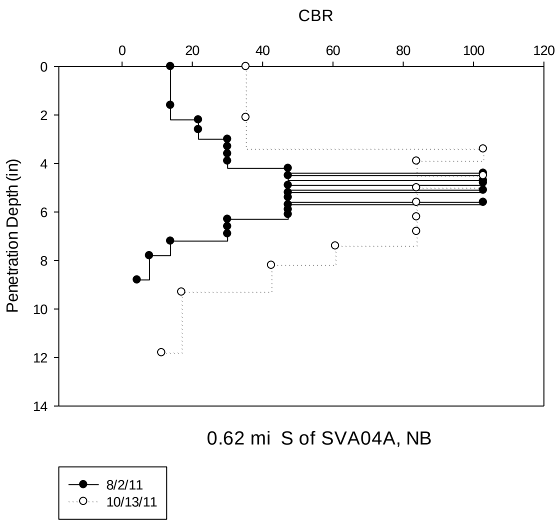
Description: US 169, south of Algona, outside shoulder on southbound, sprayed 5,786 ft long and 8.5 to 12 ft wide

GPS: South end: N 43 02.319, W 94 13.650
North end: N 43 03.358, W 94 13.637

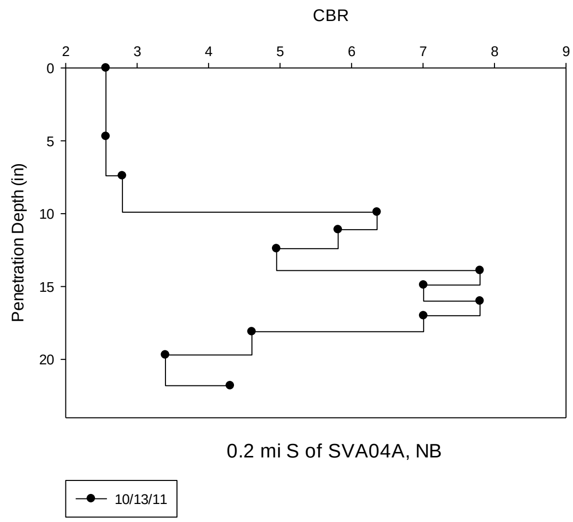
Gradation Distribution



DCP Plots

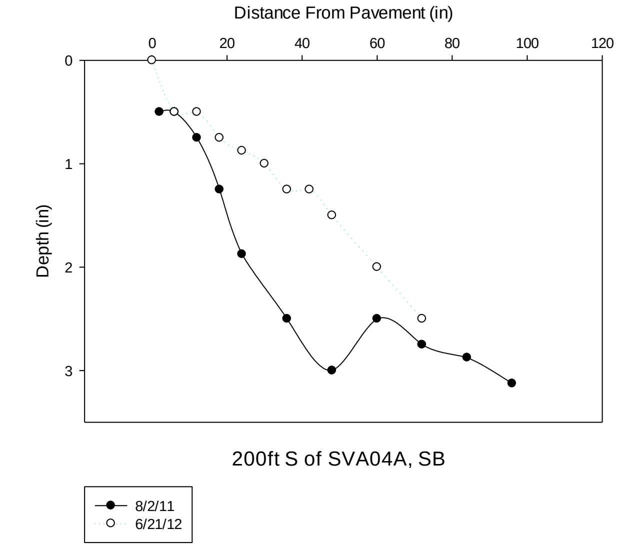


0.62 mi S of SVA04A, NB

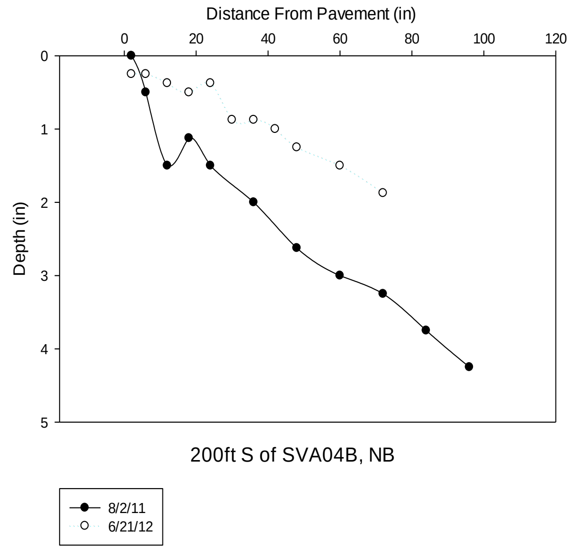


0.2 mi S of SVA04A, NB

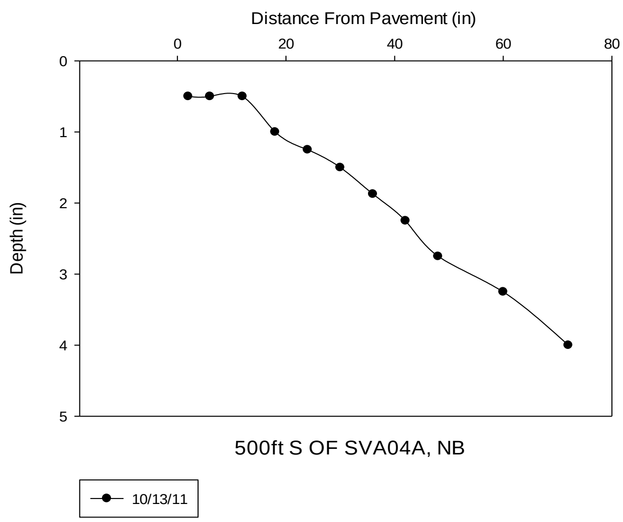
Elevation Profiles



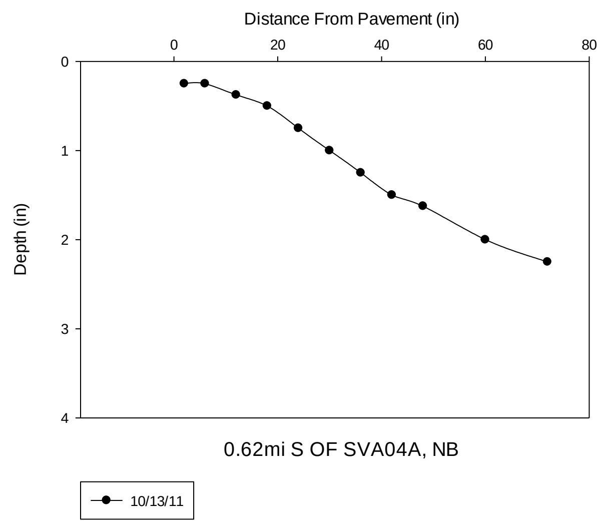
200ft S of SVA04A, SB



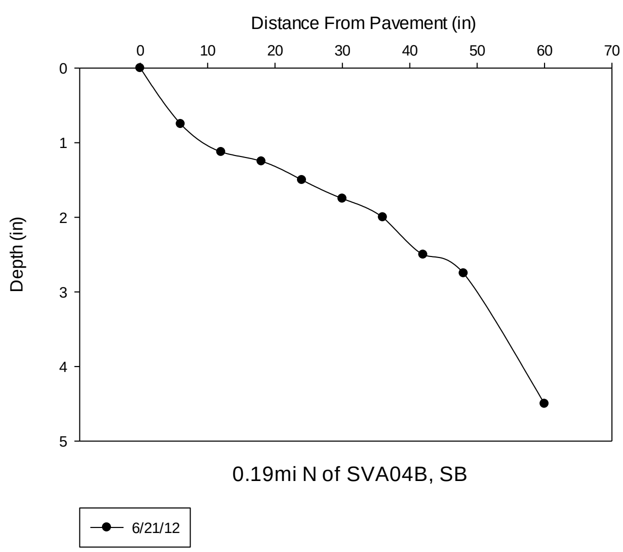
200ft S of SVA04B, NB



500ft S OF SVA04A, NB



0.62mi S OF SVA04A, NB



0.19mi N of SVA04B, SB

CBR Values

Table 31. Clegg hammer data for Section 1.04

Date	**Location**	**CIV**	**CBR**	**Average CBR**
	1.04			SB
Aug. 2011	200 ft south of SVA04A SB	28.3	60.7	55.3
	500 ft south of SVA04A SB	27.6	58.1	
	0.62 mi south of SVA04B SB	24.4	47.0	
June 2012	40 ft north of SVA04B SB	40.6	115.4	76.4
	0.19 mi north of SVA04B SB	21.5	37.9	
	200 ft south of SVA04A SB	32.1	75.8	

Area I Section 1.05 MP 194.8-195.5

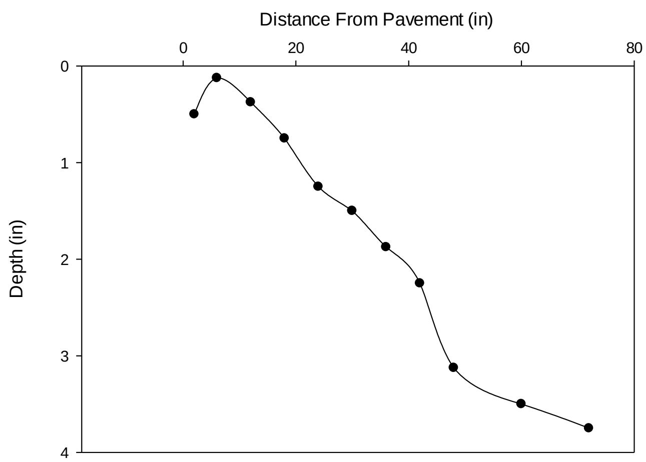
Description: US 169, south of Algona, shoulder on southbound, sprayed 5,238 ft long and 4 ft wide

GPS: South end: N 43 01.434, W 94 13.651
North end: N 43 02.319, W 94 13.650

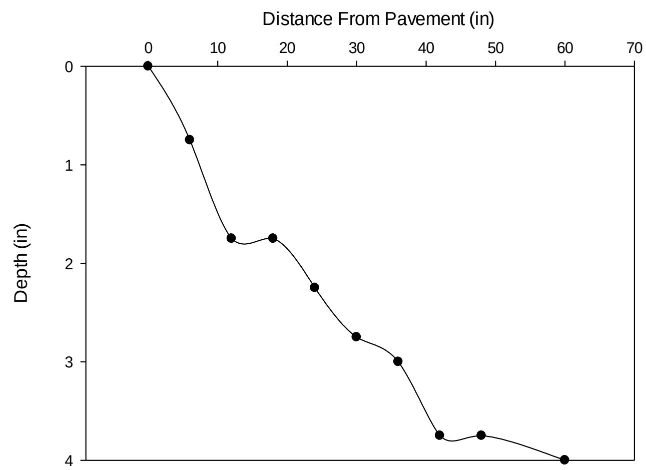
Gradation Distribution

Same as Section 1.04

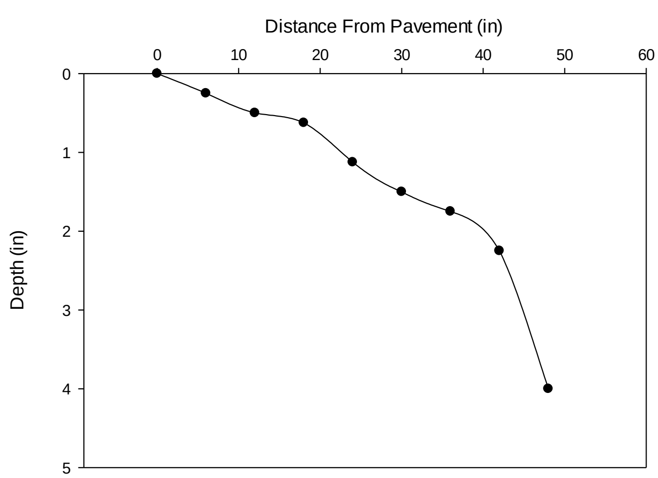
Elevation Profiles



0.2 MI S OF AF03, NB



0.13mi S of AF01, SB



0.12mi S of AF01, SB

CBR Values

Table 32. Clegg hammer data for Section 1.05

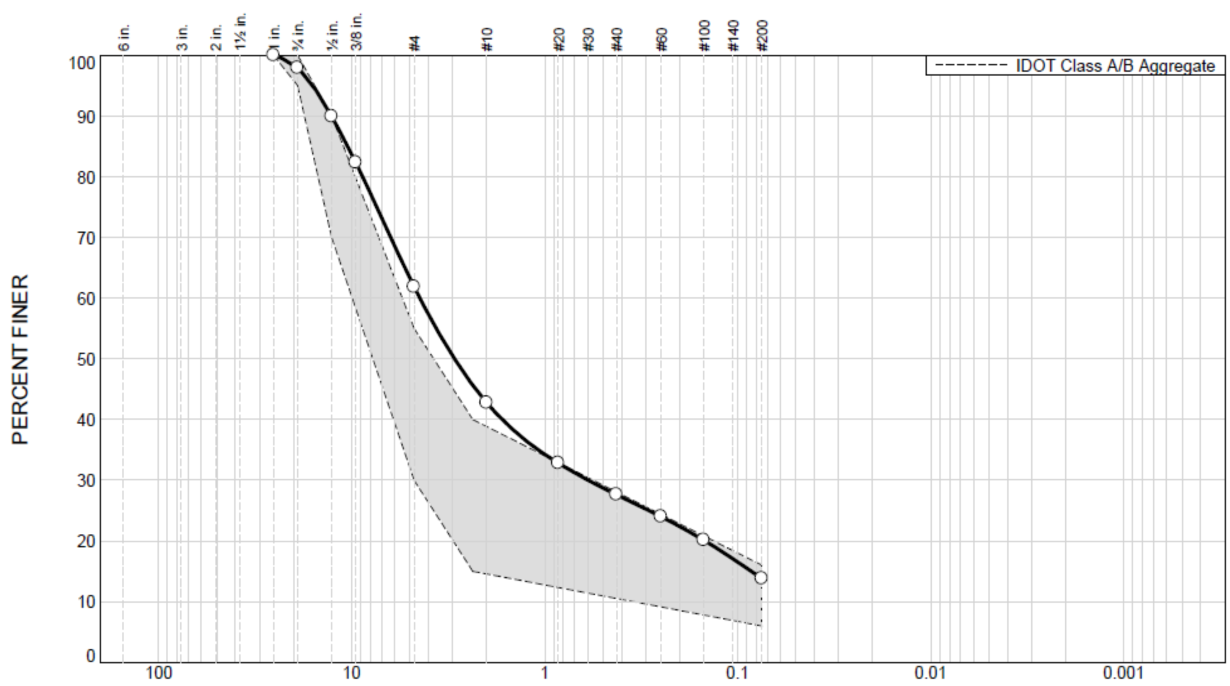
Date	Location	CIV	CBR	Average CBR
	1.05			SB
June 2012	280 ft south of AF01 SB	36.4	94.8	54.1
	0.12 mi south of AF01 SB	21.4	37.7	
	0.23 mi north of AF03. SB	27.8	58.9	
	75 ft north of AF03 SB	16.7	25.1	

Area II Section 2.01 MP 226.2-226.6

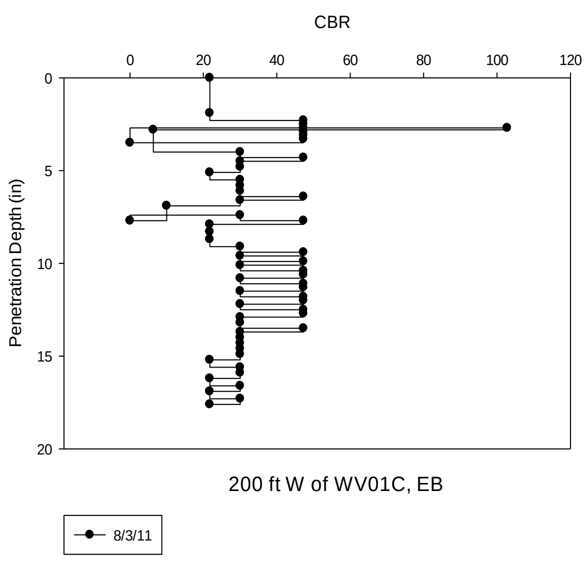
Description: IA 3, east of Waverly, shoulders on both sides, sprayed 1,192 ft long and 4 ft wide on westbound, 1,930 ft long and 4 ft wide on eastbound, applied second coat 596 ft long and 4 ft wide on westbound, 965 ft long and 4 ft wide on eastbound

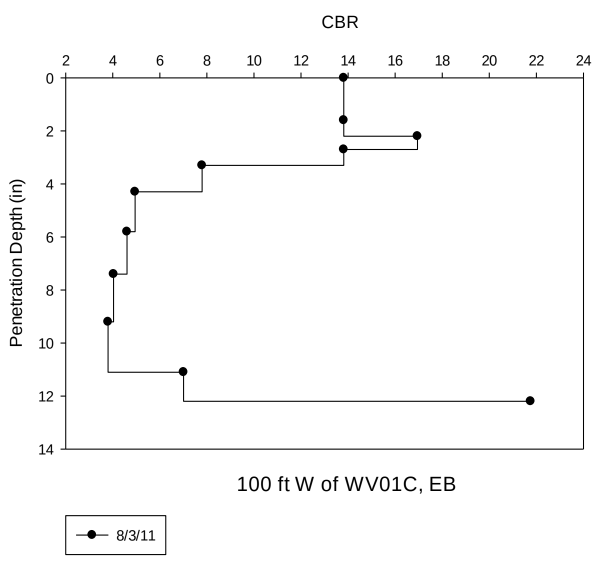
GPS: West end: N 42 42.892, W 92 22.675
East end: N 42 42.892, W 92 22.276

Gradation Distribution

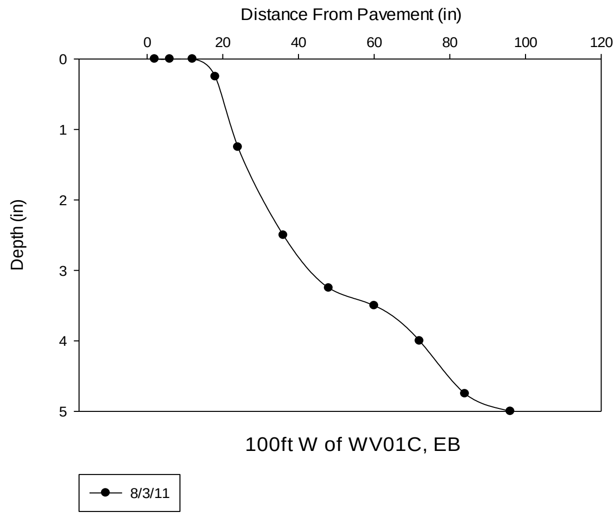


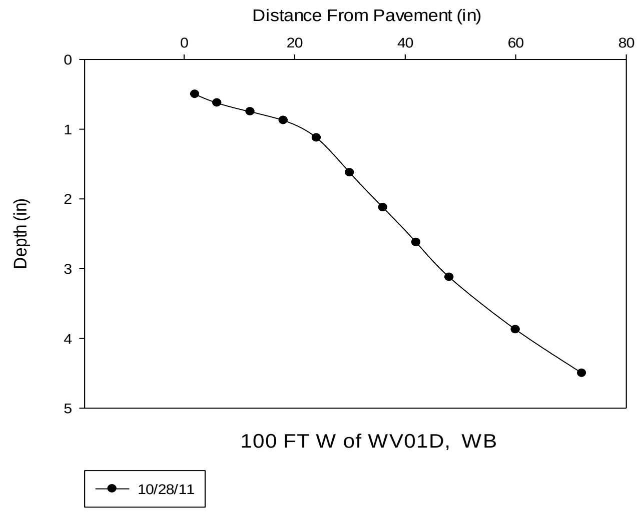
DCP Plots

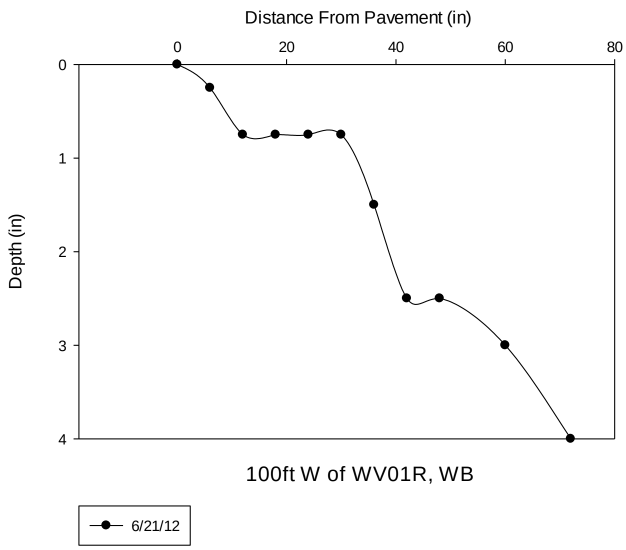


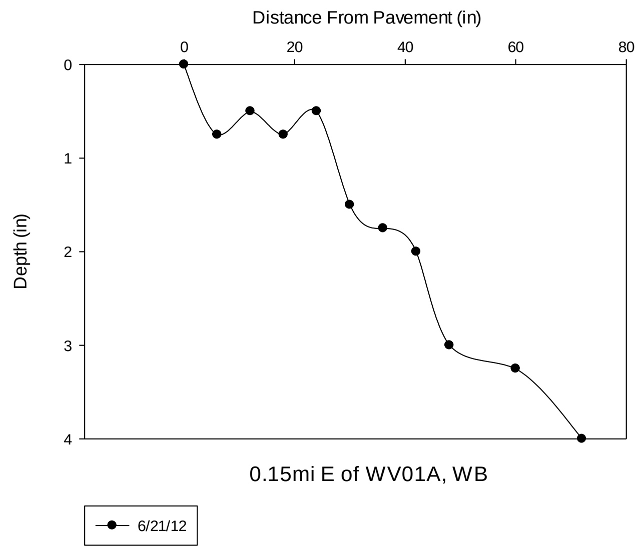


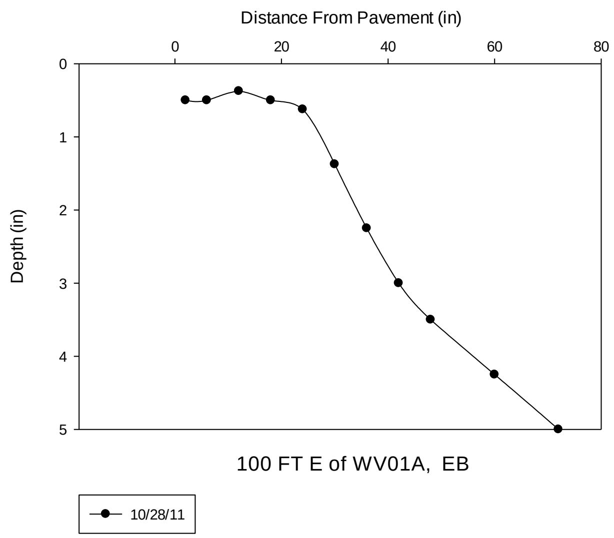
Elevation Profiles











CBR Values

Table 33. Clegg hammer data for Section 2.01

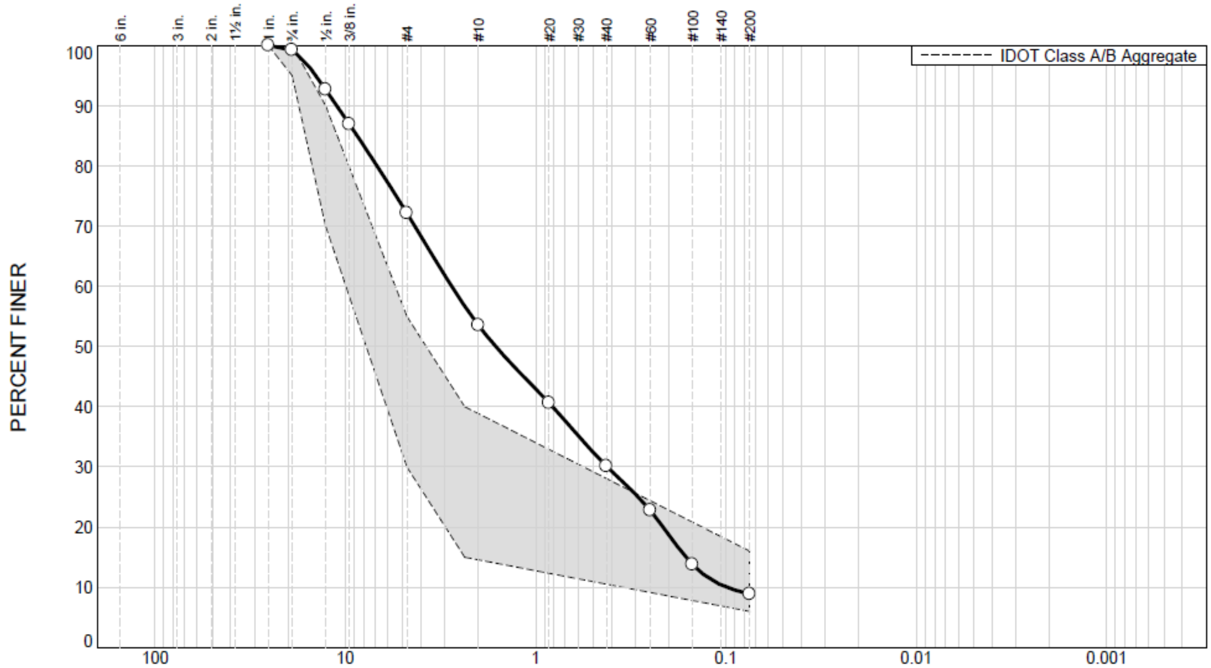
Date	Location	CIV	CBR	Average CBR	
	2.01			EB	WB
Aug. 2011	100 ft west of WV01C EB	20.1	33.9	26.1	
	200 ft west of WV01C EB	13.6	18.2		
	100 ft east of WV01A WB	22.7	41.6		47.2
	150 ft east of WV01A WB	33.7	82.6		
	250 ft east of WV01A WB	13.2	17.4		
June 2012	0.15 mi east of WV01A WB	18.9	30.6		31.6
	90 ft east of WV01R WB	20	33.6		
	100 ft west of WV01R WB	23.7	44.7		
	225 ft east of WV01A WB	13.2	17.4		
	230 ft west of WV01C EB	20.2	34.2	30.1	
	75 ft east of WV01C EB	17.1	26.1		

Area II Section 2.02 MP 174.6-177

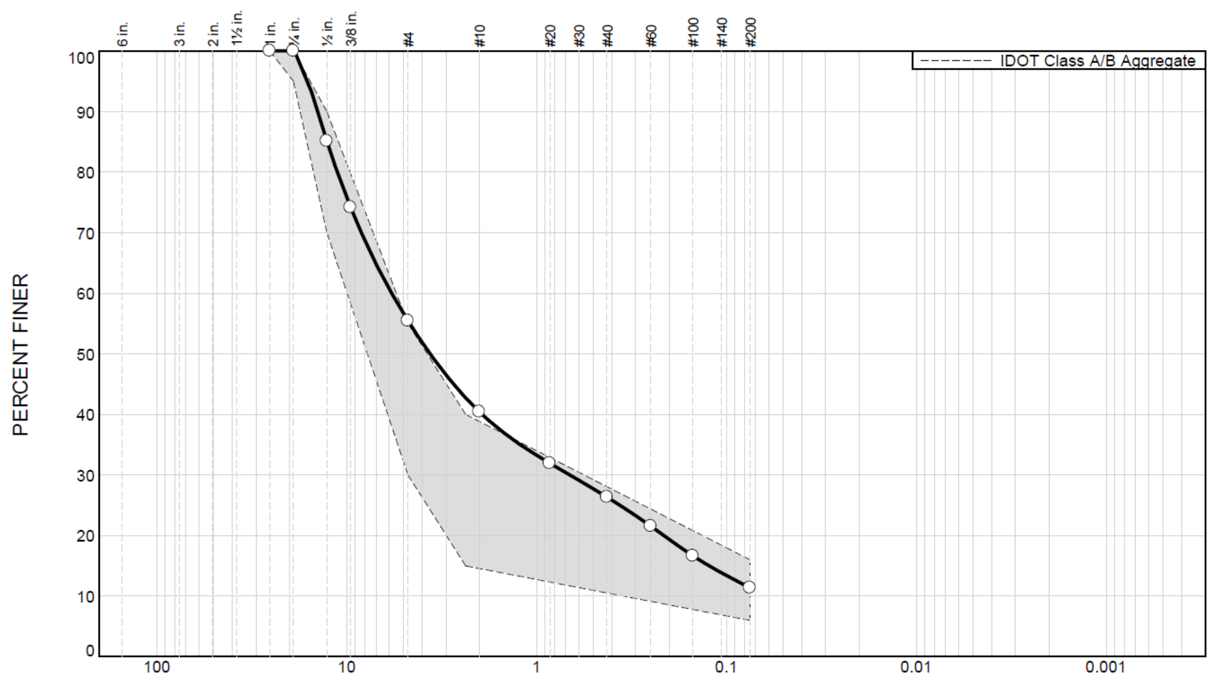
Description: US 63, four-lane divided highway, Denver, Iowa, outside and inside shoulders on both sides, each shoulder is 11,080 ft long, sprayed at whole length and 4 ft wide except for driveways or bridges, outside shoulders applied second coat 1,584 ft long and 4 ft wide on southbound, 3,168 ft long and 4 ft wide on northbound

GPS: South end: N 42 39.311, W 92 20.251
North end: N 42 41.146, W 92 20.267

Gradation Distribution

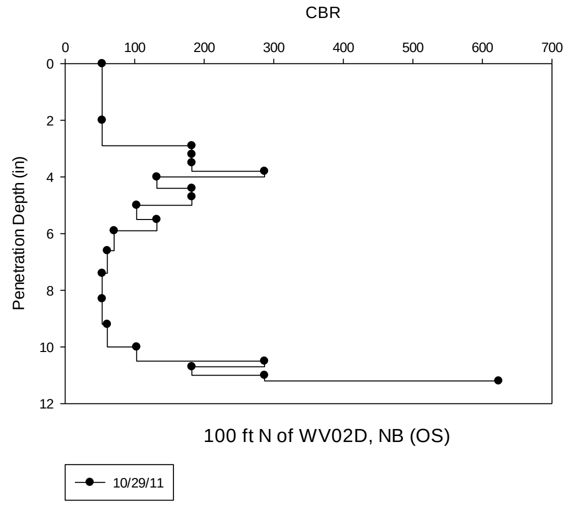


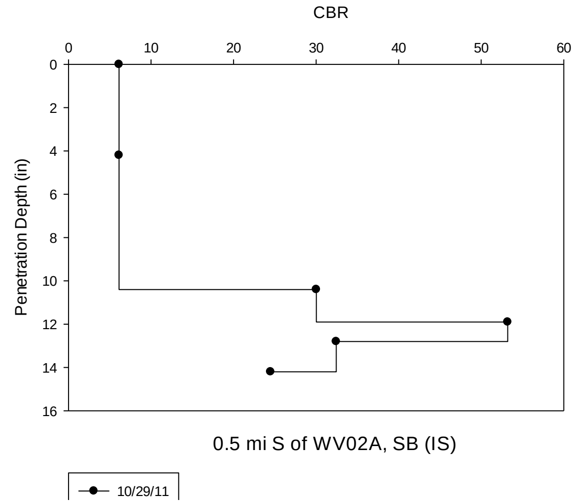
Outside shoulders on northbound and southbound

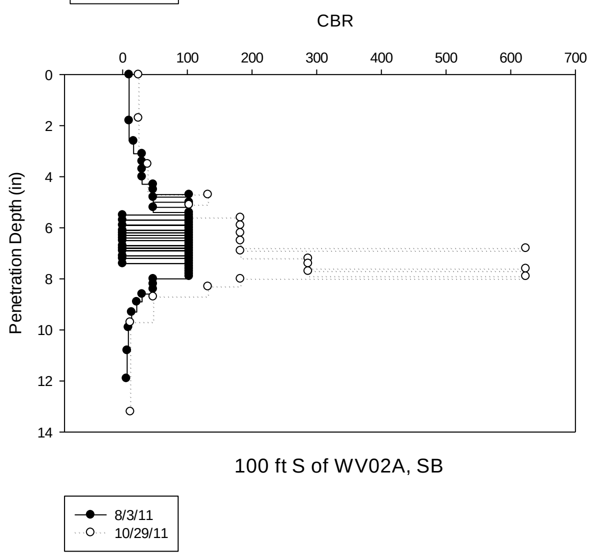


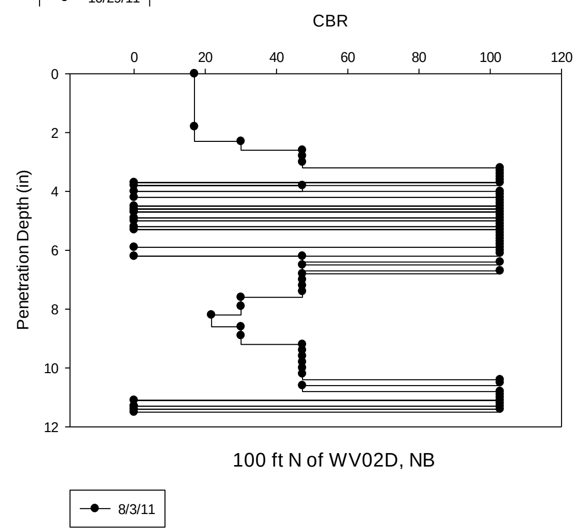
Inside shoulders on northbound and southbound

DCP Plots

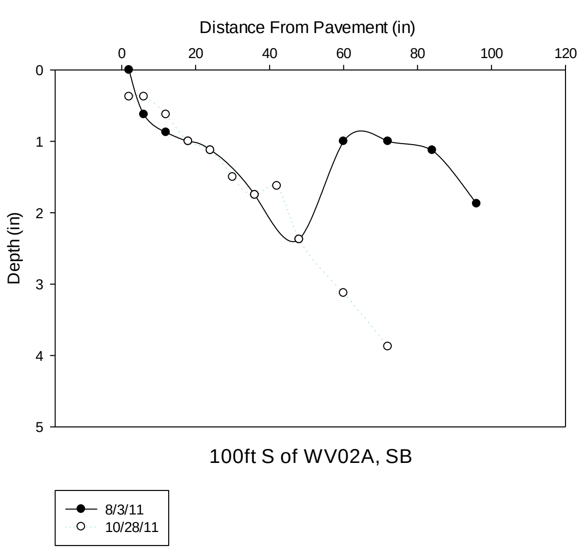


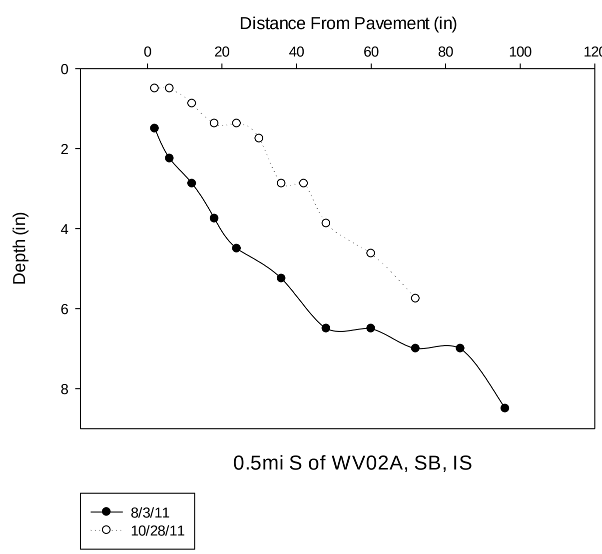


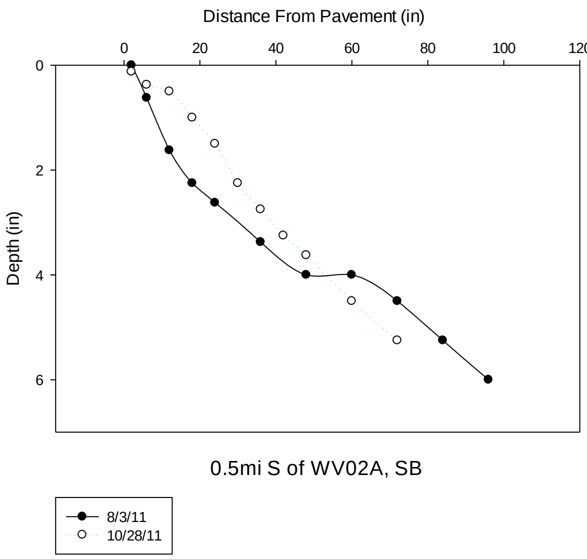




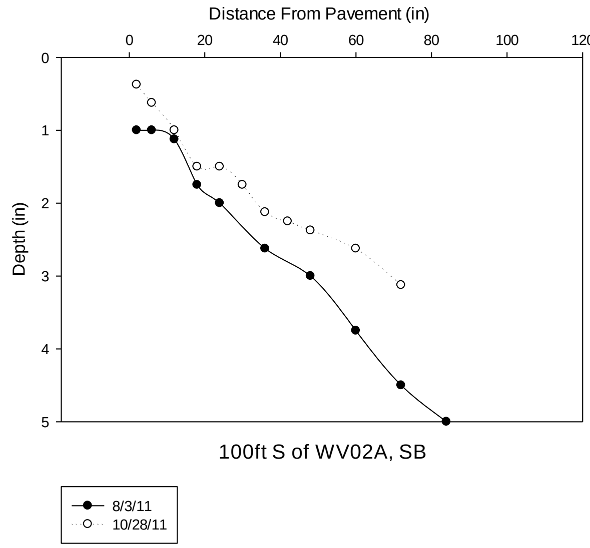
Elevation Profiles



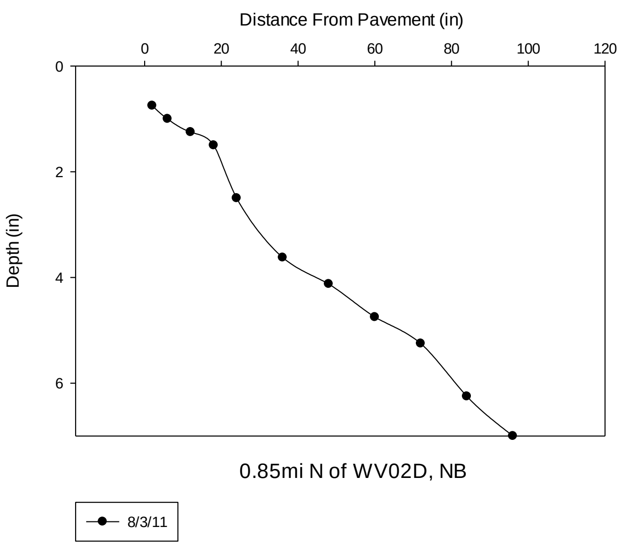




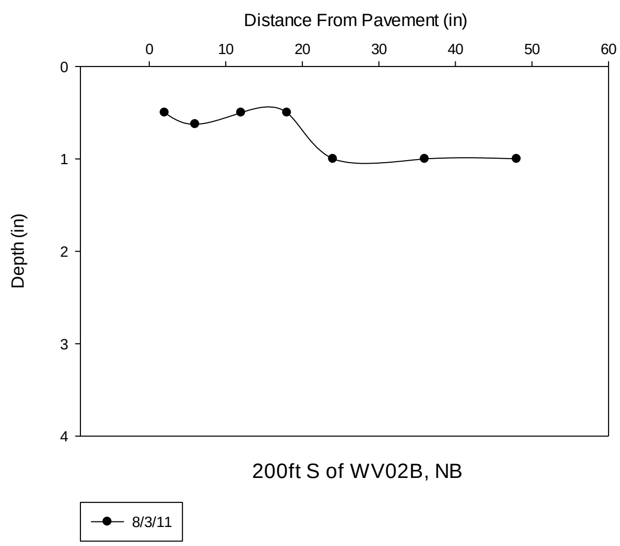
0.5mi S of WV02A, SB



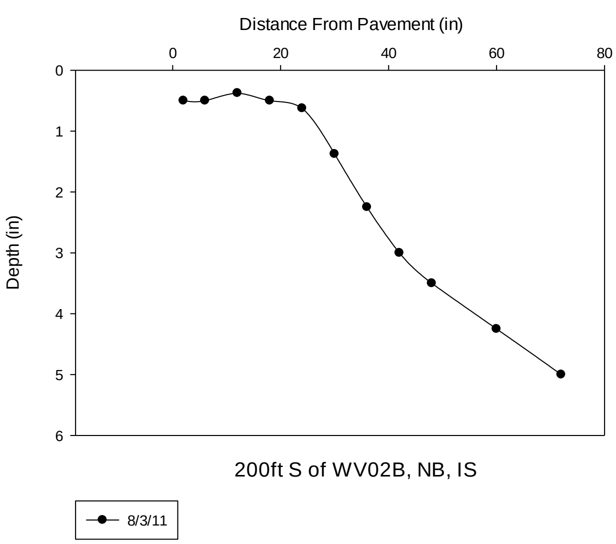
100ft S of WV02A, SB



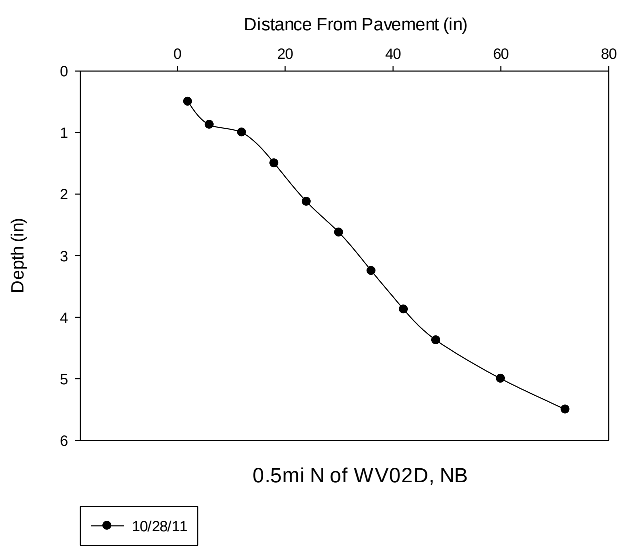
0.85mi N of WV02D, NB



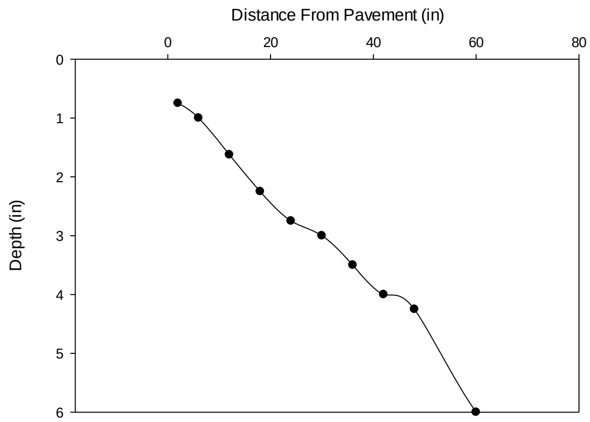
200ft S of WV02B, NB



200ft S of WV02B, NB, IS

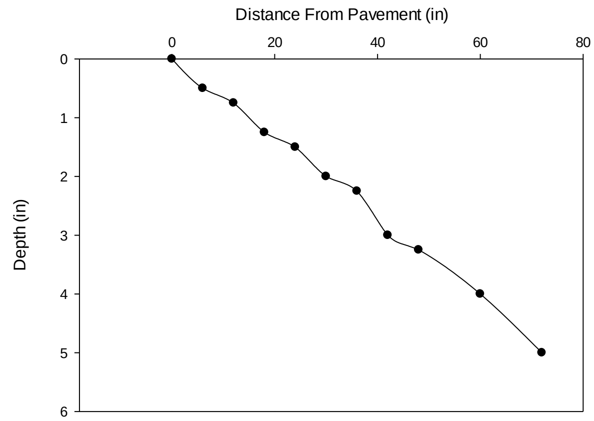


0.5mi N of WV02D, NB



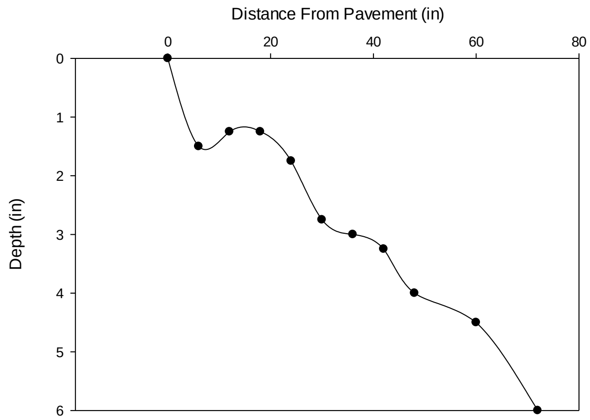
0.5mi N of WV02D,NB, IS

10/28/11



0.25mi S of WV02A, SB

6/21/12



0.4mi S of WV02A, NB

6/21/12

CBR Values

Table 34. Clegg hammer data for Section 2.02

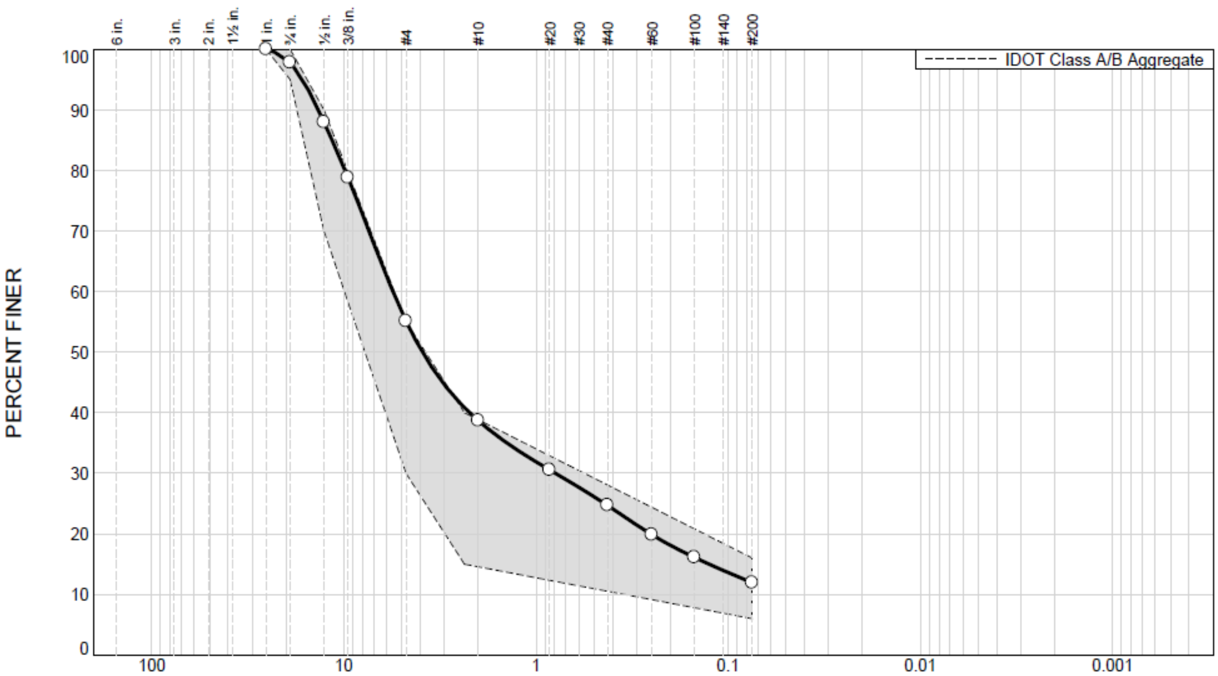
Date	**Location**	**CIV**	**CBR**	**Average CBR**			
	2.02			SB (OS)	SB (IS)	NB (OS)	NB (IS)
Aug. 2011	100 ft south of WV02A SB, OS	14.9	20.9	20.7			
	0.5 mi south of WV02A SB, OS	13.6	18.2				
	300 ft north of WV02C SB, OS	15.8	23.0				
	0.5 mi south of WV02A,SB, IS	5.4	5.3		9.1		
	0.5 mi + 50 ft south of WV02A SB, IS	10.8	12.9				
	100 ft north of WV02D NB, OS	15.2	21.6			16.9	
	0.85 mi north of WV02D NB, OS	12.2	15.4				
	200 ft south of WV02B NB, OS	11.3	13.8				
	200 ft south of WV02B NB, IS	9.8	11.2				11.2
June 2012	100 ft south of WV02A SB, OS	19	30.9	29.6			
	0.25 mi south of WV02A SB, OS	16.1	23.7				
	0.5 mi south of WV02A SB, OS	18.9	30.6				
	WV02C SB, OS	19.9	33.4				
	0.25 mi south of WV02A SB, IS	13.2	17.4		12.9		
	0.5 mi south of WV02A SB, IS	7.9	8.4				
	0.4 mi south of WV02B NB, OS	12.7	16.4			21.3	
	WV02B NB, OS	17.2	26.3				
	0.4mi south of WV02B NB, IS	7.7	8.1				8.1

Area II Section 2.03 MP 220

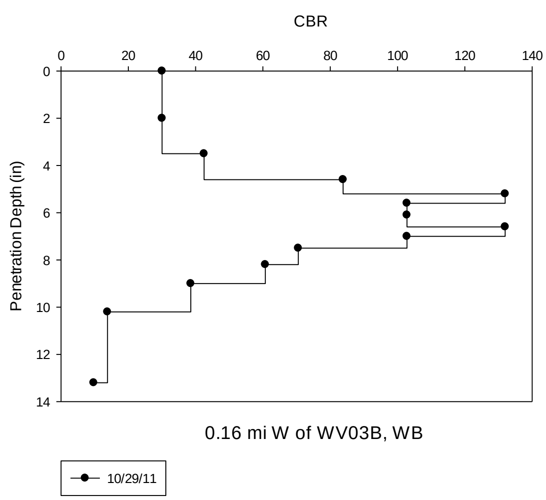
Description: IA 3, Waverly, shoulder on westbound, sprayed 1,491 ft long and 4 ft wide

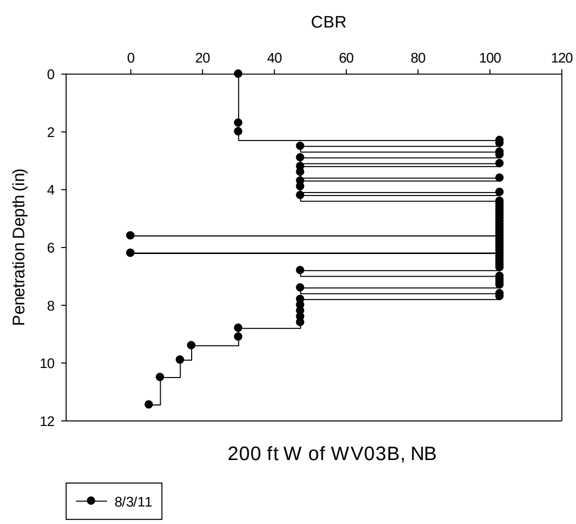
GPS: West end: N 42 43.155, W 92 29.796
East end: N 42 43.382, W 92 29.715

Gradation Distribution

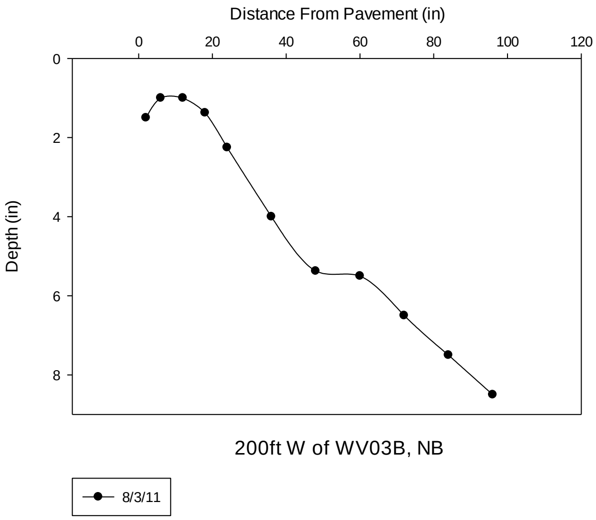


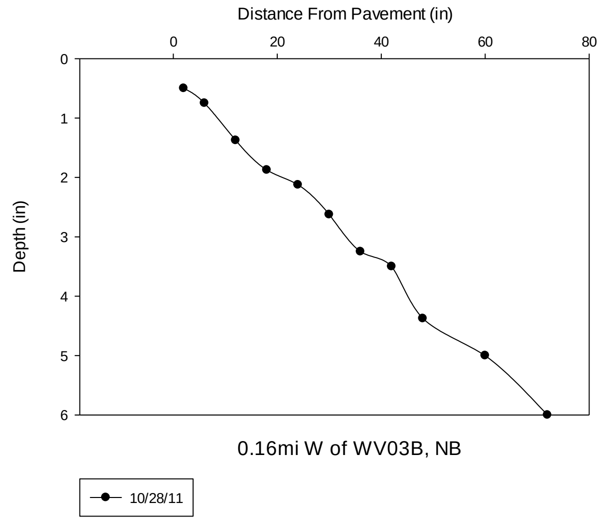
DCP Plots

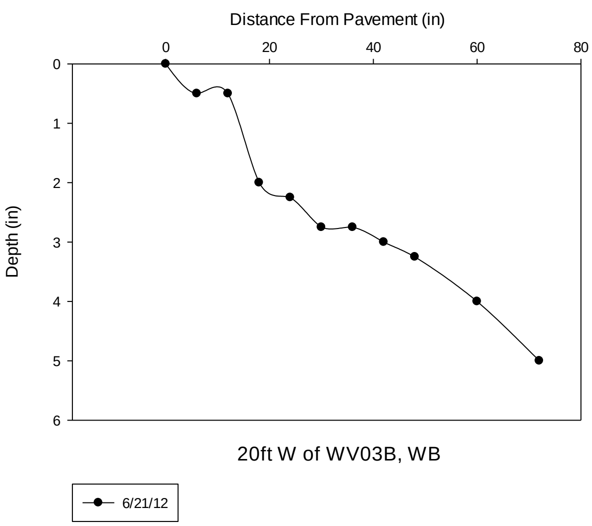


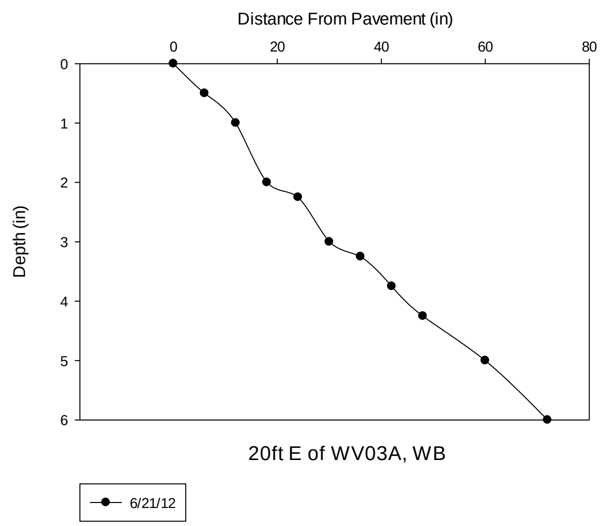


Elevation Profiles









CBR Values

Table 35. Clegg hammer data for Section 2.03

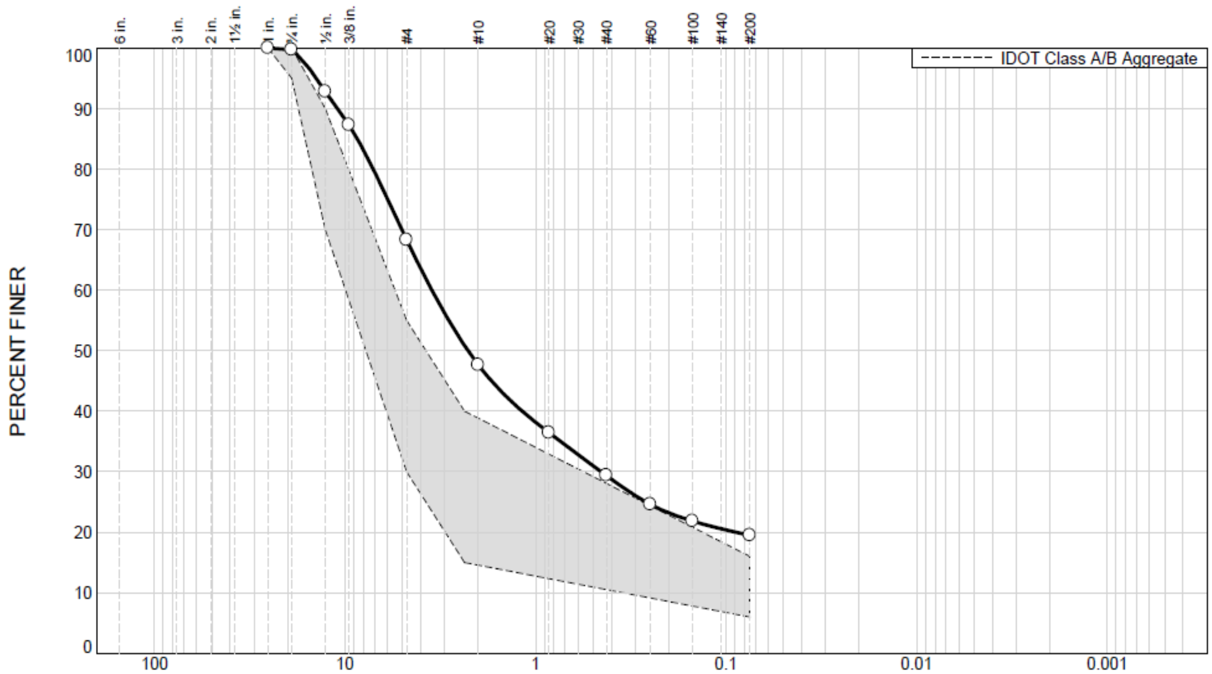
Date	Location	CIV	CBR	Average CBR
	2.03			WB
Aug. 2011	200 ft west of WV03B WB	16.5	24.6	24.6
June 2012	20 ft west of WV03B WB	25.3	50.0	43.2
	200 ft west of WV03B WB	26	52.4	
	20 ft east of WV03A WB	17.5	27.0	

Area II Section 2.04 MP 215-216

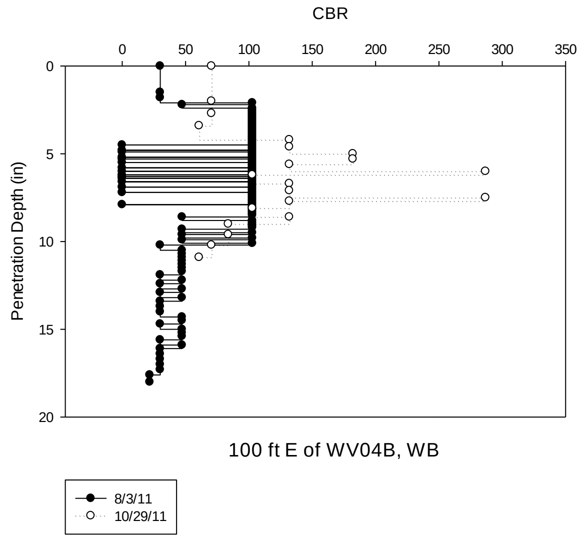
Description: IA 3, Shell Rock, shoulders on both sides, sprayed 11,170 ft long and 4 ft wide

GPS: West end: N 42 43.252, W 92 35.022
East end: N 42 42.889, W 92 33.952

Gradation Distribution

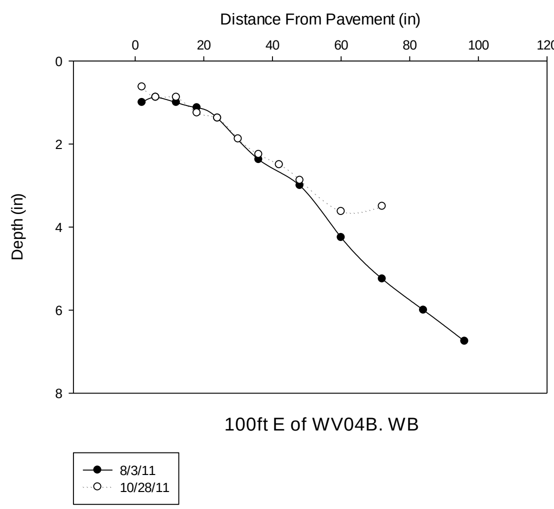


DCP Plots

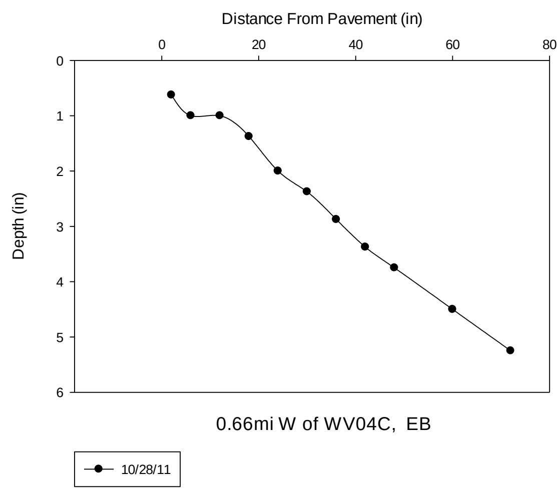


100 ft E of WV04B, WB

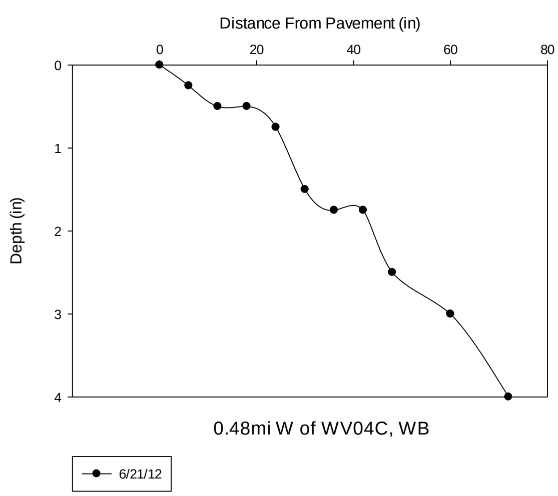
Elevation Profiles



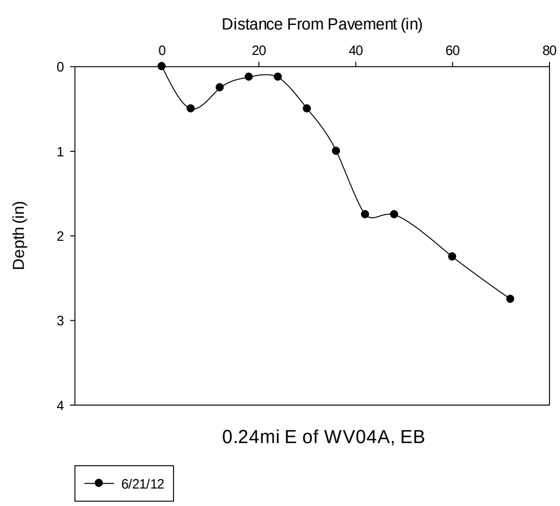
100ft E of WV04B. WB



0.66mi W of WV04C, EB



0.48mi W of WV04C, WB



0.24mi E of WV04A, EB

CBR Values

Table 36. Clegg hammer data for section 2.04

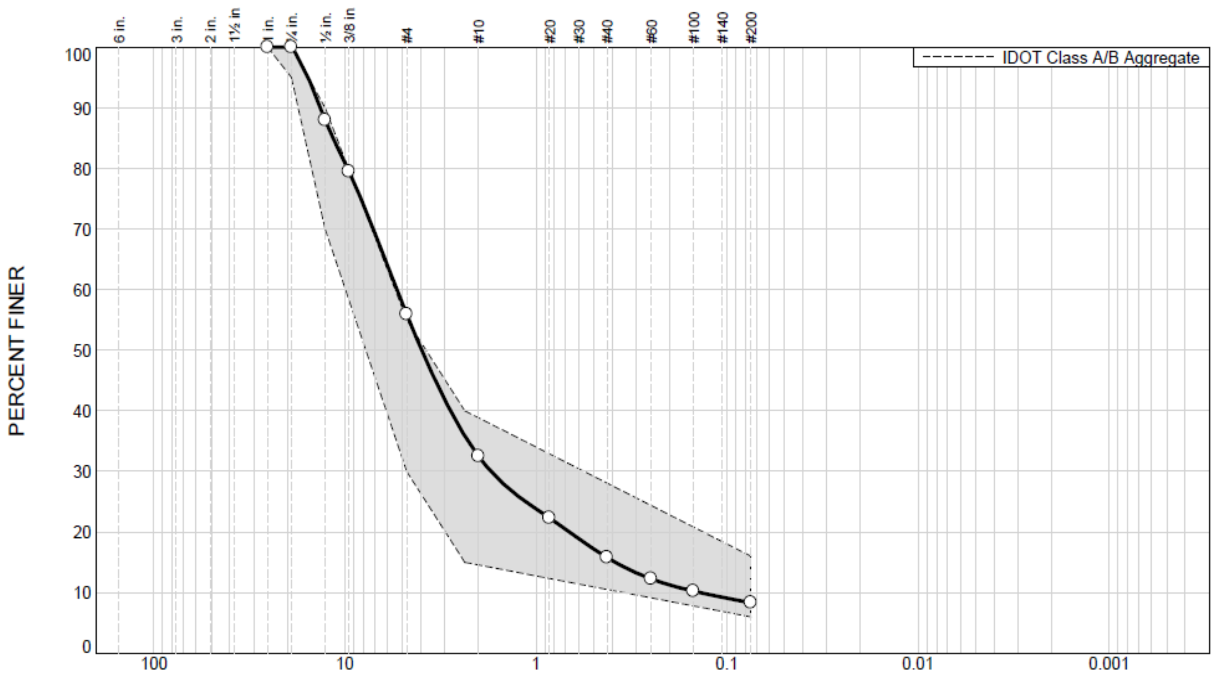
Date	Location	CIV	CBR	Average CBR	
	2.04			EB	WB
Aug. 2011	50 ft west of WV04C EB	18.8	30.4	38.9	
	200 ft west of WV04C EB	18.5	29.6		
	Near middle EB	27.2	56.7		
	100 ft east of WV04B WB	34	83.9		58.2
	Near middle WB	19.6	32.5		
June 2012	60 ft east of WV04A EB	28.6	61.8	60.4	
	0.24 mi east of WV04A EB	27.6	58.1		
	0.39 mi west of WV04C EB	27.4	57.4		
	70 ft west of WV04C EB	29.2	64.1		
	0.48 mi west of WV04C WB	37.6	100.5		80.0
	100 ft east of WV04A WB	28	59.6		

Area II Section 2.05 MP 205.1-305.7

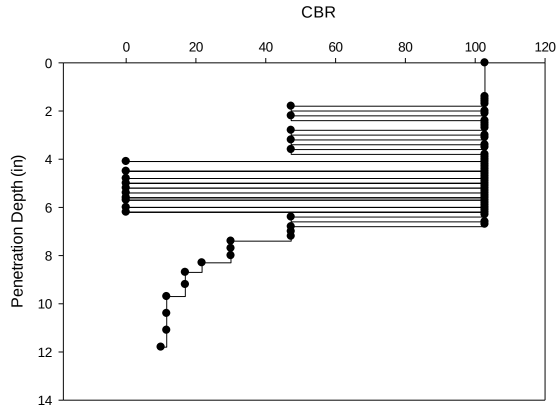
Description: IA 3, east of Allison, shoulder on both sides, sprayed 8,280 ft long and 4 ft wide

GPS: West end: N 42 44.685, W 92 47.184
East end: N 42 44.674, W 92 46.308

Gradation Distribution

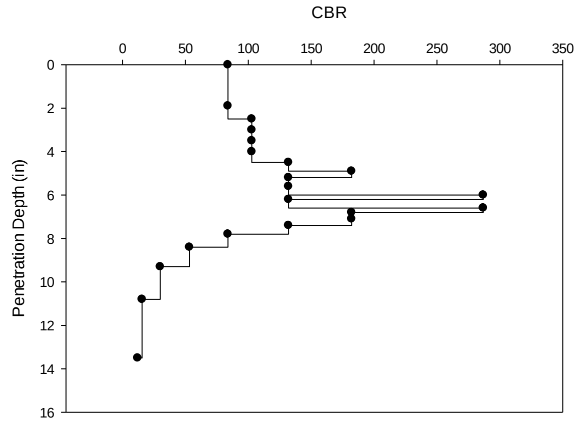


DCP Plots



50 ft W of WV05C, EB

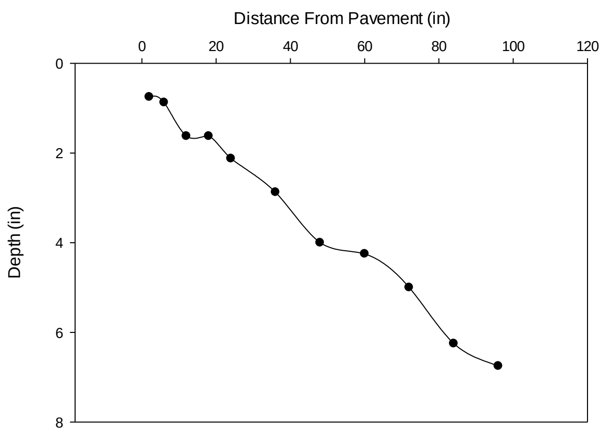
8/3/11



440 ft E of WV05A, EB

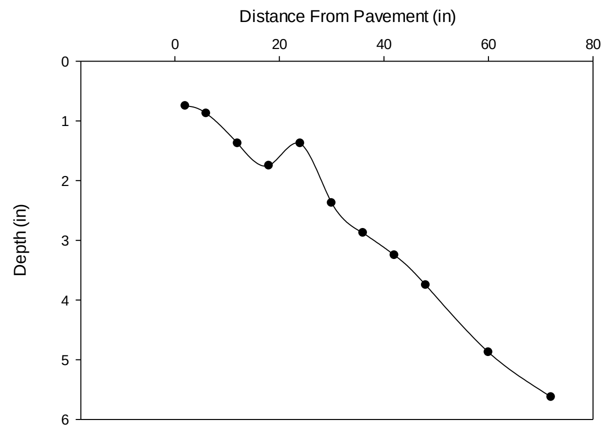
10/29/11

Elevation Profiles



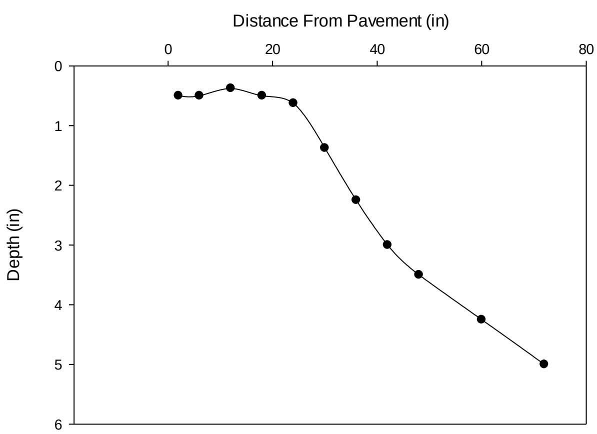
50ft W of WV05C, EB

8/3/11



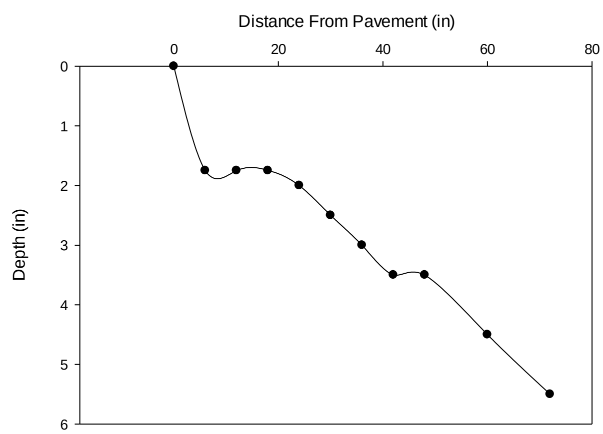
440 FT East of WV05A, EB

10/28/11



455ft E of WV05A, EB

6/21/12



40Fft W of WV05C, EB

6/21/12

CBR Values

Table 37. Clegg hammer data for section 2.05

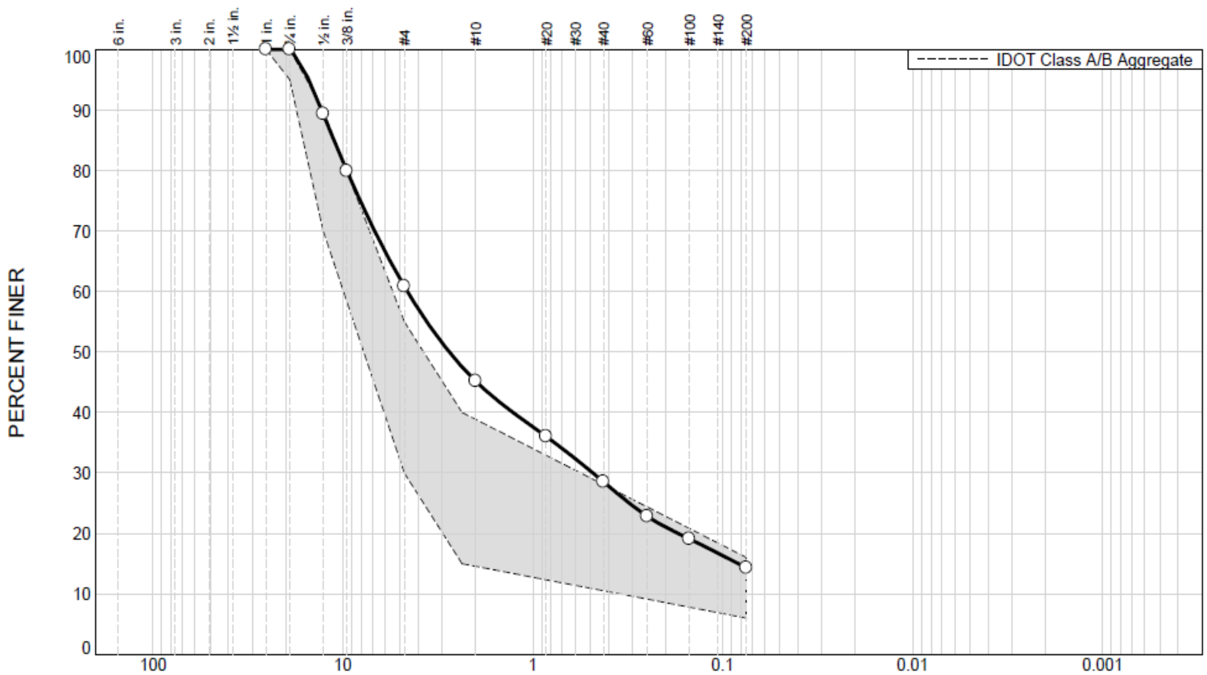
Date	Location	CIV	CBR	Average CBR	
	2.05			EB	WB
Aug. 2011	50 ft west of WV05C EB	23.1	42.8	42.8	
June 2012	455 ft east of WV05A EB	32.2	76.2	72.6	
	0.24 mi east of WV05A EB	35.4	90.2		
	0.4 mi west of WV05C EB	31.4	72.9		
	40 ft west of WV05C EB	25.7	51.4		
	0.45 mi west of WV05C WB	31.9	74.9		74.5
	WV05A WB	31.7	74.1		

Area III Section 3.01 MP 264.5-265

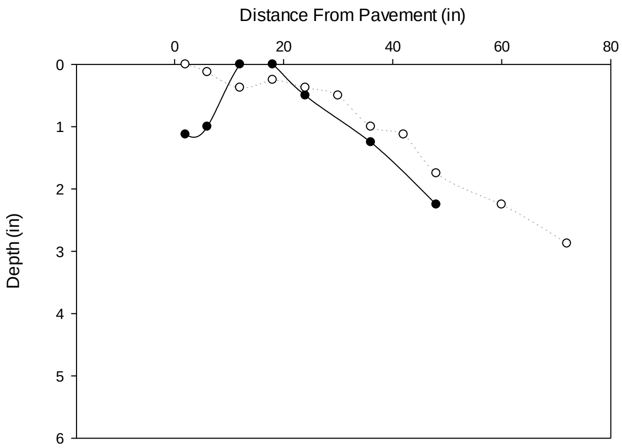
Description: US 18, east of West Union, shoulder on both sides, sprayed 3,048 ft long and 4 ft wide

GPS: West end: N 42 57.840, W 91 47.823
East end: N 42 57.996, W 91 47.450

Gradation Distribution

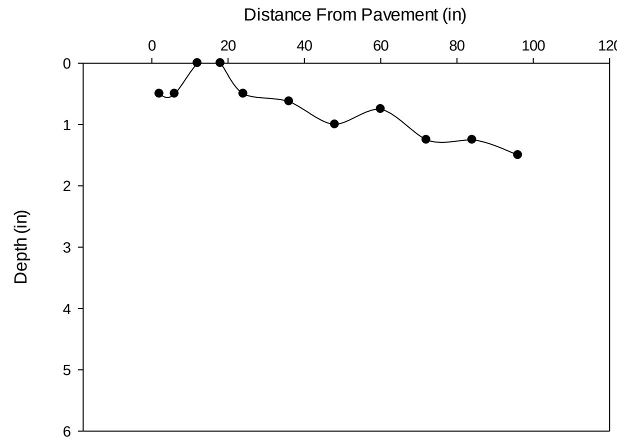


Elevation Profiles



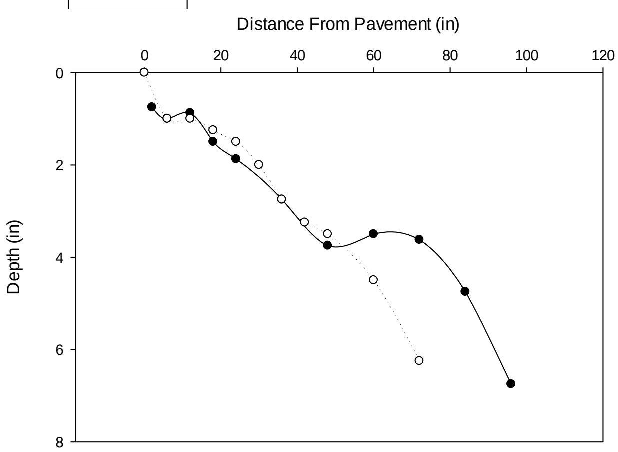
UN01A, EB

8/10/11
10/30/11



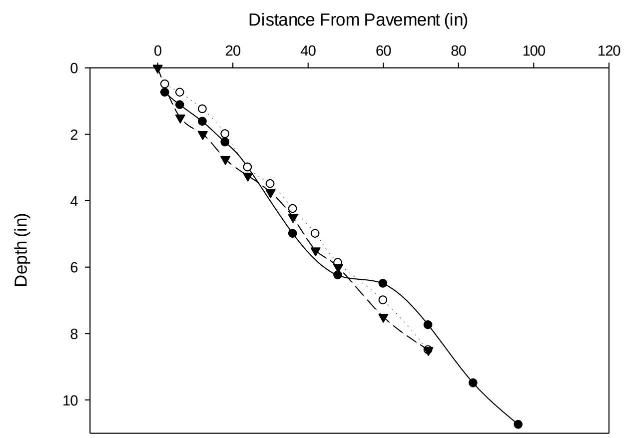
300 FT E of UN01A, EB

8/10/11



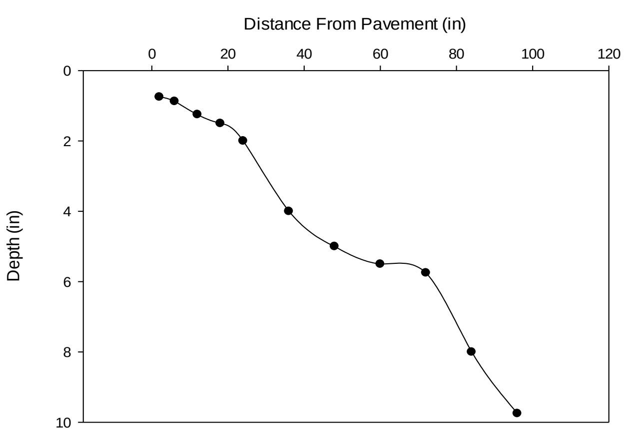
215 FT W of UN01B, EB

8/10/11
6/21/12



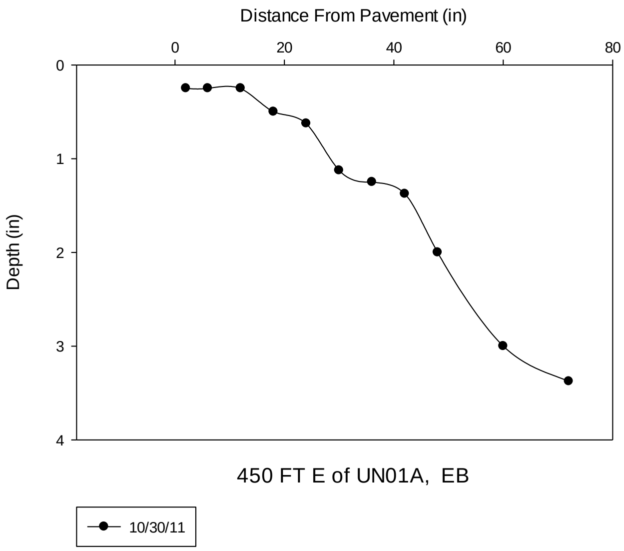
215 FT W of UN01B, WB

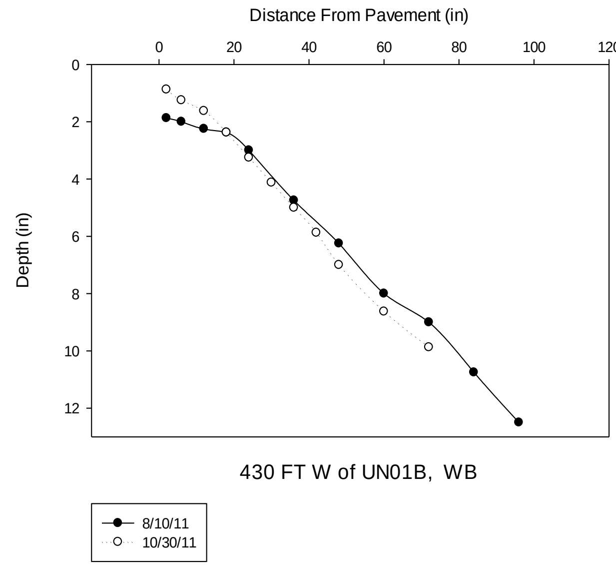
8/10/11
10/30/11
6/21/12



0.19mi W of UN01B, WB

8/10/11





CBR Values

Table 38. Clegg hammer data for section 3.01

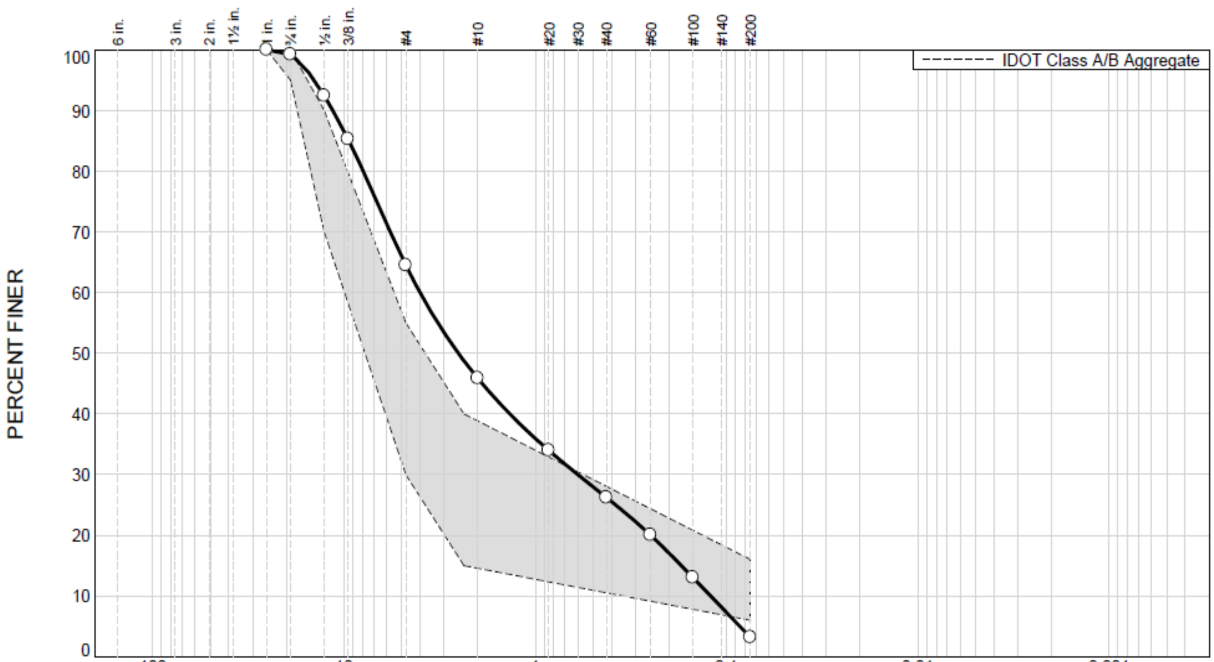
Date	**Location**	**CIV**	**CBR**	**Average CBR**	
	3.01			EB	WB
Aug. 2011	UN01A EB	27.3	57.0	57.6	
	300 ft east of UN01A EB	31.1	71.6		
	490 ft east of UN01A EB	20.8	35.9		
	215 ft west of UN01B EB	29.6	65.7		
	215 ft west of UN01B WB	26.5	54.2		44.0
	0.19 mi west of UN01B WB	20.1	33.9		
June 2012	UN01A EB	16.6	24.8	41.5	
	215 ft west of UN01B EB	27.6	58.1		
	215 ft west of UN01B WB	30	67.2		64.9
	430 ft west of UN01B WB	28.8	62.6		

Area III Section 3.02 MP 269.8-271

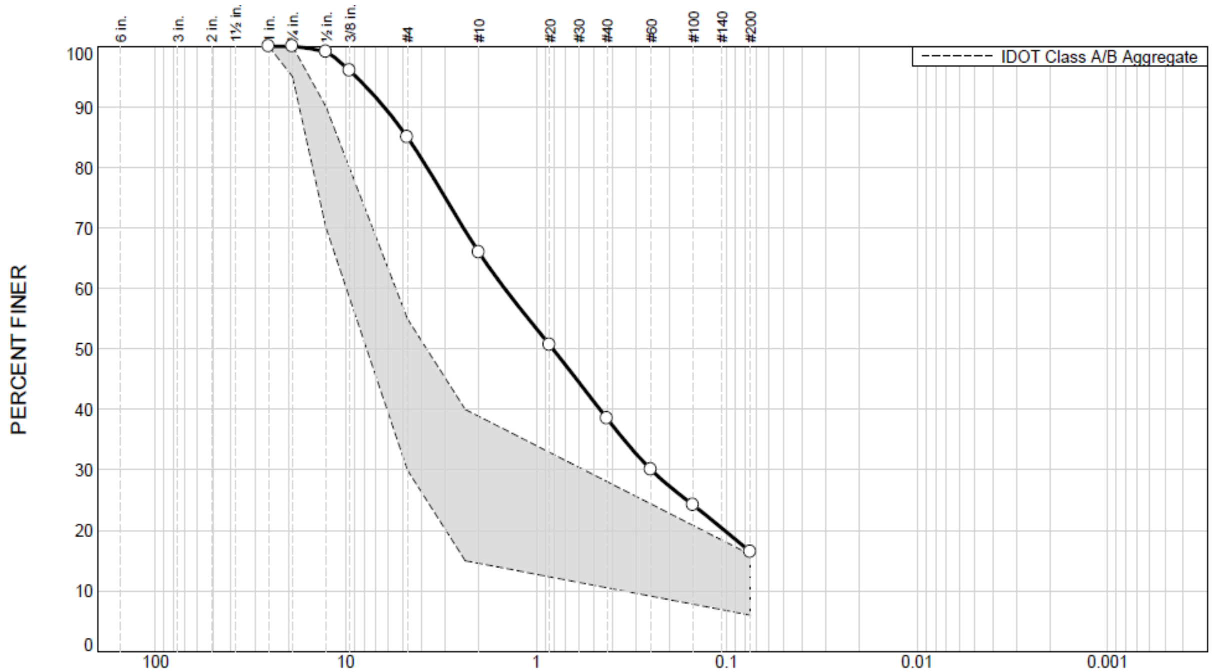
Description: US 18, west of Clermont, shoulder on both sides, sprayed 8,900 ft long and 4ft wide

GPS: West end: N 42 59.086, W 91 42.442
East end: N 42 59.354, W 91 41.483

Gradation Distribution

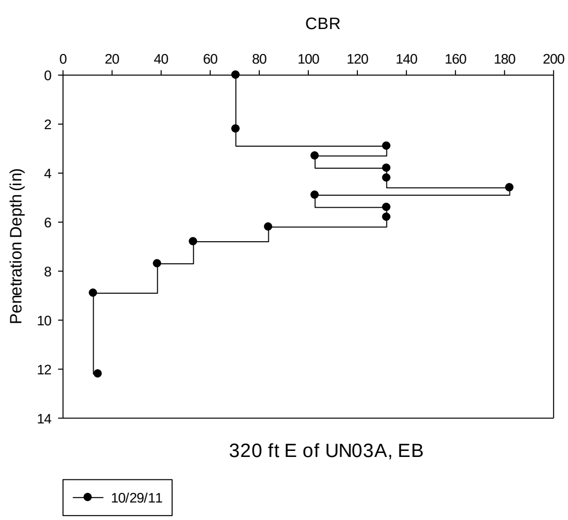


Shoulder on eastbound

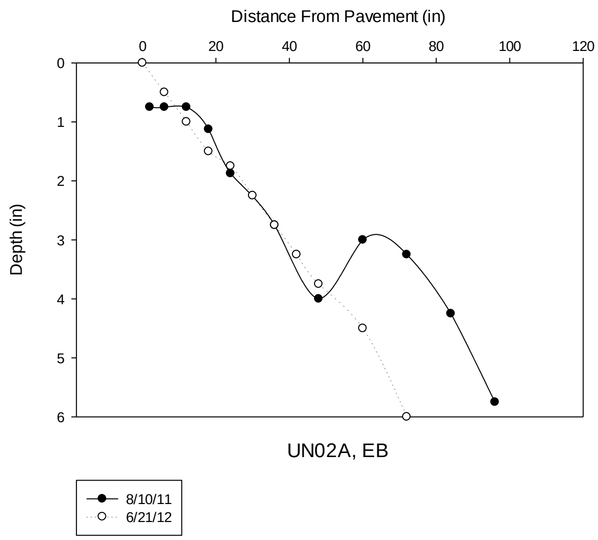


Shoulder on westbound

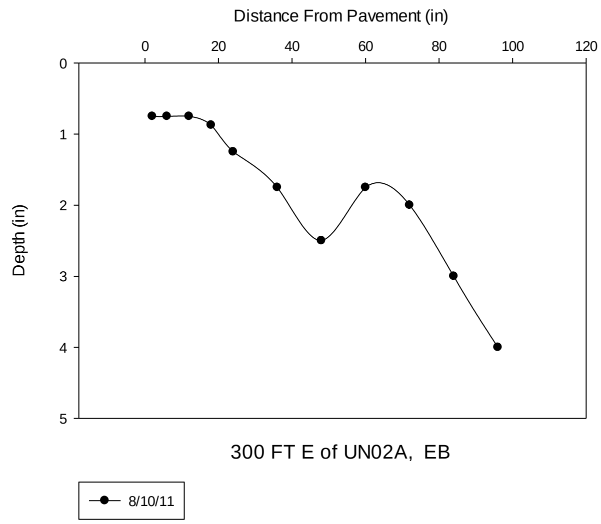
DCP Plots



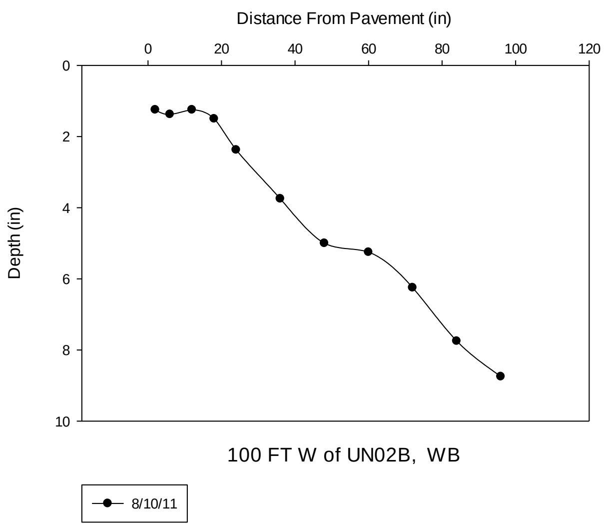
Elevation Profiles



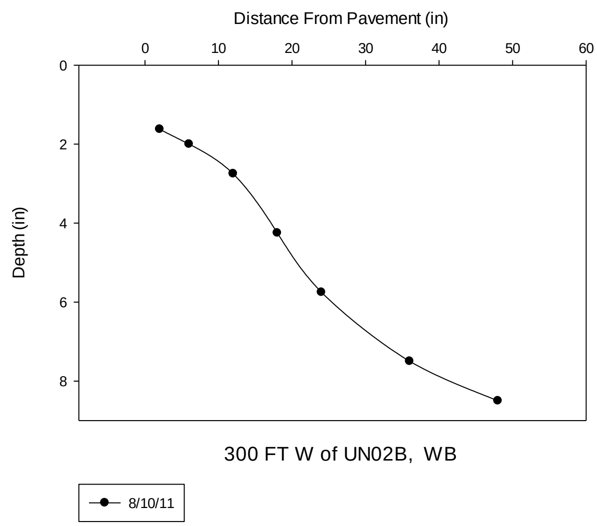
UN02A, EB



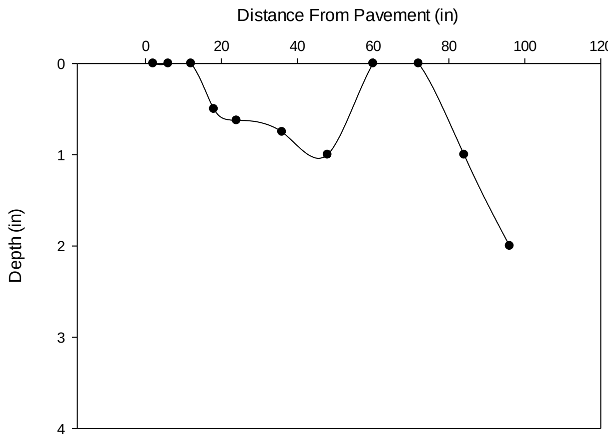
300 FT E of UN02A, EB



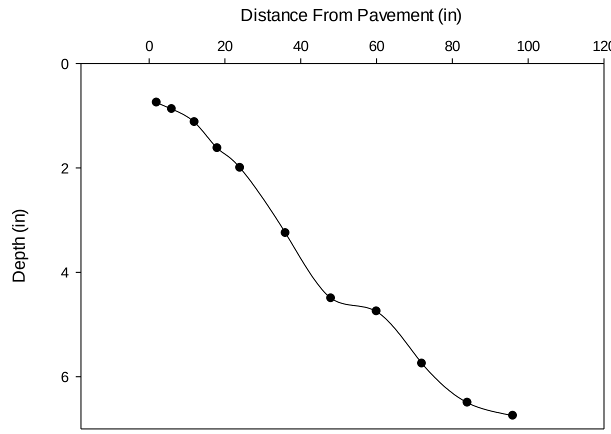
100 FT W of UN02B, WB



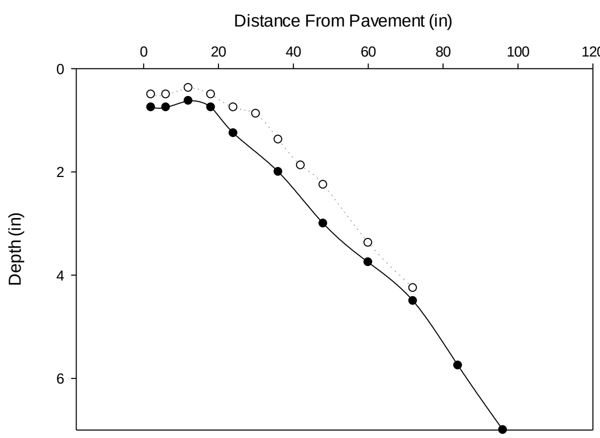
300 FT W of UN02B, WB



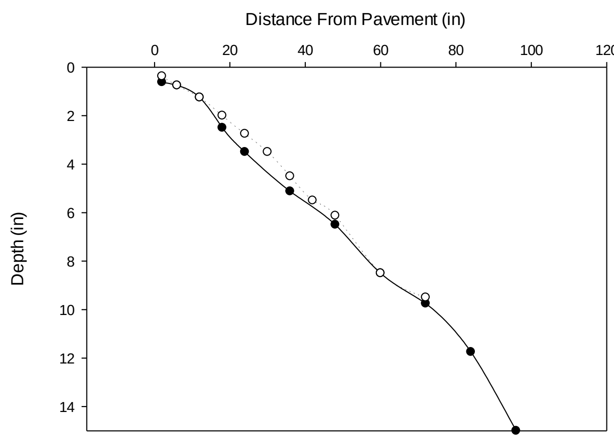
100 FT E of UN03A, EB



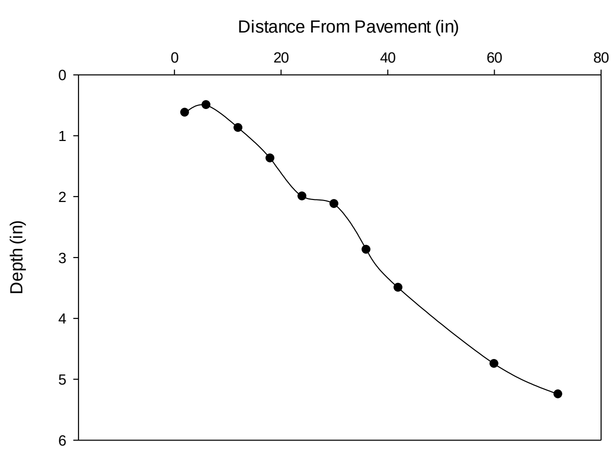
275 FT E of UN03A, EB



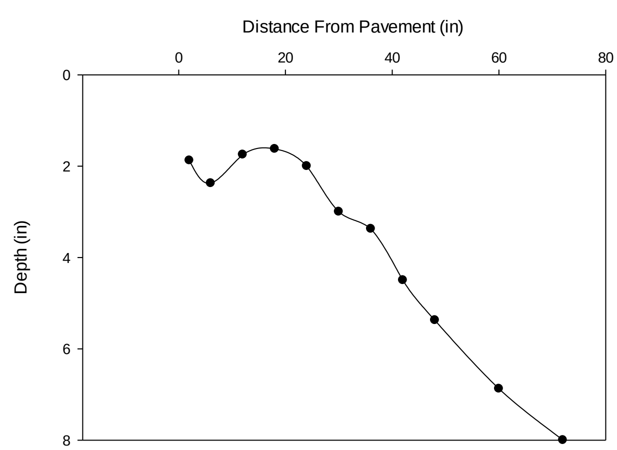
200 FT W of UN03B, WB



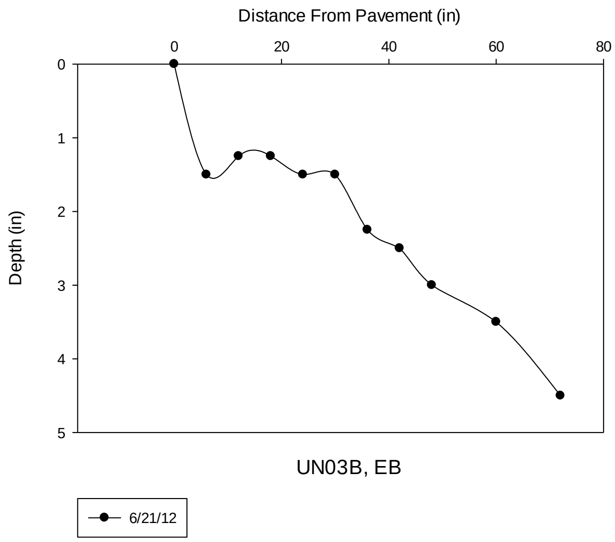
0.28mi W of UN03B, WB

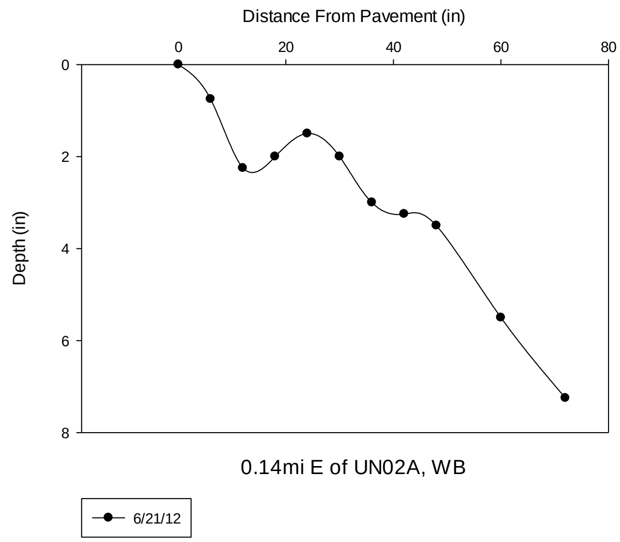


320 FT E of UN03A, EB



0.23mi W of UN03B, WB





CBR Values

Table 39. Clegg hammer data for section 3.02

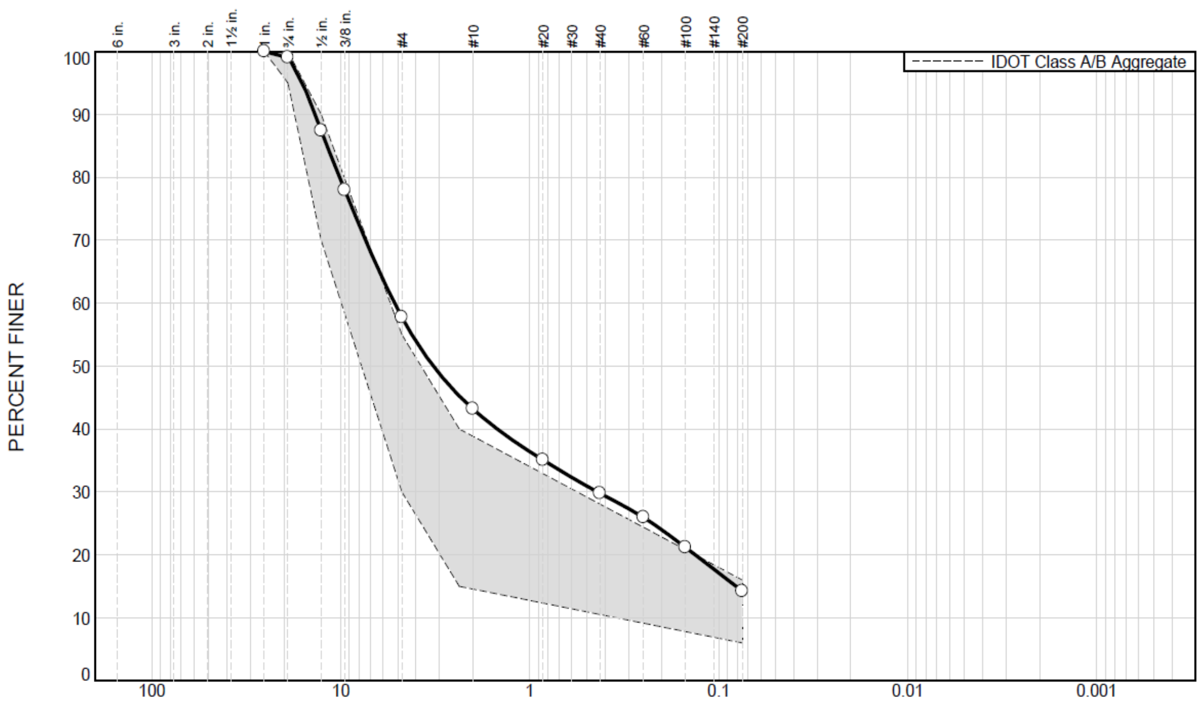
Date	**Location**	**CIV**	**CBR**	**Average CBR**	
	3.02			EB	WB
Aug. 2011	UN02A EB	32.2	76.2	66.9	
	300 ft east of UN02A EB	25.3	50.0		
	90 ft west of UN02B EB	30.8	70.4		
	100 ft east of UN03A EB	30.8	70.4		
	275 ft east of UN03A EB	30.1	67.6		
	100 ft west of UN02B WB	28.3	60.7		51.5
	300 ft west of UN02B WB	23.1	42.8		
	200 ft west of UN03B WB	28.8	62.6		
	0.28 mi west of UN03B WB	22.2	40.0		
June 2012	UN02A EB	32.2	76.2	66.8	
	300 ft east of UN02A EB	25.3	50.0		
	0.31 mi west of UN03B EB	30.8	70.4		
	65 ft east of UN03B EB	30.8	70.4		
	0.33 mi west of UN03B WB	30.1	67.6		57.1
	0.14 mi east of UN02A WB	28.3	60.7		
	60 ft east of UN02A WB	23.1	42.8		

Area III Section 3.03-3.04 MP 75-75.7

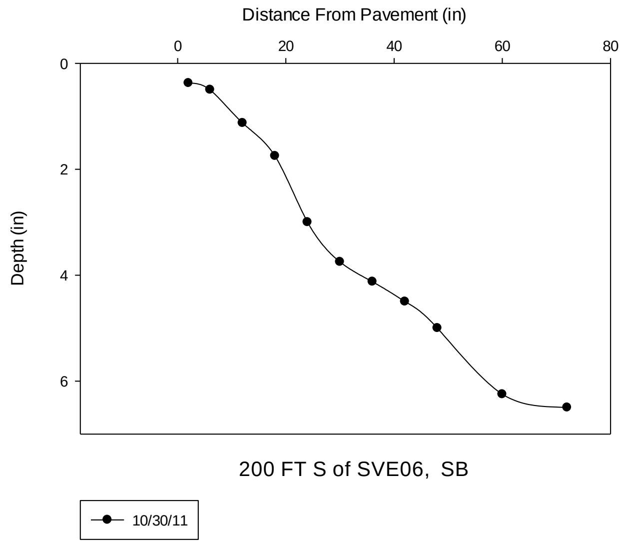
Description: IA 13, Elkader, Section 3.03 (MP 75-75.7), shoulder on northbound, sprayed 3,090 ft long and 12 ft wide; Section 3.04 (MP 75-75.2), shoulder on southbound, sprayed 1,330 ft long and 12 ft wide

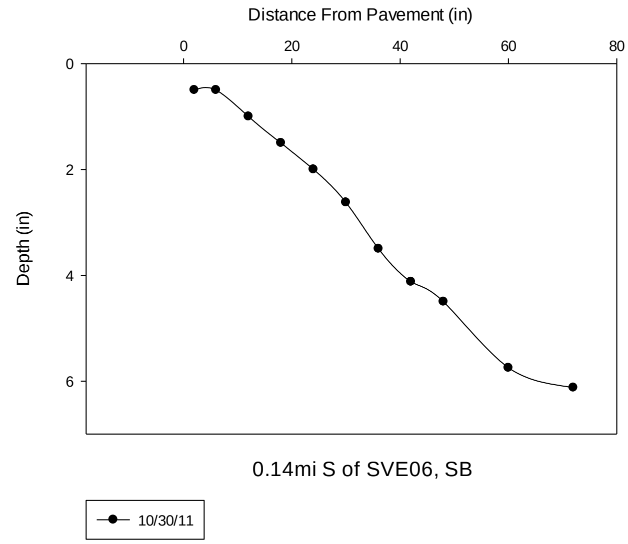
GPS: South end: N 42 51.210, W 91 23.566
North end: N 42 51.711, W 91 23.634

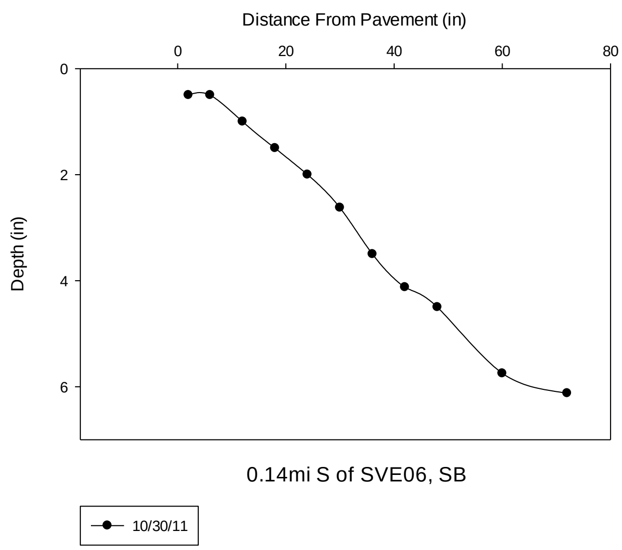
Gradation Distribution

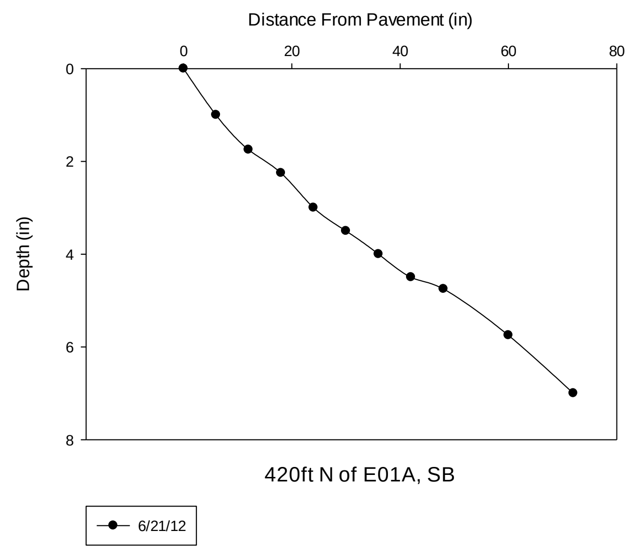


Elevation Profiles









CBR Values

Table 40. Clegg hammer data for section 3.03-3.04

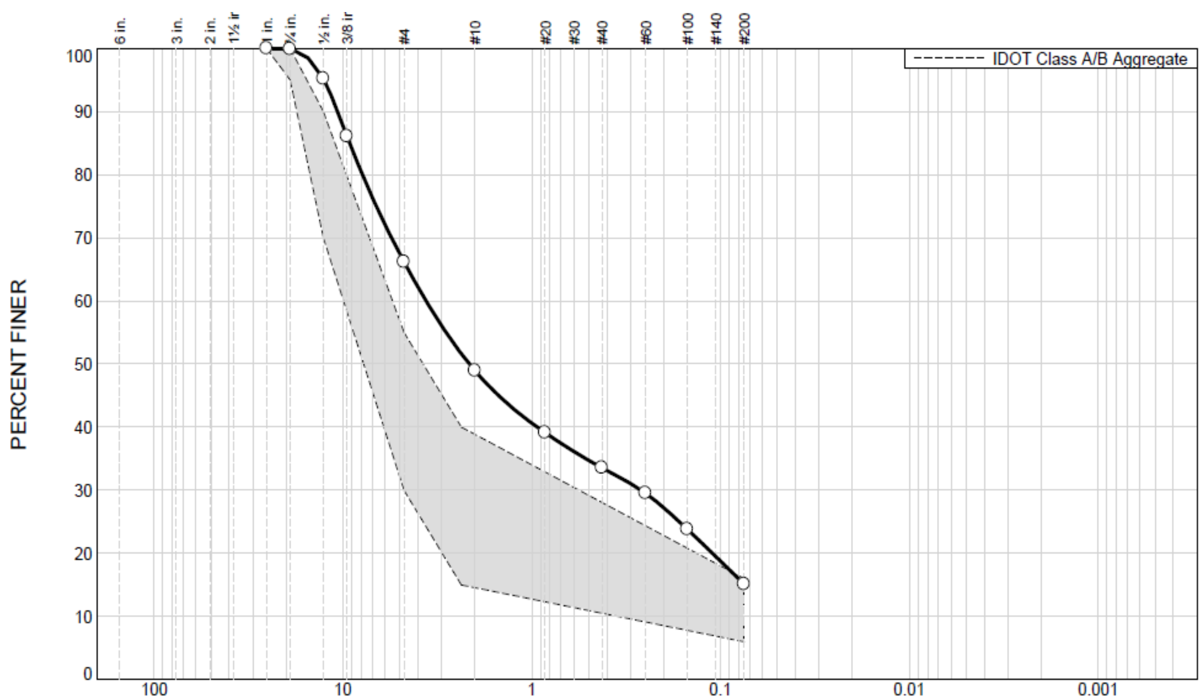
Date	**Location**	**CIV**	**CBR**	**Average CBR**	
	3.03-3.04			SB	NB
June 2012	330 ft north of E01A NB	31	71.2		58.1
	0.18 mi south of E01B NB	27	56.0		
	E01B NB	24.4	47.0		
	30 ft south of E01C SB	19.2	31.4	35.3	
	420 ft north of E01A SB	21.9	39.1		

Area III Section 3.05-3.07 MP 69.3-74

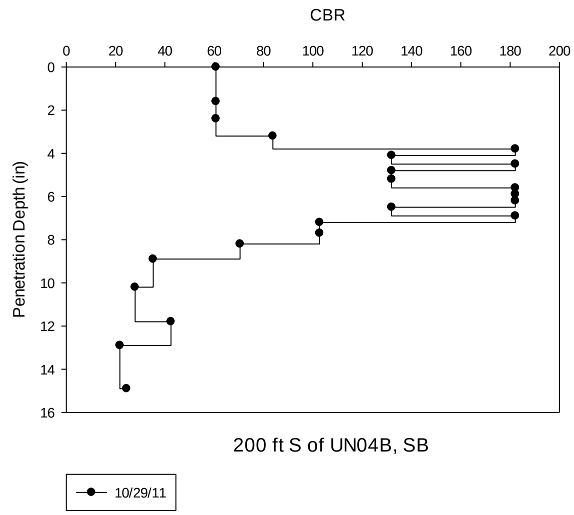
Description: IA 13, south of Elkader; Section 3.05 (MP72.4-74): shoulder on northbound, sprayed 4890ft long and 4ft wide; Section 3.06 (MP70-70.1): shoulder on northbound, sprayed 740ft long and 10ft wide; Section 3.07 (MP69.3-69.6): shoulder on northbound, sprayed 1315ft long and 10ft wide

GPS: South end: N 42 47.876, W 91 26.148
North end: N 42 50.557, W 91 24.083

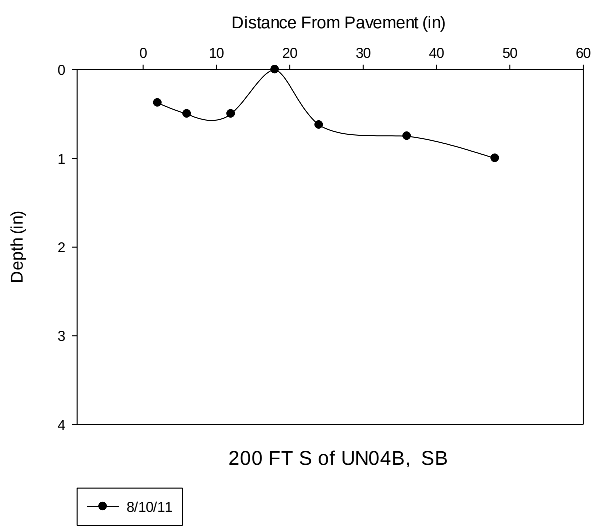
Gradation Distribution

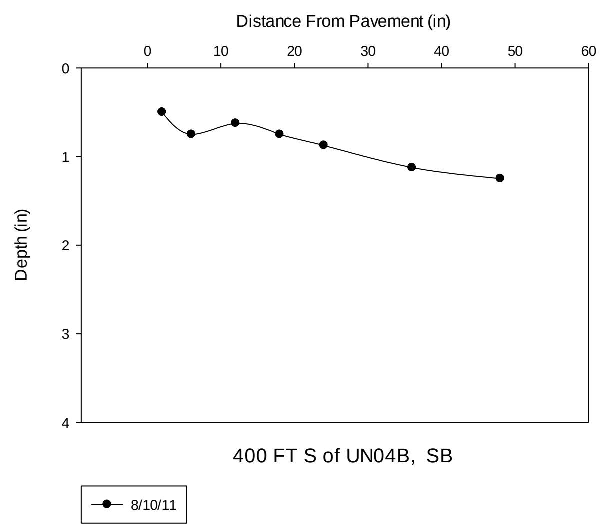


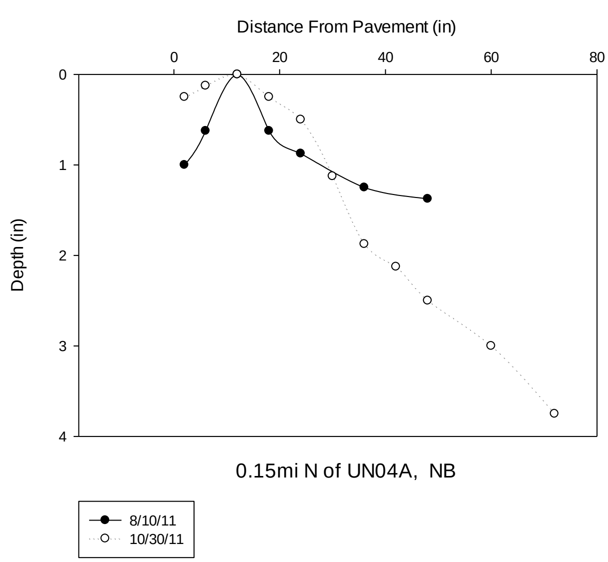
DCP Plots

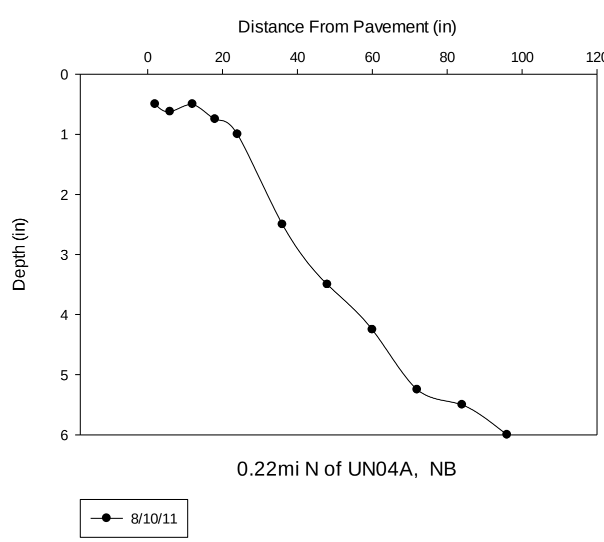


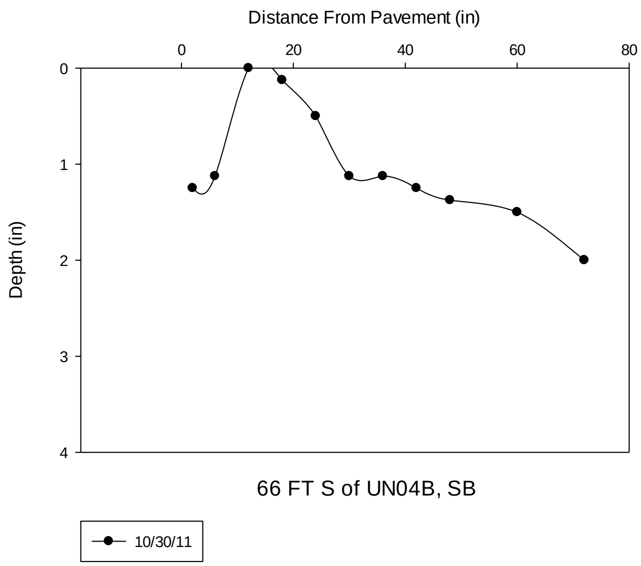
Elevation Profiles



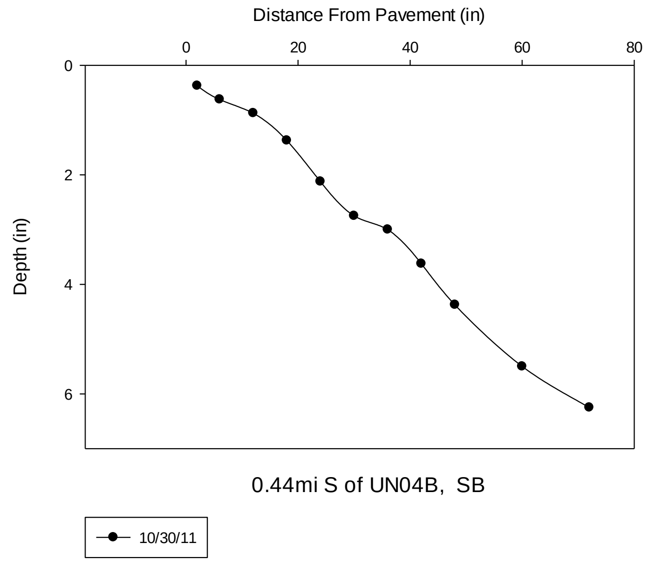




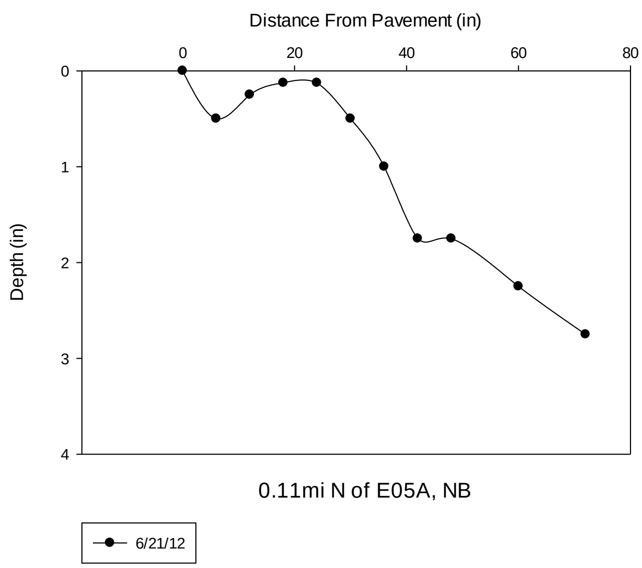




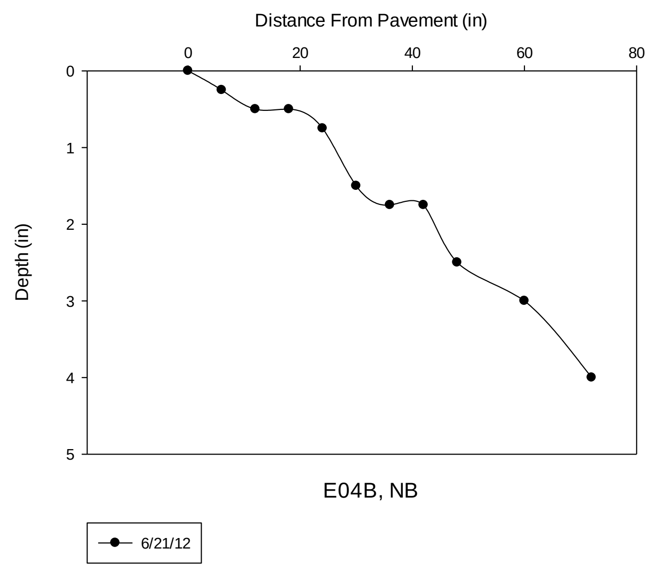
66 FT S of UN04B, SB



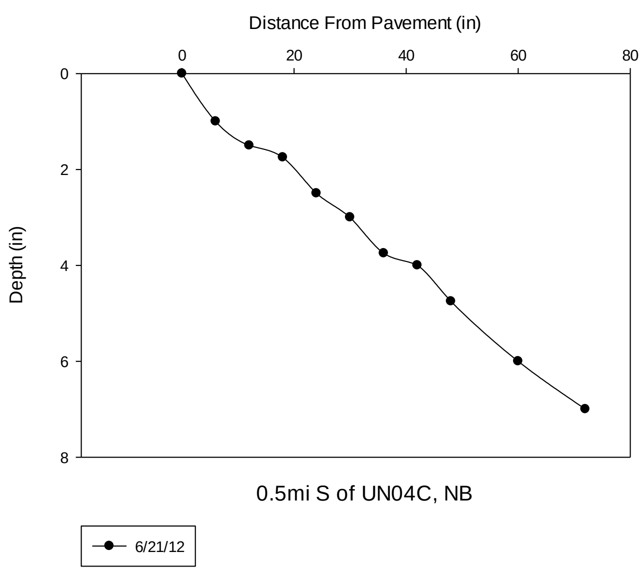
0.44mi S of UN04B, SB



0.11mi N of E05A, NB



E04B, NB



0.5mi S of UN04C, NB

CBR Values

Table 41. Clegg hammer data for section 3.05-3.07

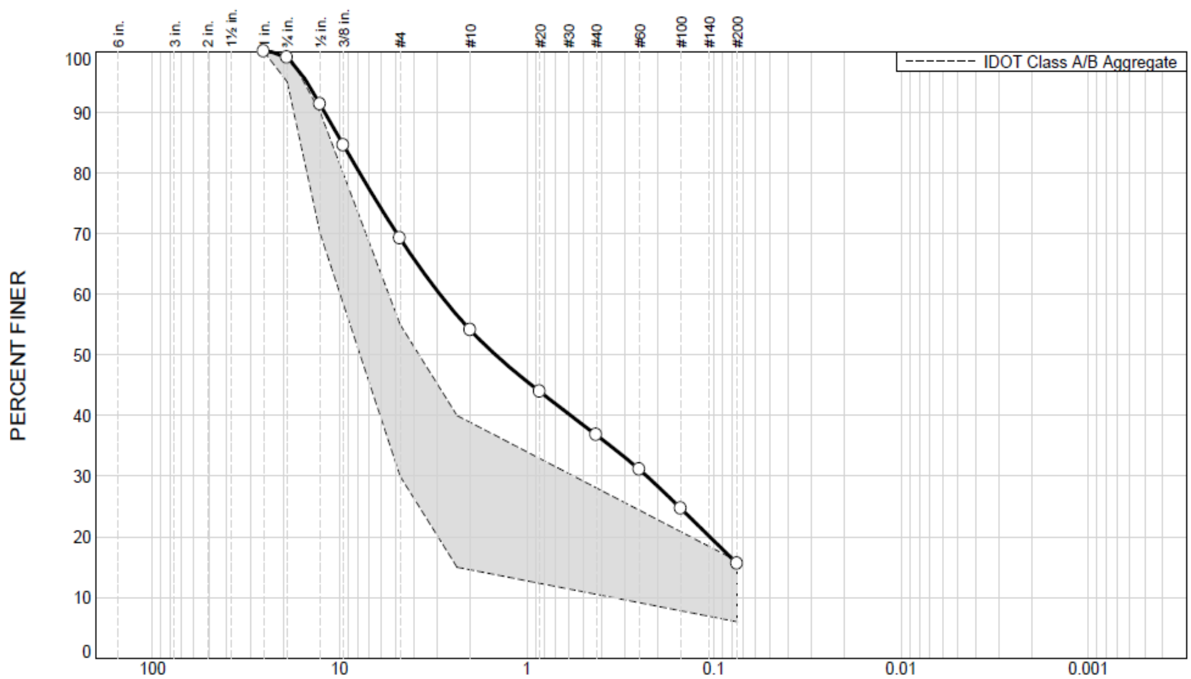
Date	Location	CIV	CBR	Average CBR
	3.05-3.07			NB
Aug. 2011	0.15 mi north of UN04A NB	26.3	53.5	58.0
	0.22 mi north of UN04A NB	28.8	62.6	
June 2012	20 ft north of E05A NB	13.8	18.6	35.5
	0.11 mi north of E05A NB	21.9	39.1	
	30 ft south of E05B NB	19.7	32.8	
	E04B NB	18.8	30.4	
	0.5 mi south of UN04C NB	26.3	53.5	
	220 ft south of UN04C NB	21.7	38.5	

Area III Section 3.08-3.10 70 ft South of Intersection W-51 and 215th Street to 4,460 ft South of Intersection W-51 and 215th Street

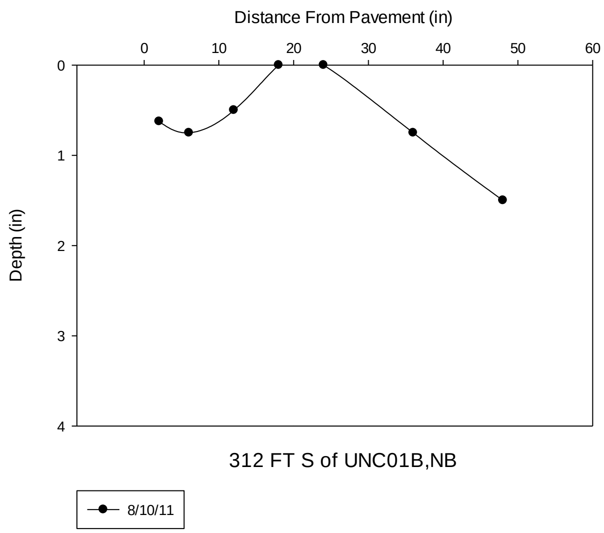
Description: W-51, south of Elgin; Section 3.08 (3,600 ft south of W-51 and 215th Street to 4,460 ft south of W-51 and 215th Street), shoulder on northbound, sprayed 860 ft long and 2 ft wide; Section 3.09 (70 ft south of W-51 and 215th Street to 1,050 ft south of W-51 and 215th Street), shoulder on northbound, sprayed 980 ft long and 2 ft wide; Section 3.10 (1,760 ft south of W-51 and 215th Street to 4,000 ft south of W-51 and 215th Street), shoulder on southbound, sprayed 2,240 ft long and 2,ft wide

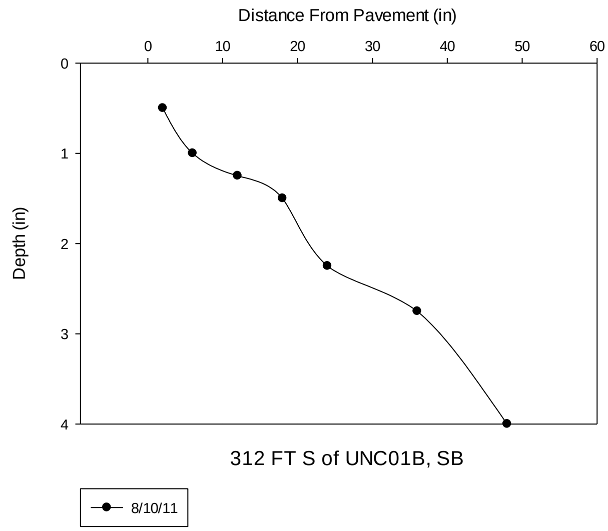
GPS: South end: N 42 56.152, W 91 39.063
North end: N 42 56.774, W 91 38.711

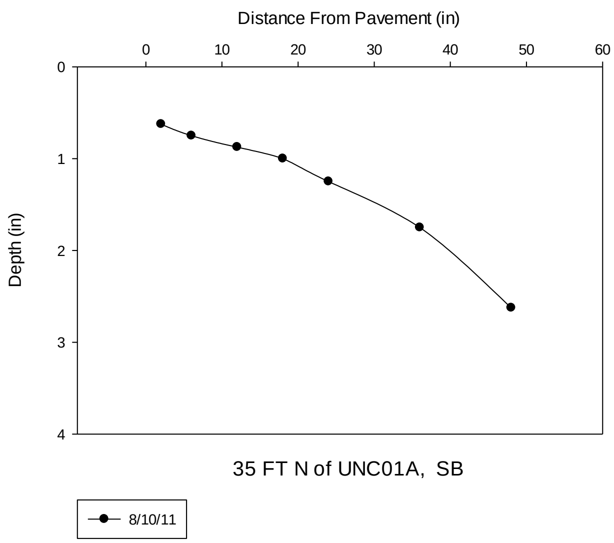
Gradation Distribution

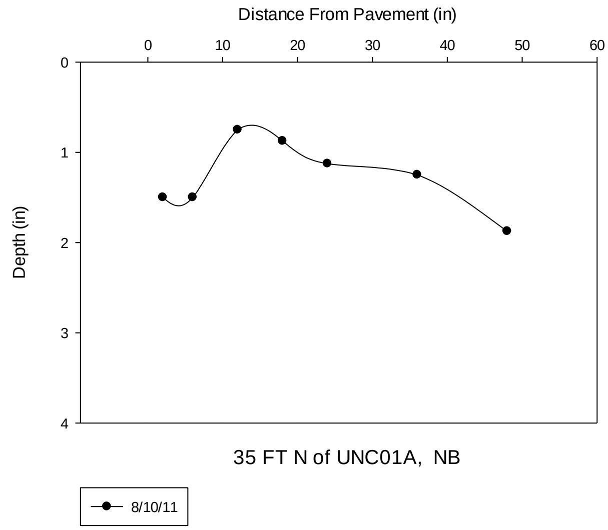


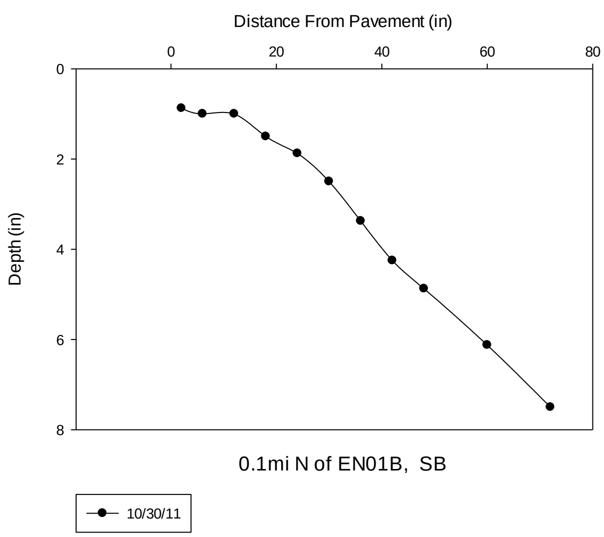
Elevation Profiles

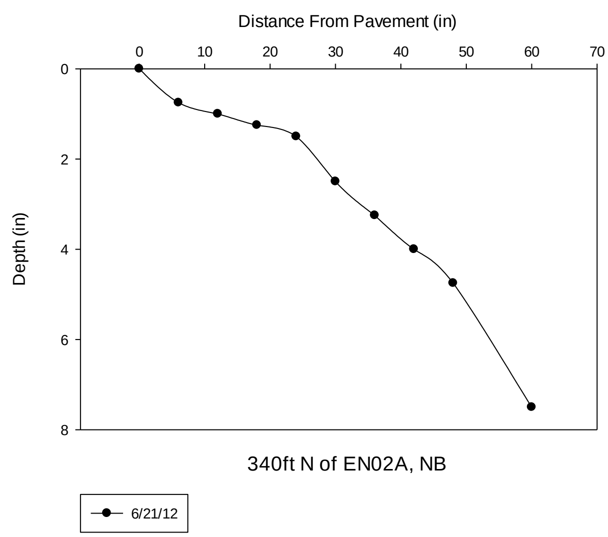


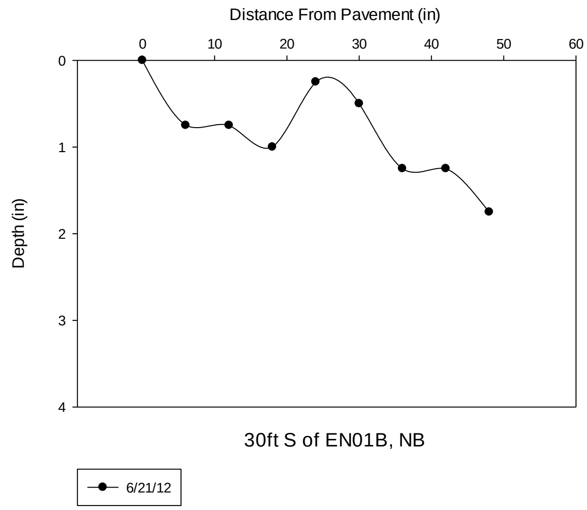












CBR Values

Table 42. Clegg hammer data for section 3.08-3.10

Date	Location	CIV	CBR	Average CBR	
	3.08-3.10			SB	NB
Aug. 2011	UNC01B SB	26	52.4	39.9	
	312 ft south of UNC01B SB	21.6	38.2		
	35 ft north of UNC01A SB	18.3	29.1		
	312 ft south of UNC01B NB	21.9	39.1		38.2
	35 ft north of UNC01A NB	21.3	37.4		
June 2012	50 ft south of ES01B SB	20.1	33.9	31.5	
	0.15 mi north of ES01A SB	21.7	38.5		
	ES01A SB	15.4	22.1		
	340 ft north of EC02A NB	21.4	37.7		39.5
	400 ft south of EN02B NB	17.7	27.5		
	EN02B NB	18.9	30.6		
	EN01A NB	30.7	70.0		
	430 ft north of EN01A NB	18.9	30.6		
	30 ft south of EN01B NB	22.3	40.3		

APPENDIX B. DRAFT SPECIFICATION FOR SOYBEAN SOAPSTOCK APPLICATION ON GRANULAR SHOULDERS

SP-12120XXX
(New)

Iowa Department of Transportation

SPECIAL PROVISIONS
FOR
APPLICATION OF ACIDULATED SOAPSTOCK TO STABILIZE GRANULAR SHOULDERS

[Name] County
[Project Number]

Effective Date
[Date]

THE STANDARD SPECIFICATIONS, SERIES 2012, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE SPECIAL PROVISIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

120XXX.01 DESCRIPTION.

Specification for the application of acidulated soapstock (herein after referred to as “soapstock”) to granular shoulders including material properties, shoulder preparation and construction.

120XXX.02 MATERIALS.

A. Granular Shoulder Aggregate.
Furnish material that meets the requirements of Article 2121.02 of the Standard Specifications.

B. Soapstock.

1. Use soapstock that meets the following requirements:
- Oil content between 30 and 36%
- Lecithin content between 36 and 47%.

- The moisture content of the vegetable oil phospholipids between 1 and 4%.
- Can be applied using a bitumen distributor (Article 2001.12 of the Standard Specifications) at the required rate according to manufacturer's instructions.

2. Provide manufacturer certification that oil, lecithin and moisture content meet above requirements according to AOCS Ja4-46 (AOCS was formerly the American Oil Chemists Society).

3. Provide material safety data sheet that meets Occupational Health and Safety Administration hazard communication requirements.

C. Sand.

1. Use Gradation No. 36 of the Aggregate Gradation Table, Article 4109.02 of the Standard Specifications.

120XXX.03 CONSTRUCTION.

A. Equipment.

1. Use equipment that meets the requirements of Article 2121.03, A, of the Standard Specifications, for application of additional aggregate and surface preparation.

2. Use equipment that meets the requirements of Article 2001.09 of the Standard Specifications, for application of water.

3. Use equipment that meets the requirements of Article 2001.12 of the Standard Specifications, for application of soapstock.

B. Weather Limitations.

1. Apply soapstock only when the temperature on a shaded portion of the existing surface is 50 degrees F and rising and when the weather is not foggy or rainy.

2. Do not apply soapstock before May 1 or after October 1, without the Engineer's written permission.

C. Materials Handling.

1. Provide a 1 gallon sample from each shipment, if requested by the Engineer. Label the sample with the following information:
   - Name of product
   - Production date
   - Name and contact information for supplier
   - Name of contractor or subcontractor that purchased the product
   - Arrival date at job site

- Location that product is intended to be placed

2. Store in sealed stainless steel containers that protect from the entry of moisture.

3. Protect from freezing or overheating.

4. Do not store over a winter.

5. Ensure uniform viscosity by recirculating material if viscosity becomes non-uniform during transport or storage.

D. Preparation of Surface.

1. Furnish additional granular shoulder aggregate at locations, quantities, and rates specified in the contract documents.

2. Deposit additional aggregate, without dumping on the pavement, material directly on the shoulder for the width designated.

3. Shape the aggregate to produce a smooth surface flush with the pavement edge and tapered to meet the shoulders at the width shown in the contract documents.

4. Moisten loose aggregate to moisture content within 2% of the optimum moisture content as determined by Materials Laboratory Test Method No. Iowa 103.

5. Thoroughly compact the moist aggregate with a minimum of six complete coverages of the entire exposed surface using a pneumatic tired roller or a steel vibratory roller.

6. Follow this with at least one complete finish coverage using a steel tired roller.

7. Remove all excess aggregate from the pavement.

E. Application of soapstock.

1. Ensure that the granular shoulders remain compacted during the surface preparation activities accomplished as described in the previous article. Repair damage by moistening and compacting as specified in the previous article.

2. Moisten the granular shoulder so that the particles are damp, but so that the shoulder material is not saturated. Allow the moisture to penetrate to produce the damp condition at least one inch below the surface.

3. Apply the soapstock at the locations and widths specified by the contract documents. Protect the pavement from overspray.

4. Apply soapstock with target application rate of 0.25 gallons per square yard.

5. Spread sand with sufficient thickness to completely blot the soapstock and prevent pickup or splashing by vehicles.

6. Compact the sand covering with four complete coverages of the entire applied surface using a pneumatic tired roller.

7. Remove soapstock and sand from the pavement. Broom and wash as necessary to accomplish removal.

F. Opening to Traffic.

1. Protect soapstock from traffic until it has penetrated and set sufficiently so it will not deform or be picked up by vehicle tires. Coordinate with traffic control provisions elsewhere in contract documents to protect soapstock. Repair damage to soapstock due to premature opening to traffic at no additional cost to Contracting Authority.
2. Arrange soapstock application methods so that shoulder traffic can be sustained within 4 hours after placement.
3. Keep road and shoulders free of construction equipment during non-working hours.

120XXX.04 METHOD OF MEASUREMENT.

A. Granular Shoulder Aggregate.
Measurement for Granular Shoulders satisfactorily placed will be computed from the weights of individual truck loads, including moisture in the aggregate at time of delivery. Moisture added after delivery will not be measured for payment.

B. Preparation of shoulders.
In stations on one side of the pavement, will be the quantity shown on the contract documents.

C. Soapstock.
In gallons computed from field measurements of distributors. When quantities computed from field measurements check within 1.0% of the billed gallons, payment will be based on billed gallons . When quantities computed from field measurements differ from billed gallons by more than 1.0%, payment will be based on the quantity from field measurements.

120XXX.05 BASIS OF PAYMENT.

A. Granular Shoulder Aggregate.
Per ton for the tons placed on the shoulder. Payment is full compensation for the following: Furnishing and placing the materials at the location required in the contract documents, including aggregate and water.

B. Preparation of Surface.
Per station for the length shown on the contract documents prepared for soapstock application in accordance with the contract documents. Payment is in full compensation

for shaping, adding moisture, providing compaction, finishing and cleanup of excess aggregate.

C. Soapstock.
Price per gallon for the quantity of soapstock applied on accepted portions of the shoulder. Payment for soapstock is full compensation for furnishing, delivering, and applying both soapstock and sand, and for all rolling, final cleanup, and incidental work necessary to complete the project and not paid for as other items.

APPENDIX C. COMMENTARY ON SPECIFICATION FOR SOYBEAN SOAPSTOCK APPLICATION ON GRANULAR SHOULDERS

Section 1. DESCRIPTION

Appendix B of this report provides a draft specification for surface preparation, soybean soapstock material characteristics, and the process of application of soybean soapstock on granular shoulders to mitigate edge rut development and erosion due to high traffic volume, water, and wind agents.

This draft of specification has been furnished for use by the Iowa DOT for road construction to prevent edge rutting on granular shoulders. The procedures, testing, and practices reflected in this specification could be performed by the Iowa DOT.

This appendix was developed to provide a commentary for the draft specification in Appendix B.

The draft specification is not a final regulation for construction or use of soybean soapstock in granular shoulders. The development of the draft specification was based on the following documents: a 2007 study, Effective Shoulder Design and Maintenance; a 2011 study, Stabilization Procedures to Mitigate Edge Rutting for Granular Shoulders; the summer 2011construction season; 2012 post-construction observations; and the experience of other experts.

The draft specification in Appendix B does not supersede other documents or specifications from the Iowa DOT. This commentary on the draft specification in Appendix B is intended to complement the draft specification by providing additional explanatory and background material.

Section 2. MATERIALS

A. Granular shoulders aggregate

The material used for granular shoulders is called Class A, which should comply with Article 4120.04 from the Iowa DOT Standard Specifications (Section 4120). This article shows the requirements for aggregate gradation and for the coarse aggregate quality of Class A material (Table 4120.04-1) shown below:

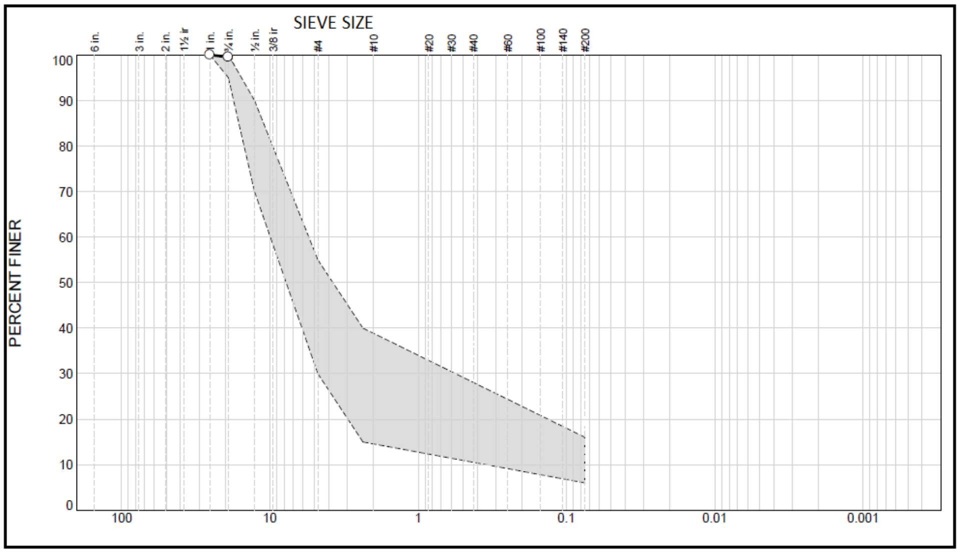


Figure 30. Gradation No. 11 for Class A aggregate

Table 43. Specification percentages for Class A granular aggregate gradation (GS Iowa DOT 2012)

SIEVE SIZE	SPEC. PERCENT
1 in	100.0 - 100.0
3/4 in	95.0 - 100.0
1/2 in	70.0 - 90.0
3/8 in	
#4	30.0 - 55.0
#10	
#20	
#40	
#60	
#100	
#200	6.0 - 16.0

Iowa DOT Class A/B Aggregate

Table 44. Coarse aggregate quality - Class A crushed stone. (GS Iowa DOT 2012)

Table 4120.04-1: Coarse Aggregate Quality (Class A Crushed Stone)

Coarse Aggregate Quality	Maximum Percent Allowed	Test Method
Abrasion	45	AASHTO T 96
C Freeze	15	Office of Materials Test Method No. Iowa 211, Method C
Clay Lumps and Friable Particles	4	Materials I.M. 368
Note: For shoulders only, abrasion limits may be raised to 55 if Alumina does not exceed 0.7 or A Freeze does not exceed 10.		

For construction of the shoulder, refer to Article 2121.02 of the Iowa DOT General Specifications (Iowa DOT Section 2121). This article describes the material and the construction process for granular shoulders. This article establishes that recycling material should not exceed 30% for new construction or 50% for existing granular shoulders. Equipment, mixing, surface preparation, and limitations can be found in that article.

B. Sand

The sand used to prevent the oil from splashing and tracking onto vehicles is regular sand. It should follow the specifications provided in Article 4125 of the Iowa DOT general specifications.

C. Soybean soapstock

The soybean soapstock is a biodegradable material that is obtained from the vegetable oil refining process (EDC 2011a). This product is obtained by the degumming of crude soybean oil, which is a procedure where the crude oil is mixed with small quantities of water and is then separated by centrifugal methods. This separation process provides information to identify the proportion of oil content, lecithin, fatty acids, and free fatty acids.

The oil content of the mixture should be in the range of 30 to 36%, which is the general range commonly obtained from any soybean oil. This indicator only shows that the product has been made from soybean oil and not another substance (Guerra's personal interview with Susana Goggi, May 7, 2012).

Another important agent is the content of lecithin, which should be in the mix in a range of 36 to 47% (EDC 2011b). Lecithin is a good emulsifier that helps with some of the physical characteristics of the soybean soapstock. Lecithin helps with the formation of surface coating, intensifies the color, and increases the dispersion of the mix (Ambuja 2006). During the summer of 2011, the supplier provided DUSTLOCK, which is a soybean soapstock brand that complies with the characteristics described above.

Table 45. List of ingredients of soybean soapstock used during 2011 tests (Boer -Howard 2012)

Chemical Properties		
		Test Method
Oil Content (%):	30-36%	
Free Fatty Acid (%):	12-17%	AOCS Ca 5a-40
Lecithin (%):	36-47%	AOCS Ja 4-46
Total Fatty Acids (%):	65-70%	AOCS Ca 5b-71

Physical Properties		
		Test Method
Gardnar Color (As Is):	-18	AOCS Ja 8-87
Moisture (KF):	1 - 4%	AOCS Ja 2b-87
Appearance:	Viscous, amber-colored fluid	

Evaporation is not a problem when using this product because soybean soapstock will not evaporate in normal weather conditions. It cannot be diluted with rainwater, so there is no risk of reducing the evaporation point. Moisture content should be around 1 to 4% for current purposes (Boer and Howard 2012); however, in a 1996 study, Mn/DOT determined that moisture content up to a maximum of 5% can be acceptable (Han and Marti 1996).

D. Storage, transportation, and disposal

The material safety data sheets state that the product should be stored in a firmly-sealed container. During storage and transportation of the material, avoid overheating and contact with other materials or products kept at high temperatures. The flash point is 380°F. The material is biodegradable but all local, state, and federal regulations should be followed when disposing of the material. The product should be stored in stainless steel or black iron tanks. If the product will be stored over winter, the containers should be sealed with heat tape. However, the manufacturer does not recommend storage times more than one year.

According to the U.S. Department of Transportation, soybean soapstock is a biodegradable nonhazardous material (DUSTLOCK 2008). The supplier recommends that ventilation be provided while storing and transporting it to avoid strong concentrations of the odor, which can cause discomfort to workers.

When handling the material, eye protection, gloves, and appropriate clothing are recommended. There are no hazards for ingesting this product, but some people may be allergic to it and it is not recommended for human consumption.

Soybean soapstock gives off an aldehyde odor, similar to french fries, around the zone where it is applied for a few months after the application. From the experience of people in Iowa and Minnesota, there is not a clear consensus on the relative strength of the smell. However, the research team recommends avoiding treating granular shoulders on residential roads until further studies help to better understand the nature of the odor, how objectionable it is, and ways to mitigate it.

E. Laboratory test for contents

The soybean soapstock material should contain 30 to 36% oil content and 36 to 47% of lecithin content according to the technical data on the material used during the construction summers of 2010 and 2011. According to Guerra (personal interview with Goggi May 7, 2012), these levels of lecithin and oil content are normal for any product based on refined soybean oil, for which a test lab should not be necessary. However, a test to determine the percentage of those components can be done by a bio-analysis laboratory. The tests to perform are from the American Oil Chemists' Society (AOCS) Ja 4-46 (1993).

F. Samples

It depends on the laboratory to suggest the sampling frequency and procedures. This sampling may not be necessary depending on the contract requirements.

G. Labeling

It is important to label the product with the name of the product, date of production, arrival date, name and contact information of the supplier, location where it will be placed, and entity that purchased the product. An example of the label is provided in Figure 31.

Name of the product

location to be placed

arrived date

Owner name and phone number

Supplier name and phone number

Supplier address

Produced date

Figure 31. Label prototype (Guerra 2012)

Section 3. CONSTRUCTION

A. Definitions

This document uses some technical expressions and abbreviations of terms that are used with some frequency throughout the different sections of this document. Definitions are provided below.

CICM: 2012 Construction Inspector's Course Manual by the Iowa DOT

Contracting Agency: The state, or any other local agency that is contracting

DUSTLOCK: A commercial brand of soybean oil soapstock that was used for the construction tests in 2010 and 2011

GS-Iowa DOT: General Specification with GS09005 Revisions of the Iowa DOT

MSDS: Material Safety Data Sheet

Soybean soapstock: A special by-product of the soybean oil refining process used for dust control and as a soil stabilizer used in this study to prevent edge rut development in granular shoulders.

VOP: Vegetable oil phospholipids obtained from crude soybean oil

B. Equipment

Certain equipment is necessary for building the shoulder, preparing the shoulder, repairing the sections where edge ruts have developed, and applying the soapstock. The equipment to be used for shoulder construction is described in Article 2001.05 B, C, D, and F and should be used according to Article 2121.03A of the GS-Iowa DOT. The preparation of the shoulder is complete when there is a compacted and graded surface where all potholes have been repaired and compacted according to Article 2121.03B.

Figure 32. Motor grader used during field tests

Particular pieces of equipment are needed for each of the three stages in applying soybean soapstock: moisturizing the soil, application, and sand placement. Brine application equipment owned by the Iowa DOT was utilized to moisturize the soil during the study; however, any water spray equipment can be used.

To apply the soybean soapstock on the moisturized shoulder, any type of distributor can be used, but the spray rig should have individually-operated nozzles. In addition, a spray protector should be placed on the edge of the truck to prevent any undesired spray over the paved road.

To place the sand over the treated shoulder, a dump truck with a chip spreader adjusted to the dump gate opening can be used. A wood plate is used to narrow the opening for sand spreading. This provides adequate sand distribution with one pass.

Figure 33. Paved road protection from soapstock splashing

C. Procedure for soybean soapstock application on granular shoulders

Successful application of soybean soapstock on granular shoulders depends on various factors that should be considered when performing this work. Some of the factors include external influences, such as the weather or quality of material, while other factors are more direct influences, such as quality of construction or equipment used. In all cases, there are specific procedures to follow and tests to perform to increase the quality of the delivered job.

Shoulder surface preparation

The first step is to prepare the surface of the granular shoulder; this includes the correction of shoulders that have already developed edge ruts. Some shoulders have suffered the impact of high traffic volume, heavy trucks, and erosion agents such as wind and water. In some cases, these factors can result in potholes at the edge of the pavement. The first step in the general process is to treat those potholes and ruts. The next step is to re-fill the edge ruts with standardized shoulder aggregate, compact them until adequate compaction is achieved as defined in the section 2121 of the Iowa DOT General Specifications, and shape them along with the rest of the shoulder into a smooth surface.

The physical characteristics of the shoulder surface, including cross-fall, gradation, and width, should comply with Article 03 of Section 2121 of the GS-Iowa DOT. The preparation of the shoulder can be the responsibility of the contractor, although the Iowa DOT can be in charge of preparing and utilizing their own resources or outsourcing this task. The contract should clearly state the name of the party in charge of this task.

Climatological conditions

Weather conditions can influence the procedures for the application of soybean soapstock on granular shoulders. It is important to have moist shoulder material that does not exceed the limits of saturation. Saturation could occur in the event of heavy precipitation during the days before the application. In this case, the application day should be postponed until observations indicate that the soil is not saturated.

Once this condition is met, the scheduled day of the application should have forecasted weather conditions with a low probability of rain because soybean soapstock should not be applied if any precipitation is occurring. Rainy weather should not follow the application of the soybean soapstock, either, because the water may wash away the product before it is able to penetrate the soil to create the internal binding forces. The forecast should predict about half a day of low probabilities of precipitation after the application, because it takes from four to six hours for penetration (Han and Marti 1996). Depending on the shoulder material conditions and quality of the material, penetration can actually take a day or even a week.

Wherever standing water is located, the soil is likely to be saturated, which is not desirable because the soapstock will not penetrate the saturated soil, leaving it untreated. Therefore, saturated areas will remain as vulnerable areas for pothole or edge-rutting development in the future.

Figure 34. Weather conditions during field tests

The product should not be applied over frozen soils. The process of thawing creates vulnerable zones due to air bubbles that are left where frozen water has been. For this reason, the product should not be applied under such conditions.

The application of soybean soapstock should occur when weather forecasts predict temperatures above 50° Fahrenheit. If the weather forest indicates colder temperatures, the product should be heated so it can penetrate the soil better. On the other hand, if the temperatures are high, the soil may lose some moisture content, so it is important to ensure that the soil is not too dry. If this is the case, the amount of water used when moisturizing the soil should be increased for that day.

The product does not present any flammable hazards until outside temperatures reach 380°F or temperature inside the sealed container reaches 190°F.

Unless winds are high enough to blow away the water and oil product spraying or large amounts of sand over the treated shoulder, wind has little influence on the process of application of the soybean soapstock. The distance between the spray bars and the ground is short enough that the application is not influenced by winds at moderate speeds. The density of the moist sand is also sufficient to resist such winds.

Soybean soapstock shoulder treatment

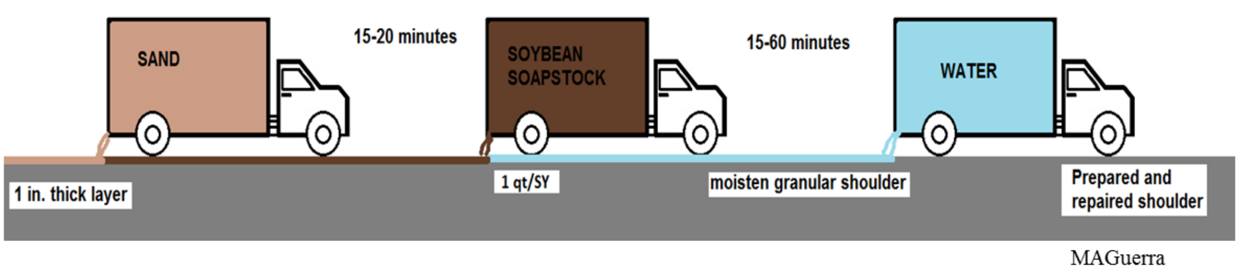


Figure 35. Workflow diagram

The first step is to moisten the shoulder material. The truck with the water sprayer goes first. The speed of the truck depends on the pressure and the configuration of the nozzles.

Based on previous experience, the spray rig should move at a fast walking speed, about 4 or 5 mph, covering the portion of the shoulder to be treated. Water can be applied to the width of the shoulder in 4 or 8 ft sections or up to the full width of the shoulder.

Figure 36. Water truck moistening the shoulder

Before continuing to the next step, it is necessary to allow the water to penetrate the soil, which can take between 15 minutes and an hour. The allowable time to let the water penetrate the soil depends on how fast the soil absorbs the water. If the soil is very dry, the water will penetrate very quickly. It can be problematic if the length of time between the applications of the water and the soapstock is very long, because the soil may become dry again.

On the other hand, if the soil is relatively moist, the time to allow the supplied water to soak in may be longer. For any of these circumstances, a visual observation by the person in charge should be enough to determine the time between the water and soapstock application. It is recommended that future studies determine optimum moisture content of the soil for the application.

After the soil is at the correct moisture content, the soybean soapstock should be applied over the shoulder. Gently heating the soapstock may improve the application process. One application manual recommends an application temperature of 110 to 120 °F for soapstock (EDC n.d.).

Figure 37. Application of soybean soapstock over the granular shoulder

To avoid spraying the product over the paved road, a spray protector should be placed on the edge of the truck. If a car gets sprayed with the product, strong liquid soap and a power wash will clean it.

It is important to coordinate the water spray speed and the time between the trucks to avoid dry materials (too much time) or small standing water areas (too little time). Between 15 and 20 minutes is a reasonable time for soybean soapstock to penetrate the shoulder material deep enough to start creating the internal binding forces, but not too deep that it fails to develop the superficial protection coat.

Figure 38. Shoulder after soybean soapstock application

After the soapstock application, a modified dump truck should spread sand over the treated shoulder.

Figure 39. Truck spreading sand over the treated granular shoulder

The sand that is spread over the treated shoulder should create a layer that fully blots the soapstock and prevents the soapstock from being picked up and/or splashed by vehicles. In particular, it is undesirable to for the material to be splashed onto the pavement (that can make the pavement slippery) or other vehicles.The sand also helps to maximize the depth of penetration to strengthen the internal binding forces because it protects the granular material and the soapstock from external agents such as wind and car traffic.

Based on previous experience, the truck speed while distributing sand should be 4 to 5 mph. Previous experience indicates that there is usually not a need for multiple passes by the trucks applying water, soybean soapstock, or sand.

D. Productivity

The application process requires checking that the surface of the shoulder is ready; loading the trucks with water, soybean soapstock, and sand; allowing adequate time between passes; returning trucks to be loaded again when they are empty; returning trucks to the spraying location; repairing any areas that present problems; and other miscellaneous activities that are challenging to anticipate.

The average expected productivity is 6 miles of shoulder treated per day with a 4 ft width application. If the width is wider, productivity for the actual spraying should not drop productivity noticeably. However, increased time will be required to load material into trucks.

When trucks need to re-load with the product, a mark of the exact point to resume should be made very clearly, because overlap for soybean soapstock should be avoided to maintain the uniformity and quality of the job.

E. Traffic signs

Work-zone signs should be used while soapstock is being applied. If a contractor is making the application, work-zone signage should follow the requirements provided by the contract documents, including the Standard Road Plans referenced for the project and the sections on Traffic Control (TC) and Signs (SI) in the plan set.

Figure 40. Use of traffic signs during construction

After application, it is recommended to keep the shoulder free from vehicle traffic for about 5 hours to allow a uniform penetration on the ground. The Iowa DOT uses various schemes for traffic control; one that can be used for this construction is shown in Figure 40 and Figure 41.

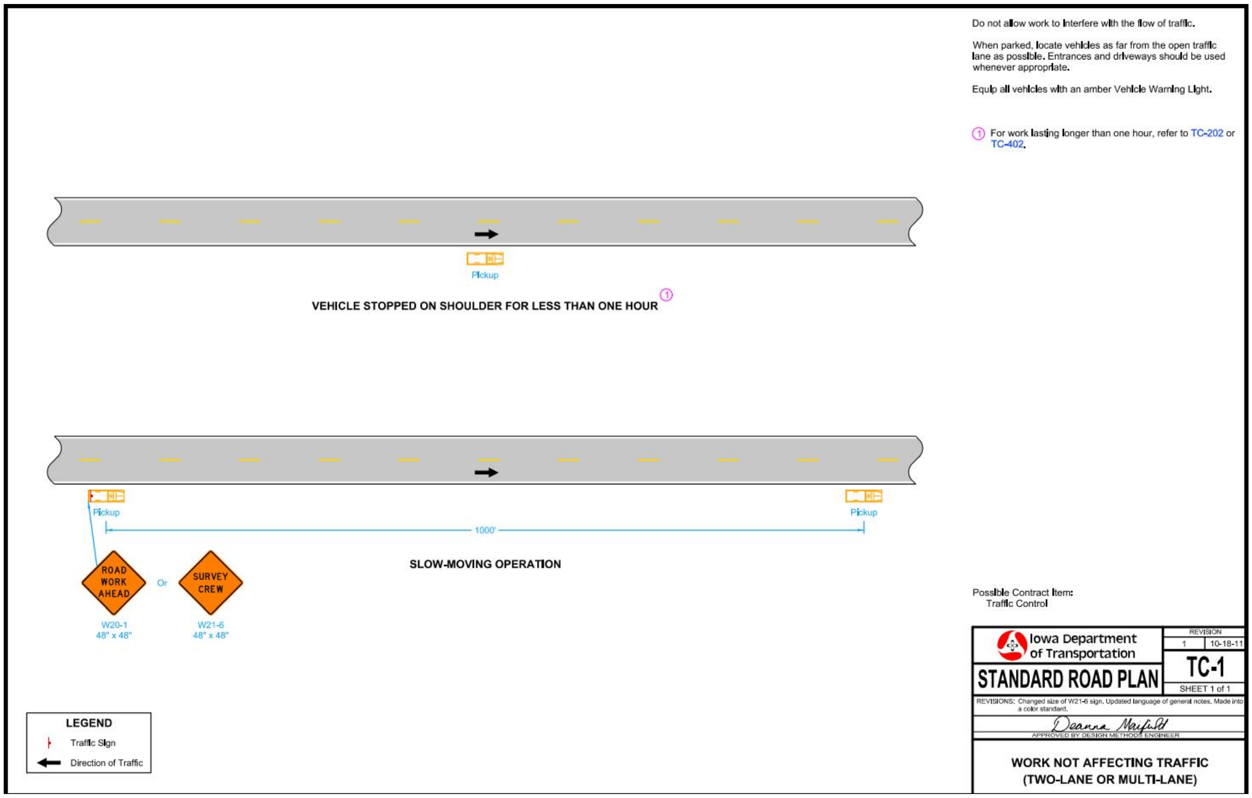


Figure 41. Example of a standard road plan - Traffic control moving operation on shoulder

F. Sampling and quality testing

The contracting agency should inspect and perform tests at any time and any location to ensure that the materials provided and being used follow the minimum recommendations. The contracting agency should reserve the right to reject any materials that do not comply with these minimum requirements.

A sample of the product should be taken to perform a quality test of the content of the soybean soapstock, as specified in paragraphs E and F under Section 2-Material.

If requested, the supplier will provide proof that the soybean soapstock meets the minimum requirements of this specification. In addition, test results from acceptable laboratories should be delivered as requested. The contracting agency should reserve the right to request additional tests.

G. Excess of Material

Refer to the contract about how to manage any excess of material. If the soybean soapstock is provided by the contracting agency, it is highly recommended that it be used somewhere else rather than storing it over a winter. The manufacturers do not recommend storage for more than one construction season. If the contracting agency must store it, it should be heated to maintain the recommended temperature. However, if the contractor is providing the soybean soapstock, the contractor will likely keep the excess.

Section 4. METHOD OF MEASUREMENT

In most cases, the measurement will be made by the gallons utilized in the shoulder treatment work. Refer to contract documents for any changes.

Section 5. BASIS OF PAYMENT

The accepted quantities, measured as provided above, should be paid for by the contracting agency at the contract unit price. Payment should be full compensation for the work required under the specification. The cost should include all tests, except for those performed by the owner. The contract documents could include penalties for delays or performance below the quality required.