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# Using Soybean Oil Soapstock for Stabilizing Granular Shoulders

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# Using soybean oil soapstock for stabilizing granular shoulders

by

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## ABSTRACT

Granular shoulders need to be maintained on a regular basis because edge ruts and pot holes could possibly develop which could pose a safety hazard to vehicles. To stabilize shoulders and reduce the number of necessary maintenance cycles per season, one possible stabilizing agent - acidulated soybean oil soapstock (referred to as "soapstock") is investigated in this research. 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 pot holes for granular shoulders. In order to achieve this goal, a pilot testing project was conducted for selected problematic shoulders around northern and northeastern Iowa. Soapstock was applied on granular shoulders with monitoring during application and pre-and post-observations. In this thesis, application techniques were documented and percentage of application success was calculated for each treated shoulder section.

As a result of this research, it is concluded that Soybean oil soapstock can be an effective stabilizer for granular shoulders under certain conditions. The documented application techniques could be used as the basis for future guidance for applying soapstock or similar products on granular shoulders. In addition, recommendations are made for future research projects that could be conducted to study the effects and sensitivities of possible influence factors listed in this thesis.

# CHAPTER 1. INTRODUCTION

## Background

Edge rutting on granular shoulders is a traffic safety concern because it poses a safety hazard for vehicles. The possible bad results include crossing to an adjacent lane, encroaching on the far side of roadway, or skidding on shoulders or roadways, which would cause potential collision or rollover (Hallmark et al. 2006). Figure 1 shows an example of edge rutting that has developed along the interface between a pavement and a granular shoulder. Edge rutting is caused by three factors, wind and air currents, vehicle off-tracking, and drainage. Over time, wind and air currents from large vehicles blow fine material away from the shoulder and large particles are exposed on the shoulder surface that are more easily removed by vehicle off-tracking. Off-tracking refers to the situation where rear tires run a different path from front tires during vehicle's turning movement. Water from pavement drainage accumulates along the pavement edge, softens the granular material and makes shoulder materials unstable.

Researchers from Iowa State University sponsored by Iowa Department of Transportation (Iowa DOT) have investigated potential strategies to stabilize shoulders and mitigate edge rutting during 2008 and 2009. One potential stabilizer is acidulated soybean oil soapstock (soapstock), a by-product of the soybean oil refining process (Han and Marti 1996). Previous investigations have indicated that, in some cases, soapstock could be effectively applied on granular shoulders, which usually reduces the number of maintenance cycles of heavy traffic roads and extends the life of moderate traffic roads (Jahren et al. 2011).

Following previous investigations, additional research tasks related to the application of soapstock on granular shoulders have been accomplished as part of this research effort.

**Figure 1. Edge rutting on granular shoulders (by Thang Phan)**

## Goal and Objectives

The overall goal of this project is to investigate the use of acidulated soybean oil soapstock (hereinafter referred to as "soapstock") as a stabilizer for granular shoulders to assess whether it could be effective in mitigating edge rutting problems. In order to achieve the above goal, following objectives would be addressed for this project.

1. Select appropriate locations and conditions for applying soapstock based on previous experience with soapstock and suggestions from Iowa DOT personnel.
2. Consider using soapstock on some shoulder sections with severe off-tracking but might not be suitable for soapstock application based on previous experience.
3. Conduct preconstruction tests and measurements.
4. Observe application techniques of soapstock for stabilizing granular shoulders during the construction phase.
5. Make periodic post-construction observations and assess the effectiveness of applying soapstock on granular shoulders.

6. Analyze data to develop conclusions and recommendations for applying soapstock on granular shoulders.

**Implementation Benefits**

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 stabilizer agent-soapstock on problematic shoulders (Figure 2). The successful mitigation of edge rut issues for granular shoulders will increase safety, and improve the procedures currently used to maintain granular shoulders in Iowa.

In addition, better performance of granular shoulders reduces the urgency of paving granular shoulders. Delaying or permanently avoiding paving shoulders where possible would allow more flexibility in making investments in the road network.

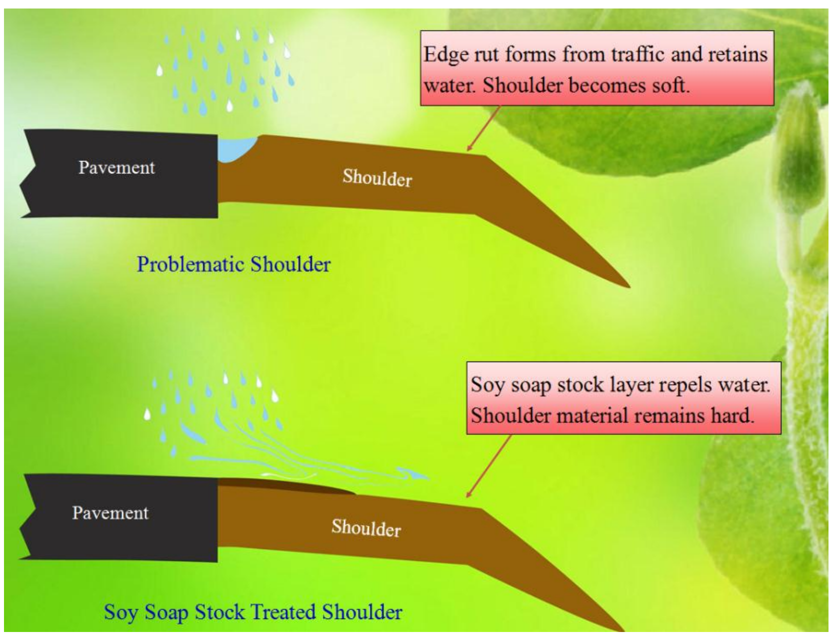


**Figure 2. Stabilizing granular shoulders with soybean oil soapstock**

**Work Locations 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). Basically, the traffic amount was within 6000 vehicles per day (recommended by Jahren et al. 2011) for those locations except for Denver where the traffic amount varied from 6500-8000 vehicles per day.

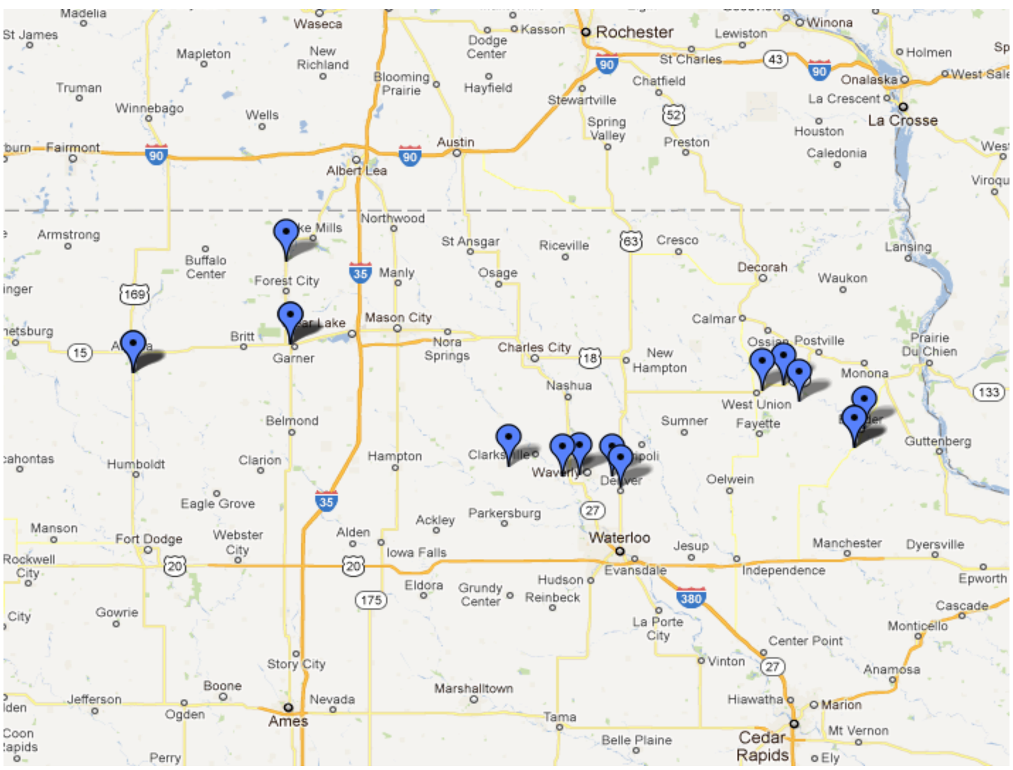


**Figure 3. General Testing Areas in Iowa**

# CHAPTER 2. LITERATURE REVIEW

## Shoulder Edge Rutting and Edge Drop-off

The pavement/shoulder edge drop-off is an important 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 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 2 inches or more, the vehicle could easily lose control (Glennon 2005).

In a study done by Berthelot and Carpentier, 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. Additionally, heavy trucks always leave clear wheel paths on the surface of the roadway or shoulders, and gravel on surface could easily be removed or broken down by several truck passes. When wheel paths are developed, the water infiltration rate on tracked portion would be decreased and the surface runoff would be increased, which results in greater water erosion. If edge rut has already existed in shoulders, the pooled water would soften the surface and increase the tendency to rut (Berthelot and Carpentier 2003). In another study done by Wagner and Kim (2004), 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 attendant safety issues (NY DOT 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 required frequency of maintenance (Jones et al. 2001). Fine materials are easily blown away 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 the 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 (Bergeson and Brocka 1996).

**Shoulder Stabilization**

Soil stabilization could 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 long life cycle (Mekkawy et al. 2010). In terms of using stabilizer, 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 greatly reduced, 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 is given as follows.

*Light Surfacing (Otta Seal)*

According to Greg Johnson (2003), "An otta seal is an asphalt surface treatment constructed by placing a graded cover aggregate on top of a thick application of 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 to 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 was investigated in Norway and has been used in the Noridic countries and developing countries since then. The service life of otta seal is expected to range between 8 to 15 years (NPRA 1999).

*Dust Control (Polymers)*

Polymer emulsions have been widely used for dust control. Soil-Sement® and Soiltac® are examples of these products with a milky white appearance. According to 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 which could support high volume traffic and survive from extreme weather. The Soiltac® manufacture claims that the Soiltac®, as a polymer-based emulsion, could provide a protective barrier with a stable and rigid base when applying 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, both of which does not include the shipping and application costs (White et al. 2007). Maintenance needs to be done in 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 surface and prevent dust and small particles from blowing away. It also protects granular material from frost heave effect in winter. It works well on granular surface 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 surface. Magnesium chloride works similarly as the calcium chloride in terms of stabilizing granular surface, but it does not work well when the temperature is higher than 71 $^{o}$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 noticeably mitigate edge ruts.

**Soybean Oil Soapstock**

Soybean oil soapstock is a biodegradable and shares many of the characteristics of light petroleum-based oil (Skorseth 2000). Soapstock manufacturer claims that it can be effectively used under various conditions (e.g., unpaved roads, driveways, airports, mining sites, parking lots, construction sites) (EDC 2011). The most common use of soapstock is for the purpose of 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 2011). Other benefits of using soapstock include that it is environmentally friendly, non-flammable and relatively safe to use, and 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 is often annoying, producers were reportedly trying to mitigate it without reducing its effectiveness of the soapstock (Lohnes and Coree 2002).

This soapstock is produced from the degumming process of crude soybean oil. The crude soybean oil is mixed with proper amount of water and then separated by using centrifugal method. By performing this separation, the proportion of oil contents, free fatty acids, lecithin, and fatty acids, and could be recognized. According to Guerra’s interview with Susana Goggi (2012), for this soapstock, the proportion of oil content varies from 30-36%, which is a common range for any products made from soybean oil. Lecithin is also an important agent because it provides a part of physical properties of soapstock and helps develop the surface coating (Ambija 2006). According to Boer and Howard (2012), the soapstock does not evaporate in a normal weather and will not be diluted in a rain.

The first reported use of soapstock as a shoulder stabilizer that was found under this research effort was sponsored by Minnesota Department of Transportation. According to Han and Marti (1996), soapstock worked well on the surface with an average daily traffic volume less than 100 and preferred to be applied in a normal and dry weather. The fine particles on the surface were preferred to be controlled within a range of 5 to 20 percent (Han and Marti 1996).

Because the penetration rate decreases with a decreasing temperature, warmer temperatures are preferable when soapstock is being applied. Usually, it takes 4 to 6 hours for the soapstock penetrate a road surface, but it could also take as long as a day to a week depending on various aggregate gradations and weather conditions. Important properties of soapstock are that it repels water and does not easily evaporate. It has medium to high viscosity which prevents it from being washed out (Han and Marti 1996).

The equipment for spraying soapstock can be a typical distributor of the type that is used for asphalt products. According to the tips for storage of soapstock provided by Minnesota DOT, stainless steel or iron tanks should be used to store the product, the length of storage should not exceed one year, and heat tape should be used to warm the material during winter storage (Han and Marti 1996).

Before applying soapstock, the road surface should be lightly graded first. For the initial application, the recommended spraying rate is 1.13 liters/m$^2$ (0.25 gal/yd$^2$), and the 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. 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 (Han and Marti 1996).

Due to the limited production of soapstock, its market price has been increasing over years, from $1.07 per gallon in 1991 to $1.12-$1.50 per gallon in 1995. In August 2011, Iowa DOT purchased soapstock for $3 per gallon (Han and Marti 1996). The Iowa Department of Transportation (DOT) District 2 conducted the first soapstock trial on granular shoulders of 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 Iowa DOT to purchase (Jahren et.al. 2011).

In 2007, researchers from Iowa State University 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 Rudd, IA, which section was located at a super-elevated curve. The edge drop-off was 4 in before the treatment and became 2 in after 2 months of treatment. However, there were also associated problems with the procedures and equipment for the treatment. Unfortunately, it clogged the spray nozzles during the operation. The maintenance crew spent considerable effort unplugging nozzles. Later, the Iowa State 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 specifically focused 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 regarding 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. METHODOLOGY

## Location Selection

Before the test sections could be constructed, locations needed to be selected for soapstock application. Originally, Iowa DOT was planning to pave shoulders identified with edge rutting problems around Iowa, but garage supervisors reported a lot more shoulders than the budget could handle. So, many problematic shoulders cannot be paved due to lack of the budget. Form those shoulders being left, researchers selected locations with a moderate traffic volume (within 6000 vehicles per day) as suggested by Jahren et al (2011) for this research use. 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. For most locations, the load amount varied from 1000 to 6000 vehicles per day, according to recommendations by Jahren et al. 2011. The exception is the location near Denver, IA which is a four-lane divided highway with both inside and outside shoulders, with an average daily traffic of 6500 per lane in the north and 8000 per lane in the south. Each location is described in table 1.

Basically, for places where the edge rut is the only concern, soapstock could be sprayed at 4-foot width. For places where the gullies are identified near the grass line, soapstock would be applied at the full width of the shoulder.

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

| Garage | Work Location |
|---|---|
| I. Algona & 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 southbound – south of Leland |
| | US 169: |
| | 1.04. MP 195.5 to 196 southbound – south of Algona |
| | 1.05. MP 194.8 to 195.5 southbound – south of Algona |
| II. Waverly & 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 & inside shoulders, both sides – Denver |
| | IA 3: |
| | 2.03. MP 220 to 220 westbound – Waverly |
| | 2.04. MP 215 to 216 both sides – Shell Rock |
| | 2.05. MP 205.1 to 205.7 both sides – east of Allison |
| III. West Union & 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 northbound – Elkader |
| | 3.04. MP 75 to 75.2 southbound – Elkader |
| | 3.05. MP 72.4 to 74 northbound – south of Elkader |
| | 3.06. MP 70 to 70.1 northbound – south of Elkader |
| | 3.07. MP 69.3 to 69.6 northbound – south of Elkader |
| | W 51 (measured from intersection of W51 & 215th St.): |
| | 3.08. 3600ft south to 4460ft south, northbound– south of Elgin |
| | 3.09. 70ft south to 1050ft south, northbound– south of Elgin |
| | 3.10. 1760ft to 4000ft south, southbound – south of Elgin |

*Mapping of Work Locations*

For selected work locations, general information such as the route and milepost 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 Iowa linear referencing system (LRS), which could be accessed from the Iowa DOT official website. As a geospatial system, the Iowa LRS database includes GPS locations for all US, interstate, and Iowa State routes with designated mileposts. Then, the latitude and longitude for work locations were manually input into the handheld GPS unit by researchers as waypoints, and also used to generate electronic maps on Google Map.

**Pre-Construction Field Tests and Measurements**

On the first set of field trips, researchers brought the printed Google maps as a 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 end points, at which the researchers marked with wood lath. Also, the handheld GPS unit was used to locate these end points 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 “Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications” (ASTM D6951 / D6951M - 09). Figure 4(b) shows researchers doing a standard DCP test. 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*

The Clegg hammer tests were also used to measure the shoulder material stiffness. The test procedure was conducted according to “Standard Test Method for Determination of the Impact Value (IV) of a Soil” (ASTM D5874 - 02(2007)). Figure 4(c) shows researchers performing a standard Clegg hammer test.

Both Dynamic Cone Penetrometer (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 end point as well as the midpoint. Although results from DCP tests might be more accurate, the accuracy level of Clegg hammer was considered to be sufficient for the purposes of this investigation. Thus, 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 and aggregate samples were taken.

*Elevation Profile Measurements*

Elevation profile measurements were conducted in order 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. In order to make sure the angle iron was level, a torpedo level was set at the midpoint of the angle iron and the G-shape clamp was adjusted accordingly. After 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(a). 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 would be taken at 60 in (152 cm), 72 in (183 cm) where applicable (Jahren et al. 2010).

In addition, the following simple test was done 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 horizontally away from the object, the elevation of the bottom surface of the angel iron was read from a ruler. After this process was repeated for ten times, it was found that the error of this measurement was within ¼ inches 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(d). Additional sample was taken only for places where fresh aggregate had been recently spread on the shoulder. The samples were used for conducting further gradation tests following "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates" (ASTM C136-01 (2001)). In addition, Atterberg Limits Tests were conducted by following ASTM D4318-10 to measure the plasticity and liquid limit of aggregate samples.


**Figure 4. (a) Profile Test, (b) DCP Test, (c) Clegg Hammer Test, (d) Dig Samples**

**Equipment Selection**

After the preconstruction observations and tests were made, researchers began to plan for the next stage for soapstock application. Some questions were being raised, such as what 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 Iowa DOT (Figure 5). In previous projects, a “Spinner” on the sand truck was used to spread sand on the shoulder, which was usually used to spread deicing salt on the road in winter. Using the spinner, more than one pass were needed to obtain a required coverage, which caused the sand application process to become the controlling process which delayed 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 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 open width. The wood plate could be easily removed.

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


**Figure 5. (a) Road grader, (b) water truck, (c) soapstock truck, (d) sand truck**

## Update of Google Map and New Diagrams

The map was updated with the beginning and end point for each work location marked on GPS unit during the first trip. By drawing a line that was snapped to the road between the two end points 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 with handy information.

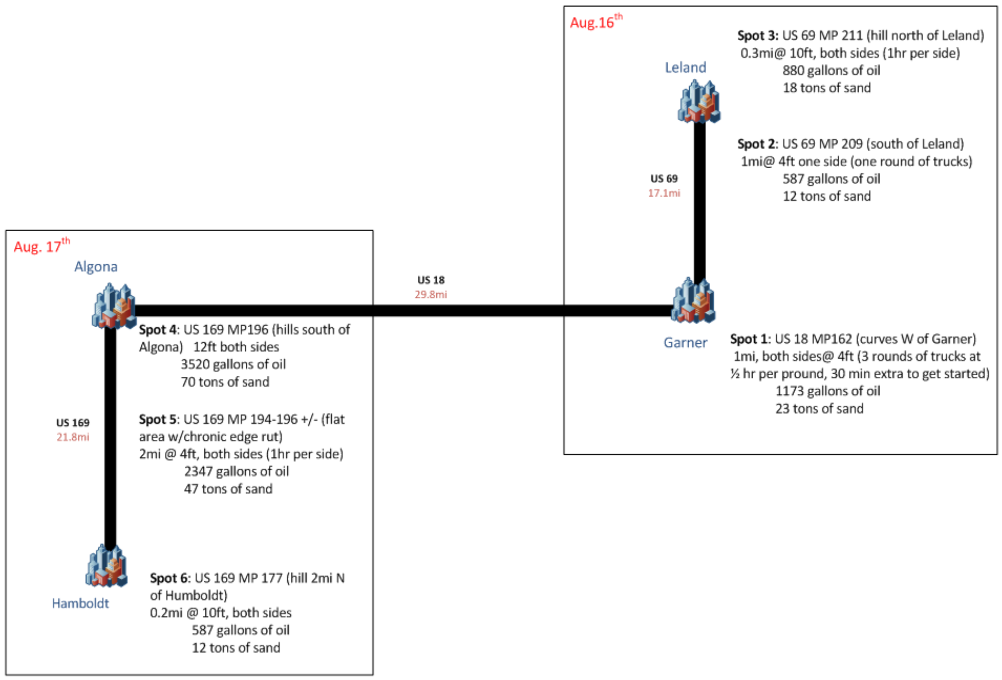


**Figure 6. Sample spraying route for Algona and Garner, Iowa**

## Construction Activities

Construction activities were conducted at the three test areas selected during the planning stage from August 16 to September 2 in 2011. The detailed dates for each area are listed in Table 2. Two of locations visited during the initial pre-construction measurements did not have any spraying work in the actual construction process, while some of the shoulders near Waverly and Denver had a second coat applied.

**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, Alison, 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, Alison, 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, Alison, and Denver |
| | 10/28/11-06/21/12 | Elgin, Wadena, S. of Elkader and E. of West Union |

* Places not sprayed during construction

**2$^{nd}$ time spraying soapstock

For the soapstock application process, the work train included a water truck, a soapstock distributing truck, and a sand truck, which would be operating in the order with the time lags indicated in Figure 7. The detailed construction activities will be further explained in the sections for each of the three geographic areas.

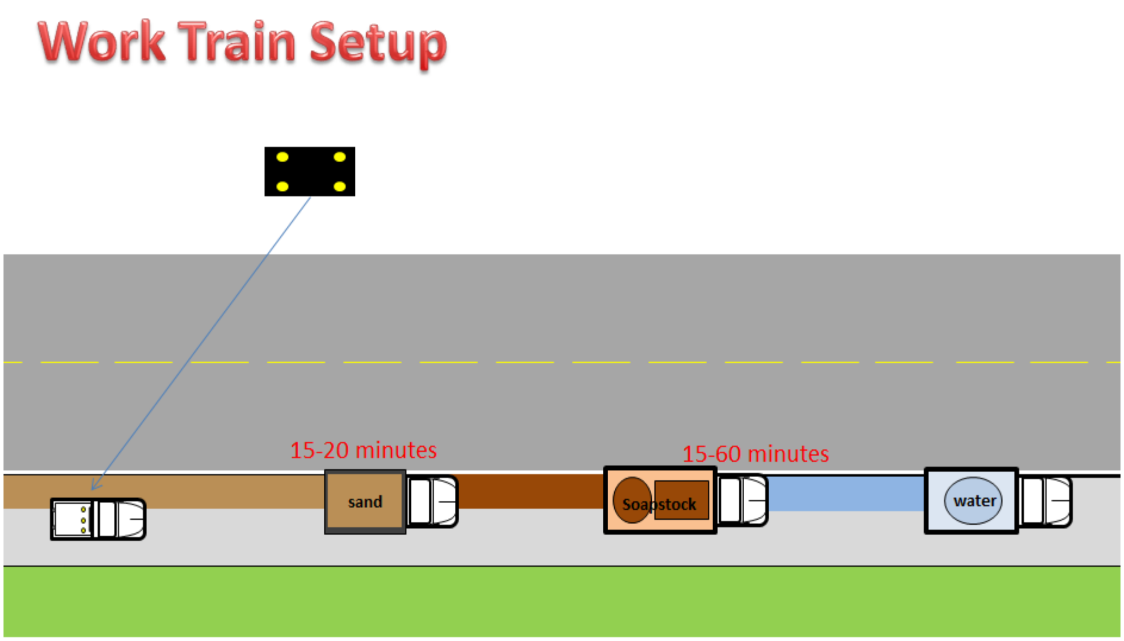


**Figure 7. Basic work train setup for soapstock application**

*Area I*

This area includes five work locations which were 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**

| Area | Location No. | County | Route No. | Beginning MP | End MP | Shoulder | Actual Length (ft) | Sprayed width (ft) | Sprayed area (sy) |
|---|---|---|---|---|---|---|---|---|---|
| I. Algona & Garner | 1.01 | Garner | US 18 | 161.6 | 161.9 | Both | 3024 | 4 | 448 |
| | 1.02 | North of Leland | US 69 | 210.8 | 211.4 | NB | 2112 | 10 | 782.22 |
| | | | | | | SB | 2112 | 6.5 | 508.44 |
| | 1.03 | South of Leland | US 69 | 209 | 209.4 | SB | 1584 | 4 | 234.67 |
| | 1.04 | South of Algona | US 169 | 195.5 | 196 | SB outside | 5786 | 8.5-12 varies | / |
| | 1.05 | South of Algona | US 169 | 194.8 | 195.5 | Both | 5238 | 4 | 776 |

On August 16 and August 17 of 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 of shoulders, no new aggregate was added, except for the northbound shoulder near north of Leland. The surface was lightly compacted to increase the stability of the surface.

2. On the day of construction, the traffic control was set up. A traffic sign was attached on a pick-up truck with amber flashing light which 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 be sprayed 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 the right 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. Usually, the width of sprayed soapstock was four feet, which required two nozzles working simultaneously. In north of Leland, soapstock was applied at full width going up to the hill, because gullies caused by water erosion were developed near the grass line.  The applied result was shown in Figure 9.

5. After 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 half an inch, and the width of sand was adjusted based on the width of soapstock applied on the shoulder. Another sand truck was waiting aside for back-up. When the sand in one truck ran out, the back-up truck would run forward and the empty one would go back for a new stock. The result of this application is shown in Figure 10.

Work Location 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 aggressive water erosion). Part of work was accomplished on the first day of construction, and the rest of work was accomplished on the second day. On August 17 2011, during the operation, the soapstock was found 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 11am on that day, one of the sand trucks had a mechanical problem which caused a delay. This made the whole operation was a little more slow than expected.

In addition, the operator of the soapstock truck tried two methods in order to obtain a heavier coverage at Location 1.05. One way was to run a second pass on the southbound shoulder. Another way was to drive slowly on the northbound shoulder. Both methods worked well in terms of achieving a heavier coverage.

**Figure 8. Soapstock application process**

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

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

In one place, the 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, which had a significant amount of fine particles (Figure 11).

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

*Area II*

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

**Table 4. Spraying work location description for area II**

| Area | Location No. | County | Route No. | Beginning MP | End MP | Shoulder | Actual Length (ft) | Sprayed Width (ft) | Sprayed Area (sy) |
|---|---|---|---|---|---|---|---|---|---|
| II. Waverly & Alison | 2.01 | East of Waverly | IA 3 | 226.2 | 226.6 | Both | 3122 | 4 | 462.52 |
| | | | IA 3 | 226.4 | 226.6 | Both | 1561** | 4 | 231.26 |
| | 2.02 | Denver | US 63 | 174.6 | 177 | SB outside | 7755 | 4 | 1148.89 |
| | | | | | | SB inside | 9063 | 4 | 1342.67 |
| | | | | | | NB outside | 7461 | 4 | 1105.33 |
| | | | | | | NB inside | 9305 | 4 | 1378.52 |
| | | | | 176.5 | 177 | SB outside | 1584** | 4 | 234.67 |
| | | | | 176 | 176.5 | NB outside | 3168** | 4 | 469.33 |
| | 2.03 | West of Waverly | IA 3 | 220 | 220 | WB | 1491 | 4 | 220.89 |
| | 2.04 | Shell Rock | IA 3 | 215 | 216 | Both | 11170 | 4 | 1654.81 |
| | 2.05 | East of Allison | US 63 | 205.1 | 205.7 | Both | 8280 | 4 | 1226.67 |

**2nd time spraying soapstock

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

On August 18, 2011, a rain was encountered during the construction activities executed around Allison and Shell Rock. Figure 12 shows the result of the soapstock application on the westbound shoulder of IA 3 nearby and east of Alison when it was raining. The rain became heavy in the afternoon, thus 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 in comparison to other work locations in post observations.

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

On August 30 and August 31 of 2011, the second coat was applied on the shoulders at Location 2.01 around east of Waverly and Location 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.

Work Location 2.02 was located on curves of US 63 near Denver. This highway is a four-lane divided highway with a traffic level heavier than the targeted level (6000 ADT). Soapstock was applied on both outside and inside shoulders and adjacent to both southbound and northbound 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**

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


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

*Area III*

This area includes ten work locations which were within the areas of responsibility for the West Union and Elkader Maintenance Garages that were 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**

| Area | Location No. | County | Route No. | Beginning MP | End MP | Shoulder | Actual Length (ft) | Sprayed width (ft) | Sprayed Area (sy) |
|---|---|---|---|---|---|---|---|---|---|
| III. West Union & Elkader | 3.01 | East of West Union | US 18 | 264.5 | 265 | Both | 3048 | 4 | 451.56 |
| | 3.02 | West of Clermont | US 18 | 269.8 | 271 | Both | 8900 | 4 | 1318.52 |
| | 3.03 | Elkader | IA 13 | 75 | 75.7 | NB | 3090 | 12 | 1373.33 |
| | 3.04 | Elkader | IA 13 | 75 | 75.2 | SB | 1330 | 12 | 591.11 |
| | 3.05 | South of Elkader | IA 13 | 72.4 | 74 | NB | 4890 | 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 | 1315 | 10 | 487.04 |
| | 3.08 | South of Elgin | W 51 | 3600' S. of intersection of W51&215$^{th}$St | 4460' S. of intersection of W51&215$^{th}$St | NB | 860 | 2 | 63.70 |
| | 3.09 | South of Elgin | W 51 | 70' S. of intersection of W51&215$^{th}$St | 1050' S. of intersection of W51&215$^{th}$St | NB | 980 | 2 | 72.59 |
| | 3.10 | South of Elgin | W 51 | 1760' S. of intersection of W51&215$^{th}$St | 4000' S. of intersection of W51&215$^{th}$St | SB | 2240 | 2 | 165.93 |

On September 1 of 2011, the weather was sunny and dry in Elkader. On September 2 of 2011, the weather was cool and cloudy with intermittent rain in some places. The general construction activities were performed following the same procedures described earlier for Area I. For location 3.03-3.04 near Elkader, soapstock was applied at 12-ft width because of the gullies developed near the grass line, as shown in Figure 15. The result of one section after sand was just spread on is shown in Figure 16. For location 3.08-3.10 south of Elgin, the shoulders were much narrower than the ones in other places. Thus, soapstock was sprayed at 2-ft width. The road had been temporarily closed during the application.

**Figure 15. 12-ft wide soapstock applied on the shoulder of IA 13 near east of Elkader**

**Figure 16. Sand applied on the shoulder of IA 13 near east of Elkader**

One action drew researchers' attention when Jerry 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 Jerry Boer, material with low viscosity tends to settle down 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 evenly distributed and provide better performance.

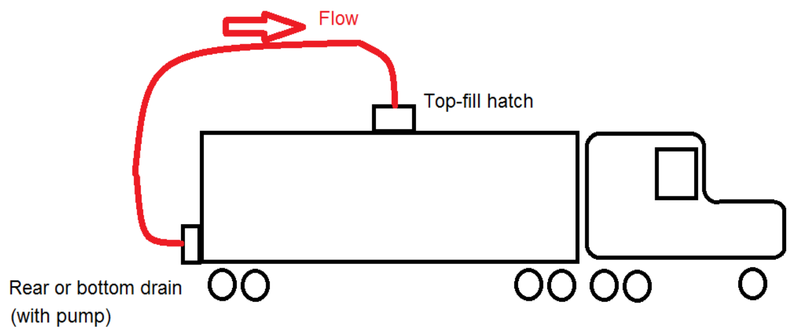


**Figure 17. Recirculating Soapstock to provide more consistent density (by Richard Harris)**

While applying soapstock onto Fayette County W51, 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). This 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 a higher shoulder surface would be scraped off the shoulder by the motor grader blade.

**Figure 18. Grader bladed over the shoulder applied with sand**

*Application Rate and Overall Productivity*

The water truck ran at a speed of 3-5 mph (5-8 km/hr.), which could spray 0.25-gallon water over one square yard of shoulder. The soapstock spray rig moved at a speed of 2-3 mph (3-5 km/hr.) when spraying soapstock on the moist shoulder with an average application rate of 0.25 gallon per square yard. Sand truck with a chip spreader spread sand on the treated shoulder at a speed of 3-5 mph (5-8km/hr.), which could achieve an average application rate of 10 lbs. per square yard.

Based on observations, the maximum productivity for the "work train" (water truck, soapstock spray rig, and sand truck) was two lane-miles per hour. After considering the allowance for start and stop time, refilling tanks and sand trucks, and other miscellaneous time, the maximum daily productivity could be 8-10 lane-miles (13-16 lane-km). During the whole construction period, there was one time that the daily productivity was up to 12 lane-miles, which was surprisingly high. 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.

Sometimes, personnel needed to make decisions or adjustments according to actual site conditions or any unexpected events.

**Post Construction Observations and Measurements**

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

*Guidance of Google map and GPS Hand Unit*

Before starting each trip, researchers printed out the Google maps showed the location of the soapstock application work. The Google 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, thus 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 would make a closer examination and try 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 of 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 differential leveling method (Caltrans 2006). The equipment researchers used for this measurement was AT-22A automatic levels (Topcon Corporation 2000) shown in Figure 20, 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*

In 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 new developed edge ruts with a measuring wheel. The error of this measurement was $\pm$0.6% which was obtained after averaging the results from 13 times of 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 entitled Results and Discussion.

### *CBR*

Clegg hammer data was collected from several locations along each shoulder section before and after soapstock application. Readings directly from Clegg hammer represent Clegg Impact Value (CIV), which could be then converted to California Bearing Ratio (CBR) to measure the stiffness of shoulder materials. For this investigation, the equation applied to make the conversion was (CLEGG 1986):

$$CBR = (0.24*CIV+1)^2$$

This equation is 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 out by using SigmaPlot® 12 (by Systat Software Inc. 2011) to show the approximate cross slope of each shoulder. Also, 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 Hills*

For every observed hill, 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 Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials standard (AASHTO).

For granular shoulders in Iowa, either type A or type B gravel is used for shoulder materials. Type A gravel refers to the crushed stone or a gravel-limestone mixture. Type B gravel 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 ¾ inch. By comparing to 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 by GEOSYSTEM® v2.1 (by GEOSYSTEM Software 1991-2001) and attached in appendix.

*Traffic Level*

The Traffic level for each shoulder section was obtained from 2010 vehicle traffic movement map on Iowa DOT website. This map provides traffic volumes expressed as Annual Average Daily traffic (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 only 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. Thus, gradation results for those places might not exactly represent the shoulder properties 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 different places.

# CHAPTER 4. RESULTS AND DISCUSSION

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

## Area I

### *Observed Performance*

Up to June 21, 2012, all newly developed edge ruts or pot holes were identified and listed in Table 6 for the five locations in area I. Problems occurred on section 1.01 and 1.05, where section 1.01 contained one rut and one pot hole and section 1.05 had two ruts. Table 7 listed the calculated percentage of success for each treated shoulder section and the overall area. The total problematic length was 276ft out of 19856ft, so the total percentage of successful application was 98.61% for area I.

**Table 6. New problematic spots identified in area I**

| Sec No. | County | Route | Location | Problematic Length (ft) | Width (in) | Depth (in) | Notes |
|---|---|---|---|---|---|---|---|
| 1.01 | Garner | US 18 | 0.15mi E of GW01A, EB | 45 | 6 | 0.5 | rut |
| 1.01 | Garner | US 18 | 90ft E of GW01A, WB | 5 | 13 | 0.75 | pot hole |
| 1.05 | south of Algona | US 169 | 0.13mi S of AF01, SB | 157 | 10 | 1.5 | rut |
| 1.05 | south of Algona | US 169 | 0.23mi N of AF01, SB | 69 | 17 | 2.5 | rut |

**Table 7. Percentage of successful application for area I**

| Sec No. | County | Route | Successful Length (ft) | Problematic Length (ft) | Total Length (ft) | Percentage of Success |
|---|---|---|---|---|---|---|
| 1.01 | Garner | US 18 | 2974 | 50 | 3024 | 98.3% |
| 1.02 | north of Leland | US 69 | 4224 | 0 | 4224 | 100.0% |
| 1.03 | south of Leland | US 69 | 1584 | 0 | 1584 | 100.0% |
| 1.04 | south of Algona | US 169 | 5786 | 0 | 5786 | 100.0% |
| 1.05 | south of Algona | US 169 | 5012 | 226 | 5238 | 95.7% |
| Total | | | 19580 | 276 | 19856 | 98.6% |

Figure 21 provides an example of good shoulder performance for this area. This shows a section of the US 169 shoulder adjacent to the southbound lane just south of Algona, where a thin layer of soapstock remained firmly on the shoulder. Another example is shown in figure 22. 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**

**Figure 21. Eastbound shoulder of US 18 near Garner**

Figure 23 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. Also, the pavement had more than one layer of asphalt which raised its elevation, which increased the elevation difference between the pavement and shoulder along the edge.

**Figure 22. Edge rut developed around south of Algona**

Figure 24 shows an example of a comparison of an untreated shoulder edge and the untreated one. The photo was taken on October 13, 2011 about 2 months after application at US 18 near Garner. On the right side of the red dividing line, a small amount edge rutting could be observed where soapstock was not sprayed. On the left side of the red dividing line, 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.

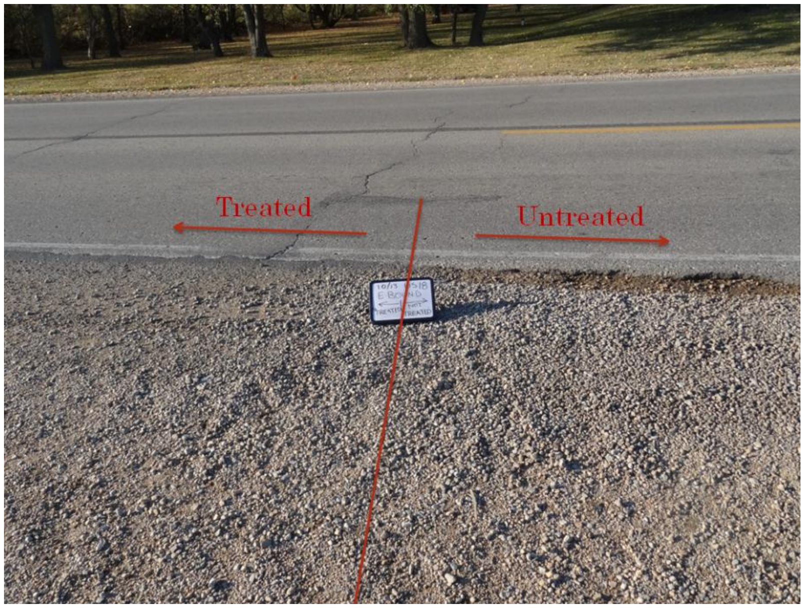


**Figure 23. Compared results of treated and untreated shoulder edge**

*California Bearing Ratio (CBR)*

For each shoulder section, CBR results before and after soapstock applications are listed in table 8. Clegg hammer data were collected on August 3th, 2011 and June 21st, 2012. More detailed CIV data with for selected locations along each section and the conversion of CIV to CBR are included in Appendix-Location 1.01-1.05.

**Table 8. CBR values of shoulder materials in area I**

| Sec No. | County | Route | Ave. 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. Elevation profiles data were collected on August, 2011 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-Location 1.01-1.05.

**Table 9. Average cross slopes of shoulder sections in area I**

| Sec No. | County | Route | Ave. slope (%) | | |
|---|---|---|---|---|---|
| | | | Aug.2011 | Oct.2011 | Jun.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 | US169 | / | 7.1 | 8 |

*Grade of Slopes*

The grade of one slope was measured for sec 1.02 near north of Leland with a grade of 3.6%. The grade of three slopes were measured just south of Algona, two of which were on sec 1.04 with slopes of 3.6% and 3.3% respectively and one of which was on sec 1.05 with a slope of 1.5%. The detailed results are listed in table 10.

**Table 10. Slopes of hills in area I**

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

*Gradation Samples Results*

The classification for each shoulder material sample is listed in table 11 along with the percentage of material above at the #4 sieves. Based on Iowa DOT Class A/B aggregate specification, the range of fine limit at #4 sieves is supposed to range between 30 to 55%.

The detailed gradation graphs for all shoulder material samples are attached in Appendix-Location 1.01-1.05.

**Table 11. Gradation results for shoulder materials in area I**

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

From this table, original shoulder materials were all finer than upper limit of Class A aggregate (55%). The shoulder sections near north of Leland (section 1.02) had the most fine materials with 20.6% above fine limit on northbound and 21.6% above fine limit on southbound. The gradations @#4 sieves for section 1.04 and 1.05 are relatively close to the spec with 7.4% above fine limit. From Atterberg Limits tests, all materials were non-plastic.

*Traffic*

The traffic levels listed in the following table were obtained from the traffic map on Iowa DOT website (Office of Transportation data 2010).

**Table 12. Traffic levels for shoulder sections in area I**

| Sec No. | County | Beginning 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 | US169 | 2750 |

## Area II

*Observed Performance*

Up to June 21, 2012, all identified problematic locations are identified and listed in Table 13 for the five locations in area II. Most of problems for this area resulted from the removal of the soapstock by the traffic rather than edge ruts or pot holes. In particular, section 2.01 had new layers of asphalt on the pavement, which raised the elevation of the pavement. Table 14 lists the calculated percentage of success for each treated shoulder section and the overall area. The total problematic length was 19715ft out of 63960ft, so the total percentage of successful application was 69.2% for area II.

**Table 13. New problematic spots in area II**

| Sec No. | County | Route | Location | Problematic Length (ft) | Width (in) | Depth (in) | 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 | 330ft S of WV02A, SB | 35 | / | / | no edge ruts, but soapstock had been removed |
| 2.04 | Shell Rock | IA 3 | The entire section | 11170 | / | / | |
| 2.05 | East of Allison | IA 3 | The entire section | 8280 | / | / | |

**Table 14. Percentage of successful application for area II**

| Sec No. | County | Road | Successful Length (ft) | Problematic Length (ft) | Total Length (ft) | Percentage of Success |
|---|---|---|---|---|---|---|
| 2.01 | east of Waverly | IA3 | 4453 | 230 | 4683 | 95.1% |
| 2.02 | Denver | US 63 | 38301 | 35 | 38336 | 99.9% |
| 2.03 | Waverly | IA3 | 1491 | 0 | 1491 | 100.0% |
| 2.04 | Shell Rock | IA3 | 0 | 11170 | 11170 | 0.0% |
| 2.05 | east of Allison | IA3 | 0 | 8280 | 8280 | 0.0% |
| Total | | | 44245 | 19715 | 63960 | 69.2% |

Figure 25 provides an example of good shoulder performance for this area. This shows a shoulder section of IA 3 on adjacent to the eastbound lanes just east of Waverly, where a thick layer of soapstock remained firmly on the shoulder. Another example was shown in figure 26. The shoulder section was on US 63 near Denver, where soapstock had penetrated into the shoulder and could not be easily seen.

**Figure 24. Eastbound shoulder of IA 3 east of Waverly**

**Figure 25. Southbound outside shoulder of US 63 near Denver**

Figure 27 shows one example of an undesired situation where most soapstock was abraded away by the traffic although neither edge ruts nor pot holes developed. This was part of the shoulder of IA 3 on eastbound near east of Allison. However, an edge drop off did exist because as asphalt overlay created an elevation difference between the pavement and the shoulder this elevation difference had not been addressed by adding shoulder aggregate after construction or the new aggregate was added had been removed since construction.

**Figure 26. Soapstock missing near east of Allison**

Figure 28 shows another undesired situation where the soapstock was not remaining on the inside shoulder of US 63 on northbound near Denver. Part of shoulder materials had been displaced by the traffic.

**Figure 27. Northbound inside shoulder of US 63 near Denver**

*California Bearing Ratio (CBR)*

For each shoulder section, CBR results before and after soapstock applications were listed in table 15. Clegg hammer data were collected on August 4th, 2011 and June 21st, 2012. More detailed data with CIV for selected spots along each section and conversion of CIV to CBR were included in Appendix-Location 2.01-2.05.

**Table 15. CBR values of shoulder materials in area II**

| Location No. | County | Route | Ave. 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 |

From this table, original shoulder materials were hard enough with CBR values greater than 10. After soapstock was applied on shoulders, CBR values had increased for all sections. Shoulders near Waverly, Shell Rock, and east of Allison showed a big increase in CBR values, which indicates a big increase of 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. Elevation profiles data were collected on August, 2011 and October 2011, and June 2012. More detailed data and plotted graphs are included in Appendix-Location 2.01-2.05.

**Table 16. Average cross slopes of shoulder sections in area II**

| Sec No. | County | Route | Ave. slope (%) | | |
|---|---|---|---|---|---|
| | | | Aug.2011 | Oct.2011 | Jun.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 |

*Grade of Slopes*

For section 2.01, 2.02, and 2.03, there was one slope identified for each of these sections, with grades of 1.6%, 1.4%, and 1.6%, respectively. From these calculated grades, the slopes were relatively gentle. The detailed results are listed in table 17.

**Table 17. Slopes of hills in area II**

| Sec No. | location | Length (ft) | Elevation difference (ft) | Slope (%) |
|---|---|---|---|---|
| 2.01 | 250ft W of WV01C, EB | 179 | 2.9 | 1.6 |
| 2.02 | 0.25mi S of WV02A, SB | 150 | 2.1 | 1.4 |
| 2.03 | 400ft W of WV03B, WB | 177 | 2.9 | 1.6 |

*Gradation Samples Results*

The classification for each shoulder material sample is listed in Table 18 along with the percentage above fine limit at #4 sieves listed. Based on Iowa DOT Class A/B aggregate specification, the range of fine limit at #4 sieves should range from 30 to 55%. Detailed gradation graphs for the shoulder material samples were attached in Appendix-Location 2.01-2.05.

**Table 18. Gradation results for shoulder materials in area II**

| Sec No. | County | Route | Location | USCS | AASHTO | % above fine limit for Class A gradation @#4 |
|---|---|---|---|---|---|---|
| 2.01 | east of Waverly | IA 3 | 100ft W. of WV01C, EB | SM | A-1-a | 6.9 |
| 2.02 | Denver | US 63 | 100ft N. of WV02A, SB, OS | SP-SM | A-1-b | 17.1 |
| | | | 100ft S. of WV02D, NB, OS | SP-SM | A-1-b | 18.6 |
| | | | at WV02A, NB, IS | SP-SM | A-1-b | 15.7 |
| | | | at WV02A, SB, IS | GP-GM | A-1-a | 0 |
| 2.03 | Waverly | IA 3 | 200ft W. of WV03B, WB | GP-GM | A-1-a | 0.1 |
| 2.04 | Shell Rock | IA 3 | 100ft E. of WV04B, WB | SM | A-1-b | 13.3 |
| 2.05 | east of Allison | IA 3 | 50ft W. of WV05C, EB | SP-SM | A-1-a | 0.9 |

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

*Traffic*

The traffic levels listed in the following table were obtained by the map on Iowa DOT website (Office of Transportation Data 2010).

**Table 19. Traffic levels for shoulder sections in area II**

| Sec No. | County | Beginning MP | End MP | Road | AADT |
|---|---|---|---|---|---|
| 2.01 | East of Waverly | 226.2 | 226.6 | IA 3 | 3400 |
| 2.02 | Denver | 174.6 | 177 | US 63 | 6500-8000 |
| 2.03 | Waverly | 220 | 220 | IA 3 | 5600 |
| 2.04 | Shell Rock | 215 | 216 | IA 3 | 3890 |
| 2.05 | East of Allison | 205.1 | 205.7 | IA 3 | 2430 |

## Area 3

*Observed Performance*

For area III, the situation was different from area I and II. The soapstock was abandoned by garage supervisor Roger Burns since late November 2011. According to Roger Burns (2012), the soapstock worked well after the application until the harvest season. During the harvest season, quite an amount of heavy farm equipment was driving slowly on the shoulders every day in this area. The unsmooth tires of heavy farm equipment scraped off the soapstock in many places. Then, Roger decided to just add new gravel and regrade all shoulders. Unluckily, researchers did not have the chance to observe that process or made any measurements before the regrading work. Thus, the percentage of success was not given for this area.

**Table 20. Percentage of successful application for area III**

| Sec No. | County | Route | Successful Length (ft) | Problematic Length (ft) | Total Length (ft) | Percentage of Success |
|---|---|---|---|---|---|---|
| 3.01 | east of West Union | US 18 | 3048 | / | 3048 | / |
| 3.02 | west of Clermont | US 18 | 8900 | / | 8900 | / |
| 3.03-3.04 | Elkader | IA 13 | 4420 | / | 4420 | / |
| 3.05-3.07 | south of Elkader | IA 13 | 6945 | / | 6945 | / |
| 3.08-3.10 | south of Elgin | W 51 | 4080 | / | 4080 | / |
| Total | | | 27393 | / | 27393 | / |

Figure 29 shows one shoulder section of US18 on eastbound near 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 30. The shoulder was also along US 18 near west of Clermont, where the whole section was regraded with new gravels.

**Figure 28. Shoulder of US 18 on eastbound near east of West Union**

**Figure 29. Shoulder of US 18 on eastbound near west of Clermont**

*California Bearing Ratio (CBR)*

For each shoulder section of Area III, CBR results before and after soapstock application are listed in table 21. Clegg hammer data were collected on August 10th, 2011 and June 21st, 2012. More detailed CIV data for selected locations along each section and the conversion of CIV to CBR are included in Appendix-Location 3.01-3.10.

**Table 21. CBR values of shoulder materials in area III**

| Sec No. | County | Route | Ave. 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 |

From this table, original shoulder materials were sufficiently stiff with CBR values greater than 10. Except for places where Clegg hammer data was not taken and section 1.03, CBR values increased after the soapstock was applied on shoulders, which indicated an increase of 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 listed in table 22. Elevation profiles data were collected on August, 2011 and October 2011, and June 2012. More detailed data and plotted graphs were included in Appendix-Location 3.01-3.10.

**Table 22. Average cross slopes of shoulder sections in area III**

| Sec No. | County | Route | Ave. slope (%) | | |
|---|---|---|---|---|---|
| | | | Aug.2011 | Oct.2011 | Jun.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 |

*Grade of Slopes*

For sections 3.01, 3.02, 3.03-3.04, and 3.08-3.10, there was one slope identified for each of these sections. The steepest slope was on section 3.08-3.10 just south of Elgin with a grade of 9.7%. Section 3.01 and 3.03-3.04 had slopes with grades of 3.6% and 3.7% respectively. The mildest slope was on section 3.02 with a grade of 1.9%. The detailed results were listed in table 23.

**Table 23. Slopes of hills in area III**

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

*Gradation Samples Results*

The classification for each shoulder material sample is listed in the following table along with the percentage above fine limit at the #4 sieve listed. Based on Iowa DOT Class A/B aggregate specification, the range of fine limit at #4 sieves is supposed to be from 30 to 55%. Detailed gradation graphs for the shoulder material samples were attached in Appendix-Location 3.01-3.10.

**Table 24. Gradation results for shoulder materials in area III**

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

From this table, original shoulder materials were all finer than upper limit of Class A aggregate (55%). The shoulder sections near west of Clermont (section 3.02) had finest materials with 30% above fine limit on westbound. The gradations @#4 sieves for section

3.03-3.04 and 3.01 are relatively close to the spec with 2.8% and 5.8% above fine limit respectively. From Atterberg Limits tests, all materials were non-plastic.

*Traffic*

The traffic levels listed in the following table were obtained by the map on Iowa DOT website (Office of Transportation Data 2010). For county highway W51, the most recent traffic data available on DOT website is for the year 2009.

**Table 25. Traffic levels for shoulder sections in area III**

| Sec No. | County | Beginning MP | End MP | Road | 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' S of int. W51& 215th St. | 4460' S of int.W51& 215th St | W 51 | 610 |

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**Summary Results for All Locations**

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

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

| Sec No. | County | Route | % of Success | AADT | % above fine limit for Class A gradation @#4 | Max Slope of Hill (%) | Ave. CBR | | Ave. Shoulder Cross Slope (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Aug. 2011 | Jun. 2012 | Aug. 2011 | Oct. 2011 | Jun. 2012 |
| 1.01 | Garner | US 18 | 98.3% | 5800 | 13.7 | / | / | 75.9 | / | 5.7 | 3.3 |
| 1.02 | north of Leland | US 69 | 100.0% | 2250 | 21.1 | 3.6 | 12.6 | 36 | 6.3 | 7.4 | 8 |
| 1.03 | south of Leland | US 69 | 100.0% | 3640 | 12.3 | 3.6 | 83.5 | 44.8 | 3.9 | 6.5 | 6 |
| 1.04 | south of Algona | US 169 | 100.0% | 2750 | 7.4 | 3.3 | 55.3 | 76.4 | 5.5 | 5.4 | 3.6 |
| 1.05 | south of Algona | US 169 | 95.7% | 2750 | 7.4 | 1.5 | / | 54.1 | / | 7.1 | 8 |
| 2.01 | east of Waverly | IA3 | 95.1% | 3400 | 6.9 | 1.6 | 36.6 | 30.9 | 7.7 | 6.5 | 5.4 |
| 2.02 | Denver | US 63 | 99.9% | 6500-8000 | 12.9 | 1.4 | 14.5 | 18 | 5.7 | 6.8 | 8.3 |
| 2.03 | Waverly | IA3 | 100.0% | 5600 | 0.1 | 1.6 | 24.6 | 43.2 | 10.4 | 8.6 | 7.7 |
| 2.04 | Shell Rock | IA3 | 0.0% | 3890 | 13.3 | / | 48.6 | 70.2 | 5.1 | 5.7 | 4.2 |
| 2.05 | east of Allison | IA3 | 0.0% | 2430 | 0.9 | / | 42.8 | 73.6 | 7.4 | 6.8 | 7.1 |
| 3.01 | east of West Union | US 18 | NA | 2660 | 5.8 | 3.6 | 50.8 | 53.2 | 5.7 | 8.5 | 8.3 |
| 3.02 | west of Clermont | US 18 | NA | 2660 | 19.8 | 1.9 | 59.2 | 61.9 | 10 | 8.6 | 6 |
| 3.03-3.04 | Elkader | IA13 | NA | 2150 | 2.8 | 3.7 | / | 46.7 | 8.3 | 10.1 | 8.3 |
| 3.05-3.07 | south of Elkader | IA13 | NA | 2150 | 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 this table, it is apparent that most shoulders had good performance. Fourteen out of twenty sections had 100% good performance, which means no edge ruts of pot holes 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% of successful application. No edge ruts were observed for these two sections, but most soapstock applied on shoulder surface had been removed. Traffic levels were well below the upper limit of 6000 AADT suggested by Jahren (2011) with 3890 AADT in Shell Rock and 2430 AADT in east of Waverly. No hills were found around these places, and shoulder cross slopes were not really steep. Shoulder materials were hard enough with CBR values greater than 10.

For both places, there was a rain during the 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. Additionally, some of soapstock had been washed away during the rain. The poor performance of shoulder test sections at both places apparently confirms 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 application was mostly successful with 98.3% and 95.7% success respectively. The edge rut in Garner was not severe at only 0.5in deep. There was also one 0.75in-deep pot hole identified nearby. The highway near Garner had relatively high volume traffic (5800 AADT), which might contribute to the developed of new the edge ruts and pot hole. The edge ruts just south of Algona were somewhat deeper, one of which was 1.5 in deep and the other one was 2.5 in deep. One rut was developed at near the bottom of a hill, and runoff from above might have contributed to its failure.

In east of Waverly and Denver, shoulder sections 2.01 and 2.02 had a few spots where soapstock being removed. For shoulder near 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 an asphalt overlay was added to the pavement and the additional granular shoulder material was insufficient compared to the overlay thickness or the added material was somehow displaced from its original location. For shoulder near Denver, the traffic level varied from 6500 to 8000AADT which were higher than the recommended 6000AADT. So, the high traffic volume might be one cause for the failure soapstock. In addition, the granular material on the inside shoulder appeared to be less stable in comparison 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 its garage supervisor Roger (2012), the soapstock worked well after the application until the harvest season when the unsmooth tires of heavy farm equipment scraped off the soapstock applied on shoulders.

For some test sections like the ones south of Leland and east of West Union, pot holes were identified before the soapstock was applied. Maintenance personnel used pot hole patcher to place alternate layers of aggregate and asphalt emulsion to fill the holes. This combination use of soapstock and pot hole patcher seemed to be effective in addressing these pot holes.

## Multiple Regression Model for Rut Mitigation

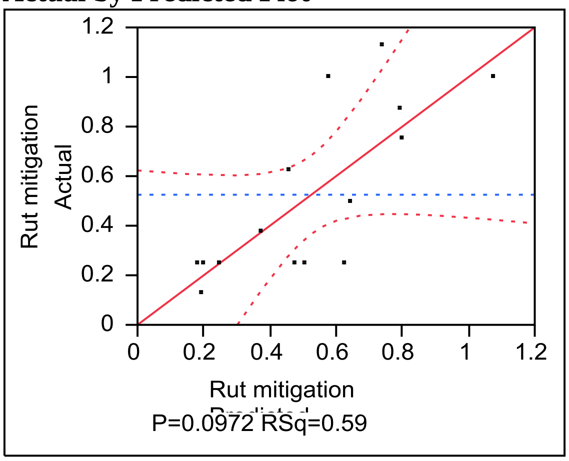
Based on the data obtained from the research, the original shoulder properties (shoulder cross slope, CBR, % gravel, and % sand), road traffic volume, and change of rut depth after the application are shown in table 27. With this data set, a statistical analysis is performed to identify the relationship and significance of various factors or attributes that affect rut mitigation. A multiple regression model is developed using JMP Pro 10 (SAS Institute Inc. 2012) statistical software package in order 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.

**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 | 6500 |
| 0.5 MILE South of WV02A, SB | 0.25 | 5.58 | 21 | 27.9 | 63.2 | 6500 |
| 0.5 Mile South of WV02A, SB, IS | 1 | 6.65 | 5.3 | 27.9 | 63.2 | 6500 |
| 100 FT North of WV02D, NB | 0.625 | 5.02 | 19.7 | 26.4 | 67.4 | 8000 |
| 200' West of WV03B, WB, | 1 | 8.37 | 30.3 | 44.9 | 43.2 | 5600 |
| 100FT East of WV04B. WB | 0.375 | 6.69 | 83.9 | 31.7 | 48.8 | 3890 |
| 200 FT South of SVA04A, SB | 0.25 | 4.07 | 55.3 | 35.9 | 56.9 | 2750 |
| 200 FT South of SVA06A, SB | 0.75 | 2.85 | 2.8 | 32.7 | 56.4 | 3640 |
| 200 FT South of SVA07A, SB | 0.875 | 4.1 | 3.9 | 23.4 | 58.7 | 2250 |
| 200 FT South of SVA07A, NB | 0.5 | 5.43 | 5.3 | 24.4 | 60.4 | 2250 |
| UN01A, EB | 1.125 | 2.78 | 57 | 39.2 | 46.5 | 2660 |
| 215 FT West of UN01B, WB | 0.25 | 10.58 | 54.2 | 39.2 | 46.5 | 2660 |
| 275 FT East of UN03A, EB | 0.125 | 7 | 67.6 | 15 | 68.6 | 2660 |
| 200 FT West of UN03B, WB | 0.25 | 6.77 | 62.6 | 15 | 68.6 | 2660 |
| 0.28 MILE West of UN03B, WB | 0.25 | 14.7 | 40 | 15 | 68.6 | 2660 |

A multiple regression model assumes a linear relationship between independent variables and dependent variables keeping other independent variables constant. Equation 1 shows regression model along with its estimates for each independent variables. 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 Y= (-2.192) + (-0.033) $X_1$ + (-0.009) $X_2$ + ($3.7*10^{-5}$) $X_3$ + 15.988 $X_4$+ 140.247$X_5$

**Parameter Estimates**

| | **Term** | **t Ratio** | **Prob>\|t\|** |
|---|---|---|---|
| $\beta_0$ | 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, R square equals to 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 tested locations were selected based on the traffic amount within 6000 AADT, the traffic amount did not have a direct impact just 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 also possible reasons why vehicles are driving 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 hard to quantify and present in this thesis. 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 5. 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 soapstock had been abandoned after the harvest season of last year because the unsmooth tires of the heavy farm equipment scraped off the soapstock in many places. For places where soapstock worked well during the latest observation, a hard crust was formed on shoulder surface after applying with soapstock, and it could support the traffic loads while surviving 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 the rain was encountered during the 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 soapstock that was applied on shoulder surface was visible. In Garner and south of Algona, shoulder sections 1.01 and 1.05 experienced small percentages of failure, 1.7% and 4.3% respectively. The edge rut in the section near Garner was not severe, (only 0.5 in deep). There was also one 0.75 in-deep pot hole identified nearby. 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 have a strong base which could support the expected traffic loads, indicated by average CBR greater than 12 which is recommended by Mekkawy et al. (2010). The aggregate gradation is generally finer than specified by Iowa DOT, indicated by percentages above upper fine limit of the Iowa DOT Class A aggregate at #4 sieves. Most shoulder sections meet the Iowa DOT specified 4% of slope, but there are a few places with shoulder slope less than 4% which indicates a potential of water erosion. In addition, the shoulders near the bottom of hills also have larger risks of suffering from water erosion.

The application of soapstock is taken place on twenty locations in over ten counties of Iowa. The soapstock worked effectively despite situations where aggregate gradation was finer than allowable range for new shoulder material.

The observed causes of failure include rain or saturated moisture condition during application and high traffic volume (especially heavy farm equipment with unsmooth tires) during operation. For places with pot holes, the failure could be usually corrected with a pot hole patcher.

Method of application was 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/sy target rate, and spreading a layer of sand about half an inch thick over the soapstock. In most cases, one pass per truck was sufficient.

For this research, there were certain limitations existed. The application was only tested on crushed limestone which is the basic material for granular shoulders in Iowa in the region on the test sections. The investigation for the soapstock itself was limited, because the product specifications are proprietary. The tests were only done in Iowa so the results would be most applicable to location with similar climate and operational characteristics. Because of time and equipment limitations, the application rate was not recorded for each location, so some details of application rates are not known. Additionally, the shoulders were not fully and systematically compacted before application. Despite these limitations, this investigation provides solid proof that the concept of applying soapstock to shoulders is sufficiently successfully 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 to refine the use of Soapstock to stabilize granular shoulders that have a stiff subbase but avoid those on grain traffic route.

Meanwhile, 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 the soapstock as a granular shoulder stabilizer. Too much or too little moisture is not good for 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 terminated until after excessive moisture has evaporated.

Some actions observed during this research might be helpful for the application, which is worthwhile to be studied further. For example, the recirculation of soapstock in the tank might help soapstock to be distributed evenly on the shoulder and obtain a uniform density. Compaction of the shoulder before and after application might be helpful for the treated shoulders to have a better performance. For places with a relatively high traffic volume, adding a second coat of soapstock might help stabilize granular shoulders.

More advanced investigations could be conducted in the future to further determine the effects of these factors on soapstock application for unpaved shoulders. The target number of observations should probably be more than 30, and then this model or the modified model could be tested again to provide a comparison for this result. In addition, for each shoulder section, the level of effort on preparation before application and compaction after application might be documented in a straight forward manner such as selecting between sufficient/insufficient/no effort so that researchers can determine at what level makes a difference with regard to the 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

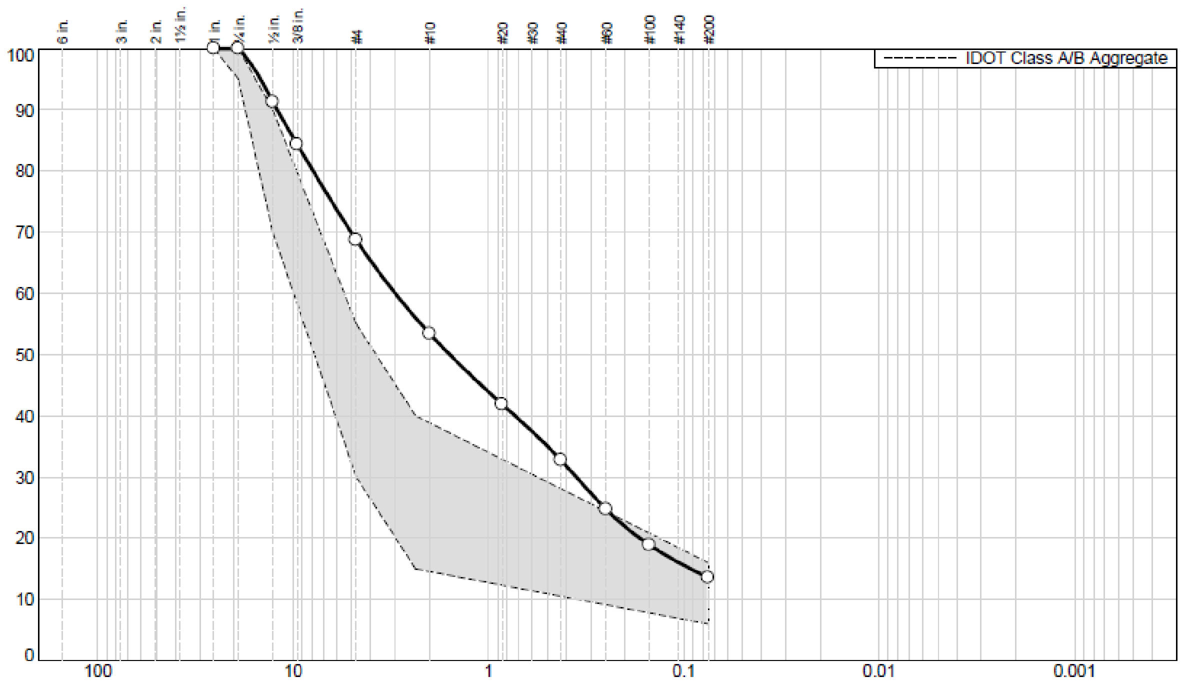
## Location 1.01_MP161.6-161.9

Description: US 18, Garner, shoulders on both sides, sprayed 3024ft long and 4ft wide

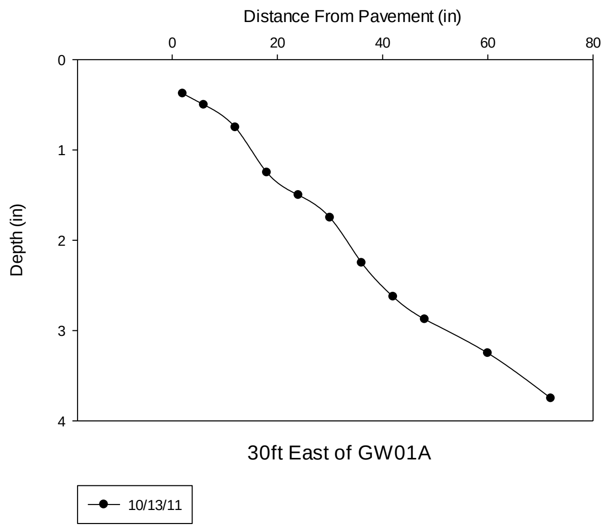
GPS: West end: N 43 06.299, W 93 37.316

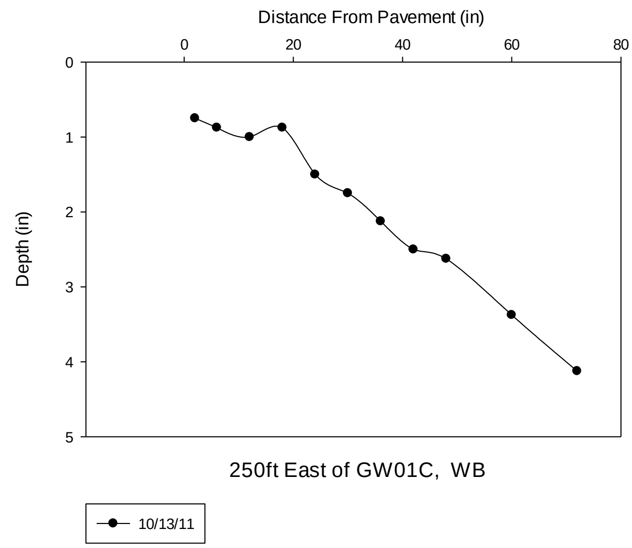
East end: N 43 06.336, W 93 36.975

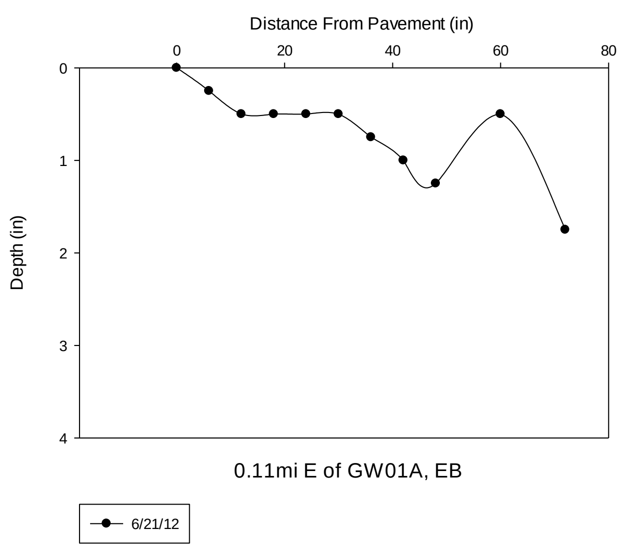
Gradation Distribution

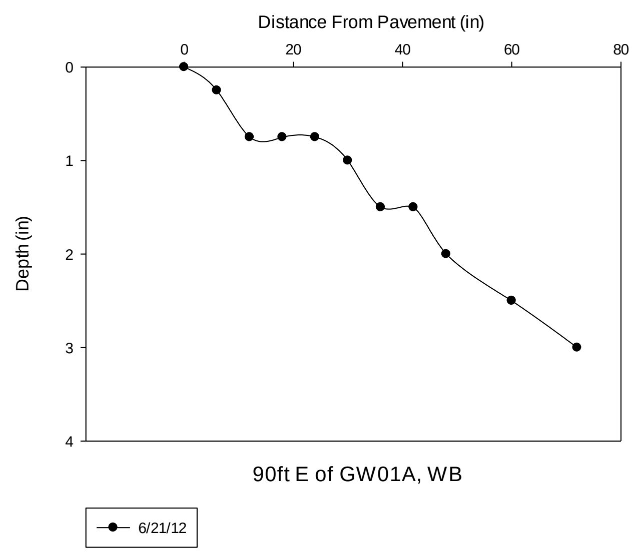


# Elevation Profiles



CBR Values

**Table 28. Clegg hammer data for section 1.01**

<table>
<tr><th>Date</th><th>Location</th><th>CIV</th><th>CBR</th><th colspan="2">Average CBR</th></tr>
<tr><td rowspan="7">Jun.2012</td><td>1.01</td><td></td><td></td><td>EB</td><td>WB</td></tr>
<tr><td>30 ft E of GW01A, EB</td><td>30.8</td><td>70.4</td><td rowspan="3">81.1</td><td></td></tr>
<tr><td>0.11mi E of GW01A, EB</td><td>33.7</td><td>82.6</td><td></td></tr>
<tr><td>155ft W of GW01B, EB</td><td>35.4</td><td>90.2</td><td></td></tr>
<tr><td>155ft W of GW01B, WB</td><td>32.4</td><td>77.0</td><td></td><td rowspan="3">70.6</td></tr>
<tr><td>250ft W of GW01A, WB</td><td>32.6</td><td>77.9</td><td></td></tr>
<tr><td>90ft E of GW01A, WB</td><td>27.3</td><td>57.0</td><td></td></tr>
</table>

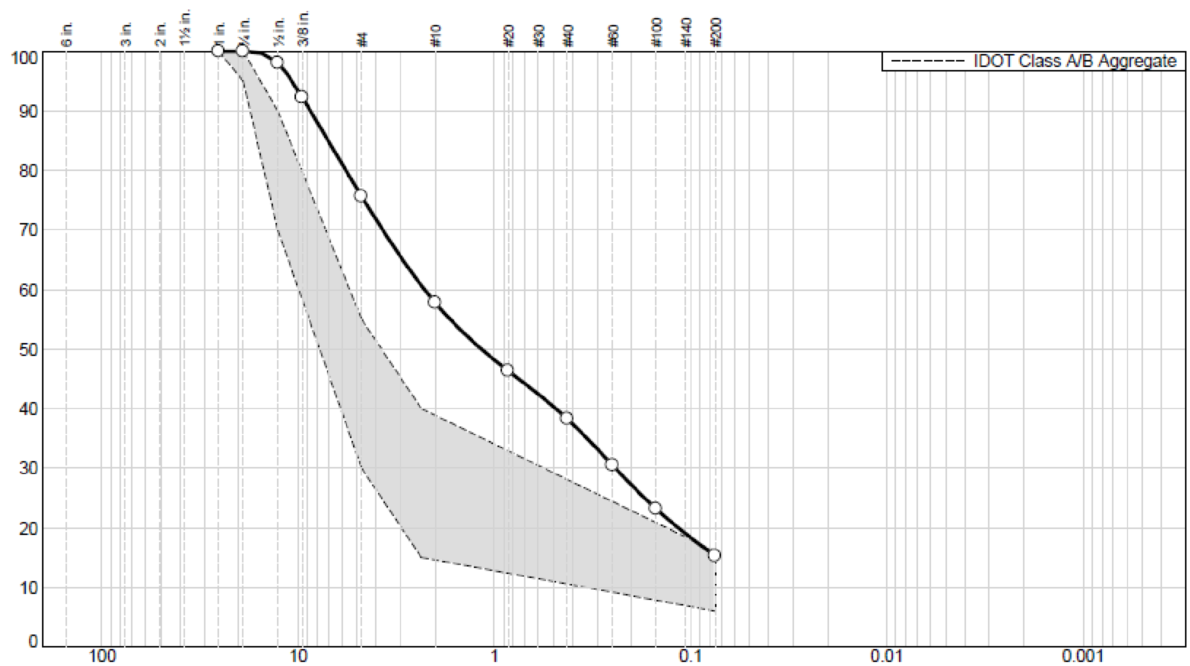
**Location 1.02_MP210.8-211.4**

Description: US 69, north of Leland, shoulders on both sides, sprayed 2112ft long and 10ft wide on northbound, 2112ft long and 6.5ft wide on southbound

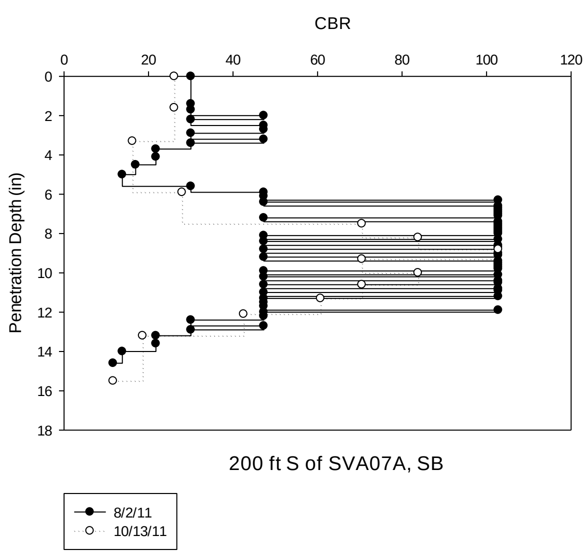
GPS: South end: N 43 21.062, W 93 38.207

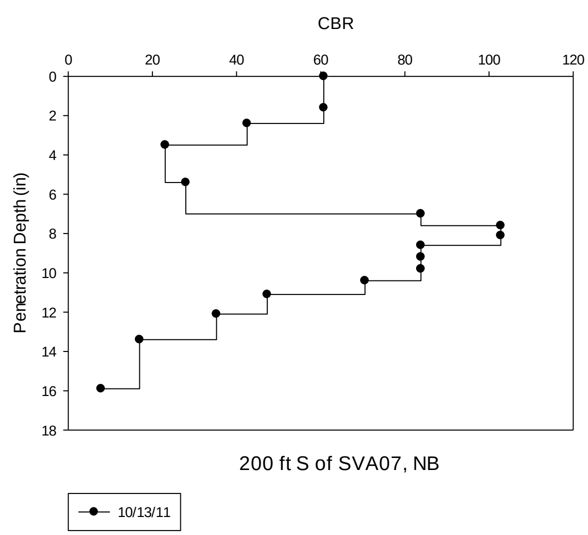
North end: N 43 21.411, W 93 38.212

Gradation Distribution

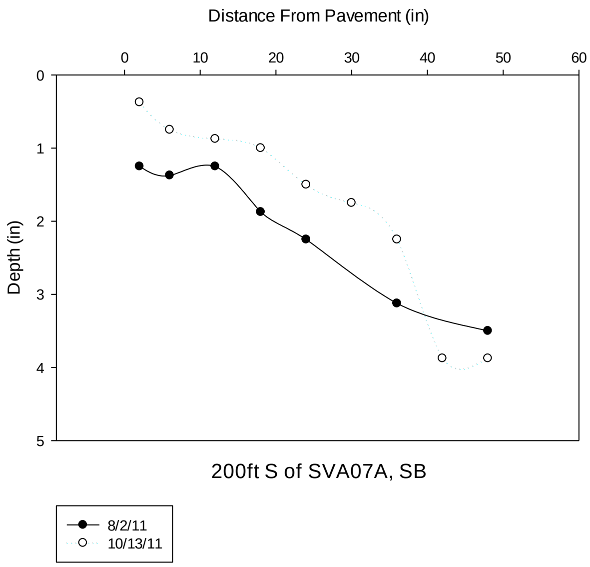



DCP Plots

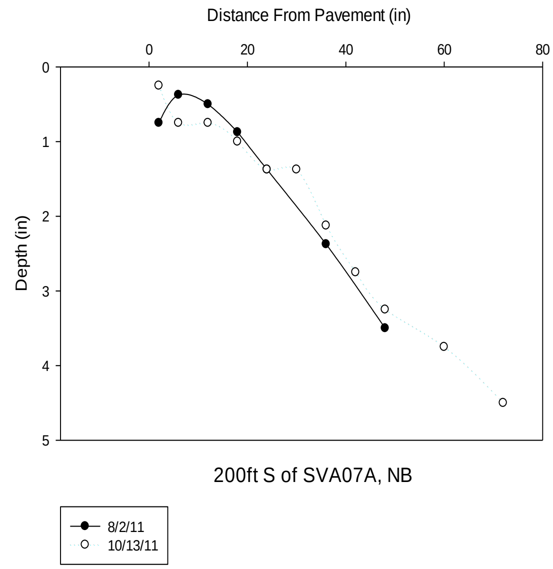


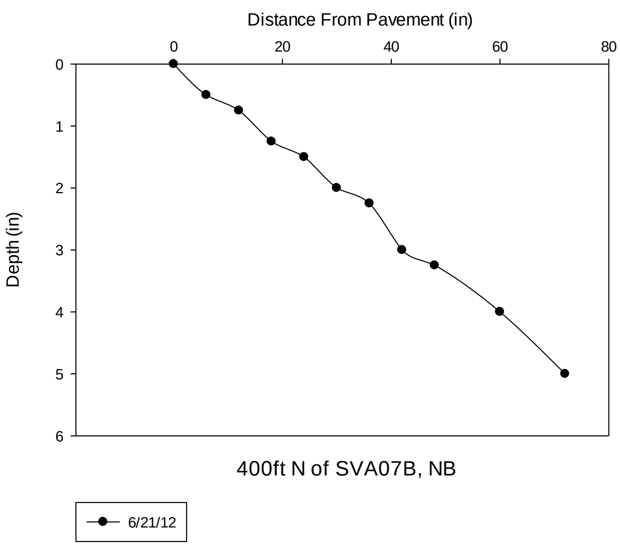
# Elevation Profiles



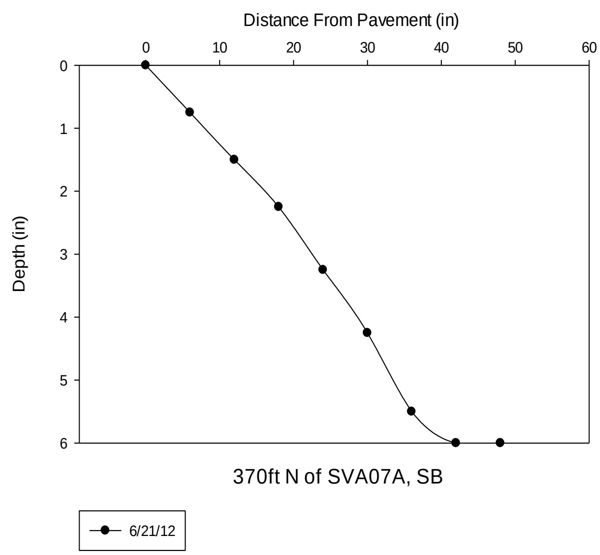

200ft S of SVA07A, SB



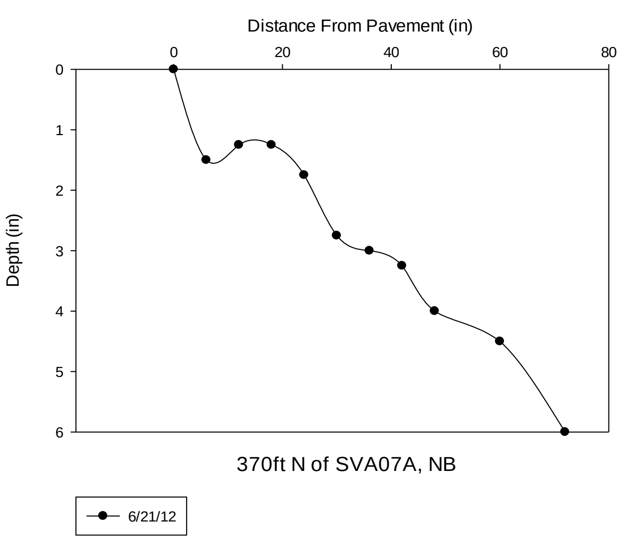

200ft S of SVA07A, NB




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**

<table>
<tr><th>Date</th><th>Location</th><th>CIV</th><th>CBR</th><th colspan="3">Average CBR</th></tr>
<tr><td>Aug.2011</td><td>1.02</td><td></td><td></td><td>SB</td><td>NB</td><td>overall</td></tr>
<tr><td></td><td>200 ft S of SVA07A, SB</td><td>10.3</td><td>12.1</td><td>12.1</td><td></td><td rowspan="2">12.6</td></tr>
<tr><td></td><td>200 ft S of SVA07A, NB</td><td>10.9</td><td>13.1</td><td></td><td>13.1</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td>Jun.2012</td><td>400ft N of SVA07B, NB</td><td>21.8</td><td>38.8</td><td></td><td rowspan="3">39.5</td><td rowspan="5">36.0</td></tr>
<tr><td></td><td>200ft S of SVA07A, NB</td><td>23.6</td><td>44.4</td><td></td></tr>
<tr><td></td><td>370ft N of SVA07A, NB</td><td>20.6</td><td>35.3</td><td></td></tr>
<tr><td></td><td>370ft N of SVA07A, SB</td><td>21</td><td>36.5</td><td rowspan="2">32.5</td><td></td></tr>
<tr><td></td><td>350ft S of SVA07A, SB</td><td>18.1</td><td>28.6</td><td></td></tr>
</table>

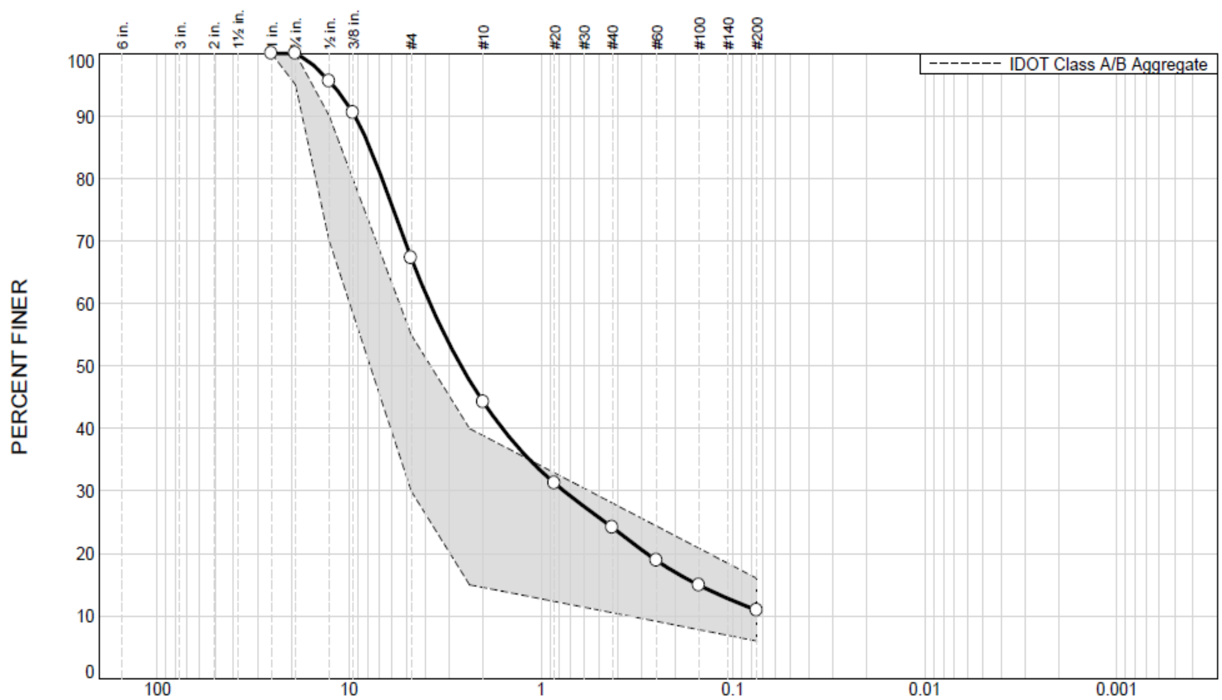
**Location 1.03_MP209-209.4**

Description: US 69, south of Leland, shoulder on southbound, sprayed 1584ft long and 4ft wide

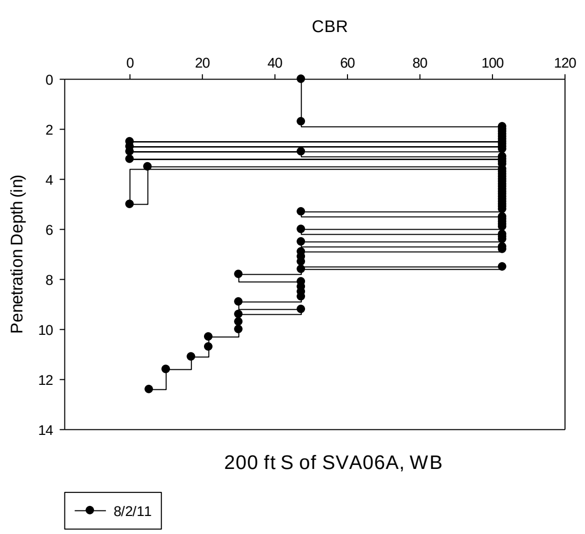
GPS: South end: N 43 19.307, W 93 38.196

North end: N 43 19.553, W 93 38.214

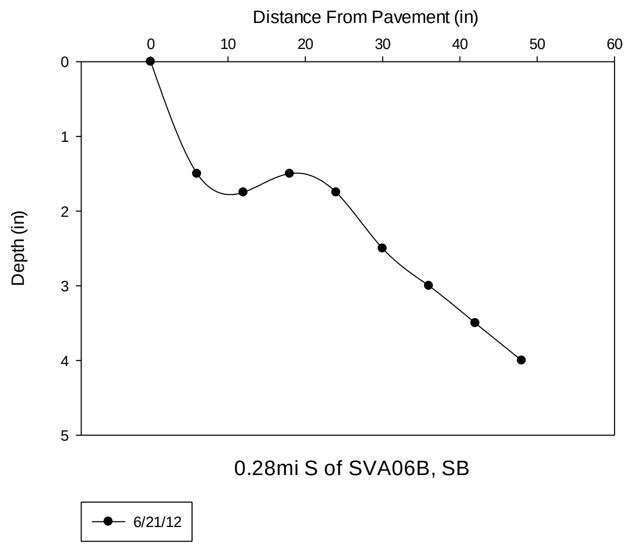
Gradation Distribution

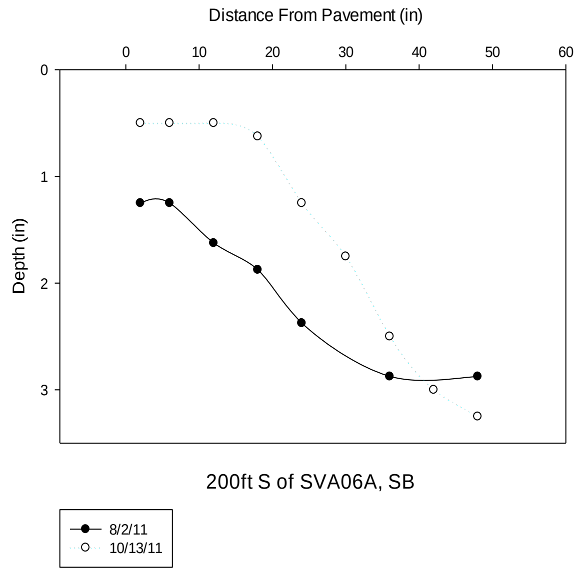



DCP Plots



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 S of SVA06A, SB | 33.9 | 83.5 | 83.5 |
| | | | | |
| Jun.2012 | 0.28mi S of SVA06B, SB | 20.7 | 35.6 | 44.8 |
| | 310ft N of SVA06B, SB | 27 | 56.0 | |
| | 0.35 mi N of SVA06B, SB | 23.1 | 42.8 | |

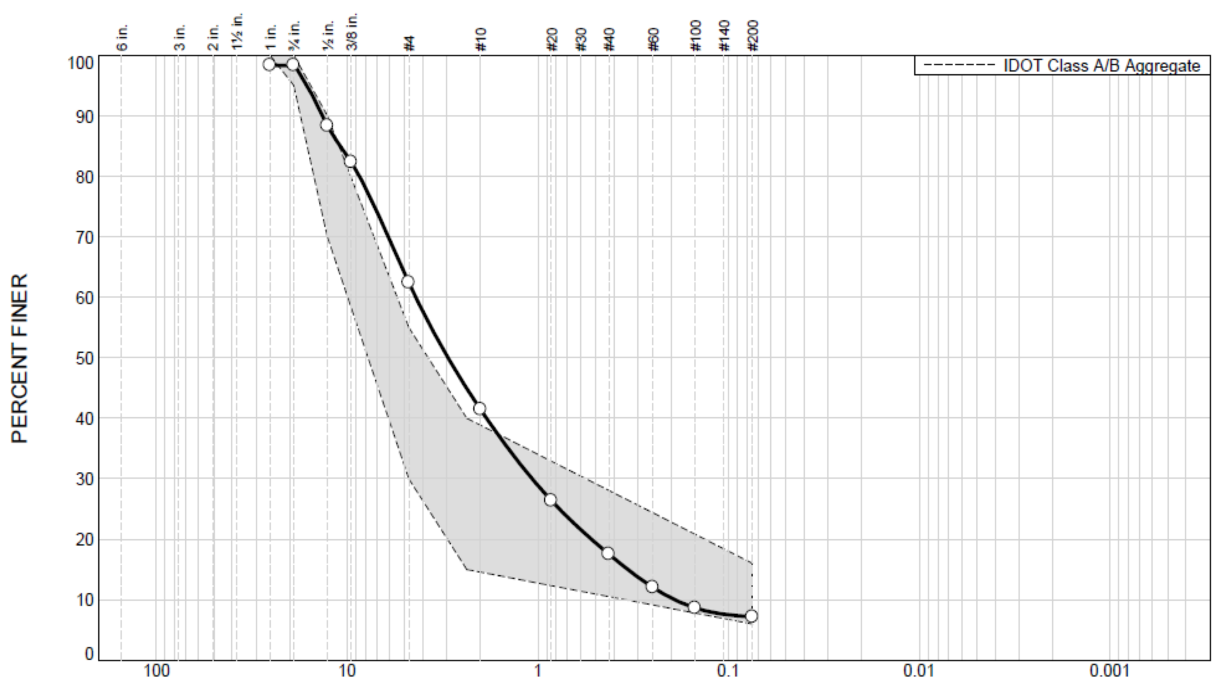
**Location 1.04_MP195.5-196**

Description: US 169, south of Algona, outside shoulder on southbound, sprayed 5786ft long and 8.5-12ft wide

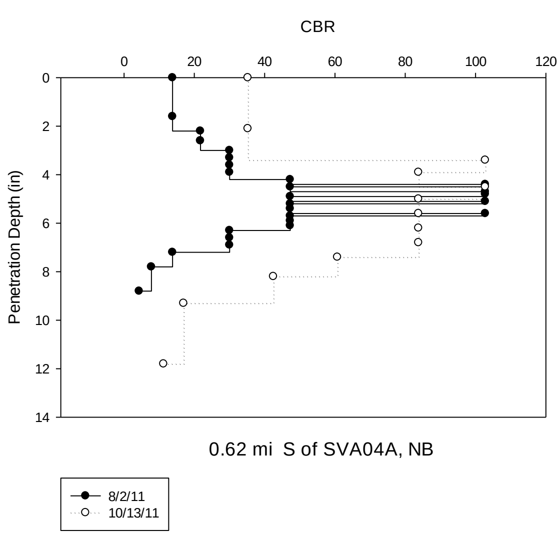
GPS: South end: N 43 02.319, W 94 13.650

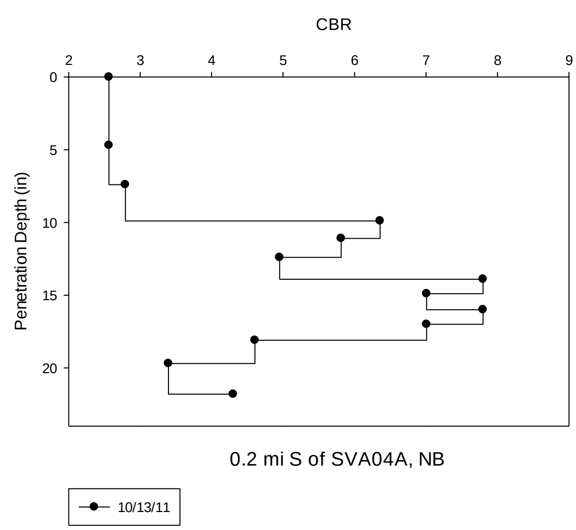
North end: N 43 03.358, W 94 13.637

Gradation Distribution

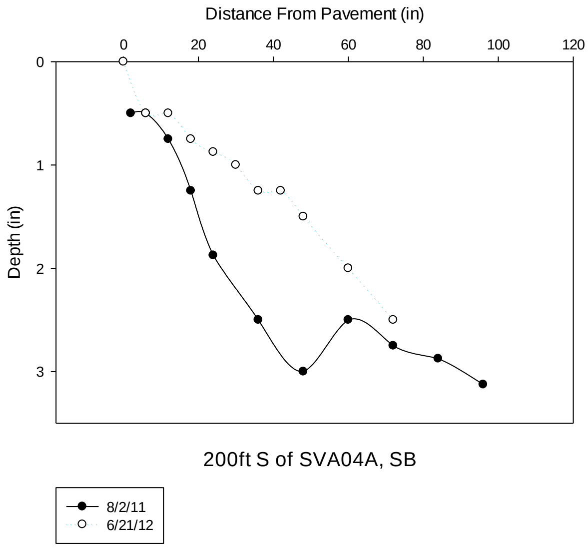



DCP Plots

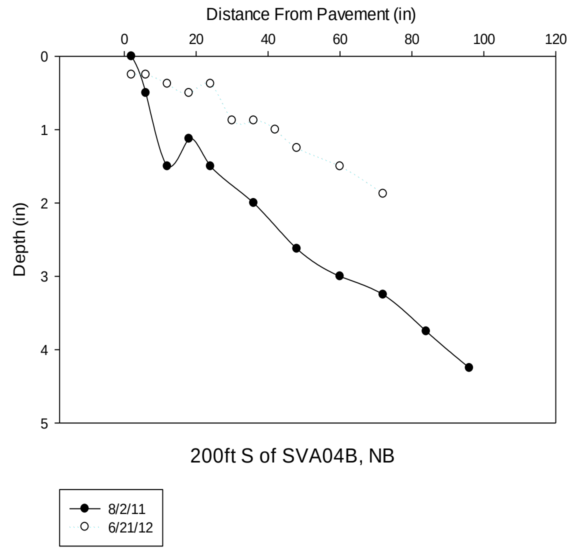


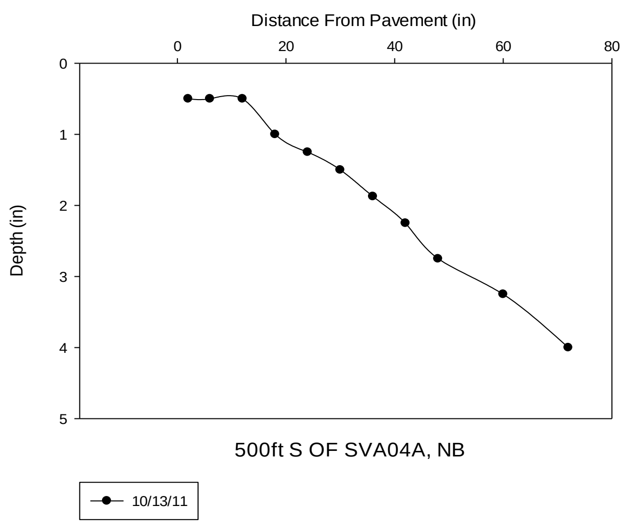
## Elevation Profiles



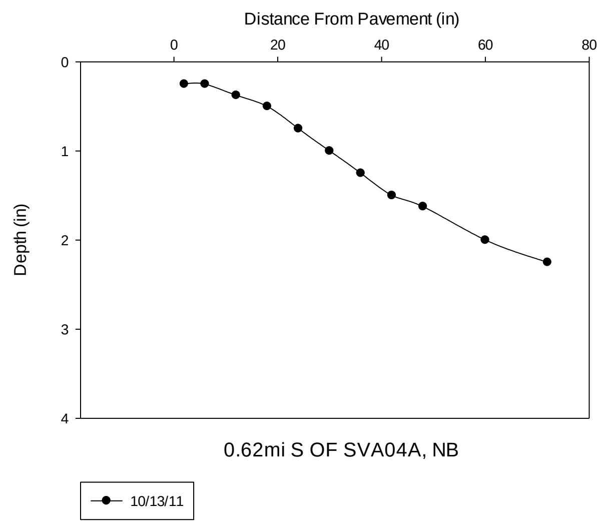

200ft S of SVA04A, SB



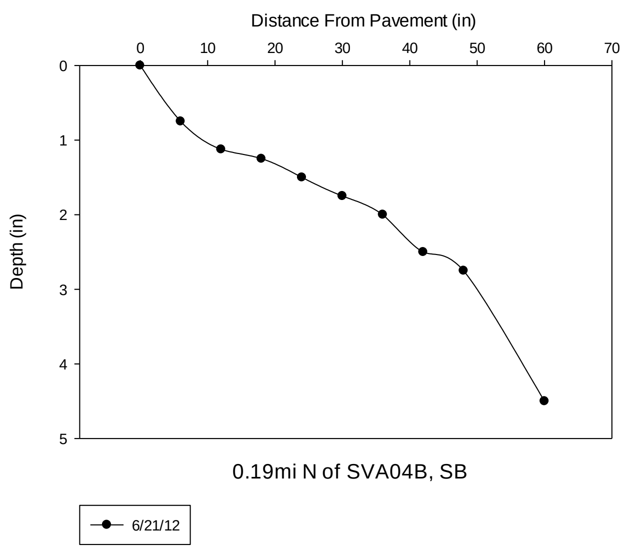

200ft S of SVA04B, NB




500ft S OF SVA04A, NB




0.62mi S OF SVA04A, NB




0.19mi N of SVA04B, SB

CBC Values

**Table 31. Clegg hammer data for section 1.04**

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

**Location 1.05_MP194.8-195.5**

Description: US 169, south of Algona, shoulder on southbound, sprayed 5238ft long and 4ft wide

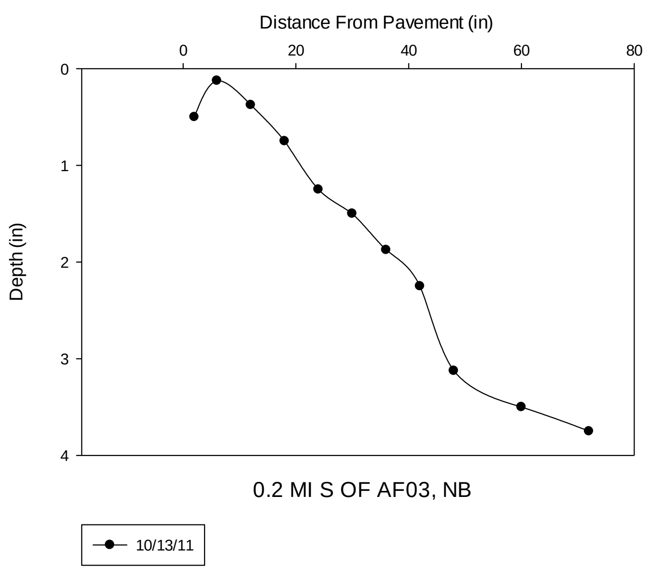
GPS: South end: N 43 01.434, W 94 13.651

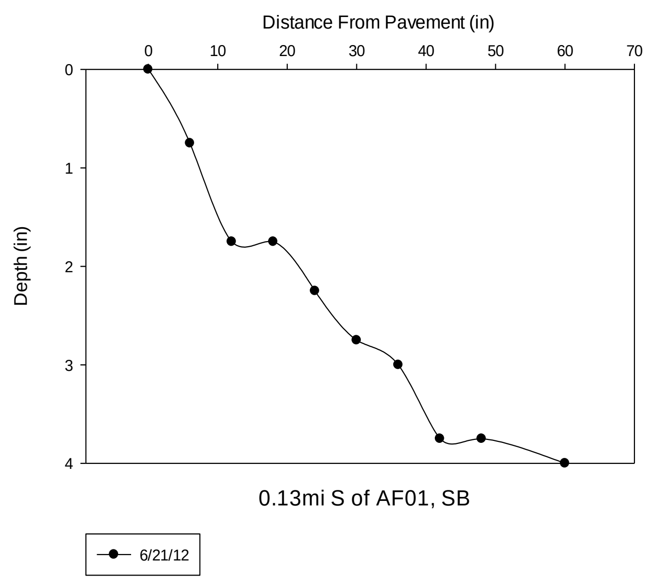
North end: N 43 02.319, W 94 13.650

Gradation Distribution

Same to Location 1.04

Elevation Profiles



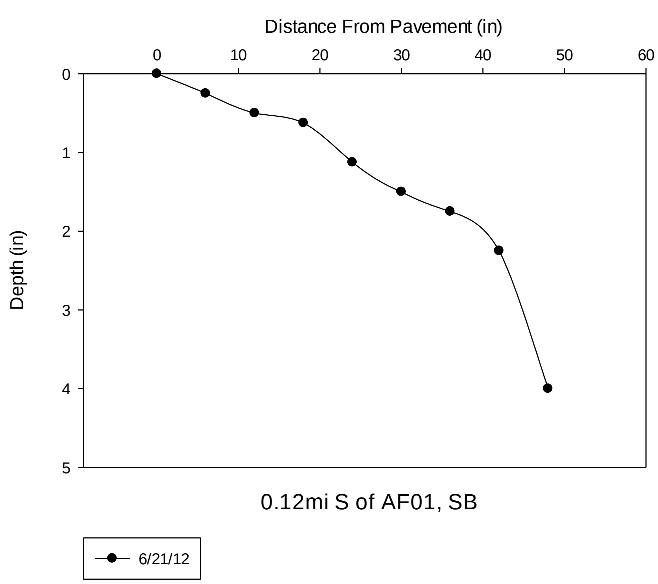



**Table 32. Clegg hammer data for section 1.05**

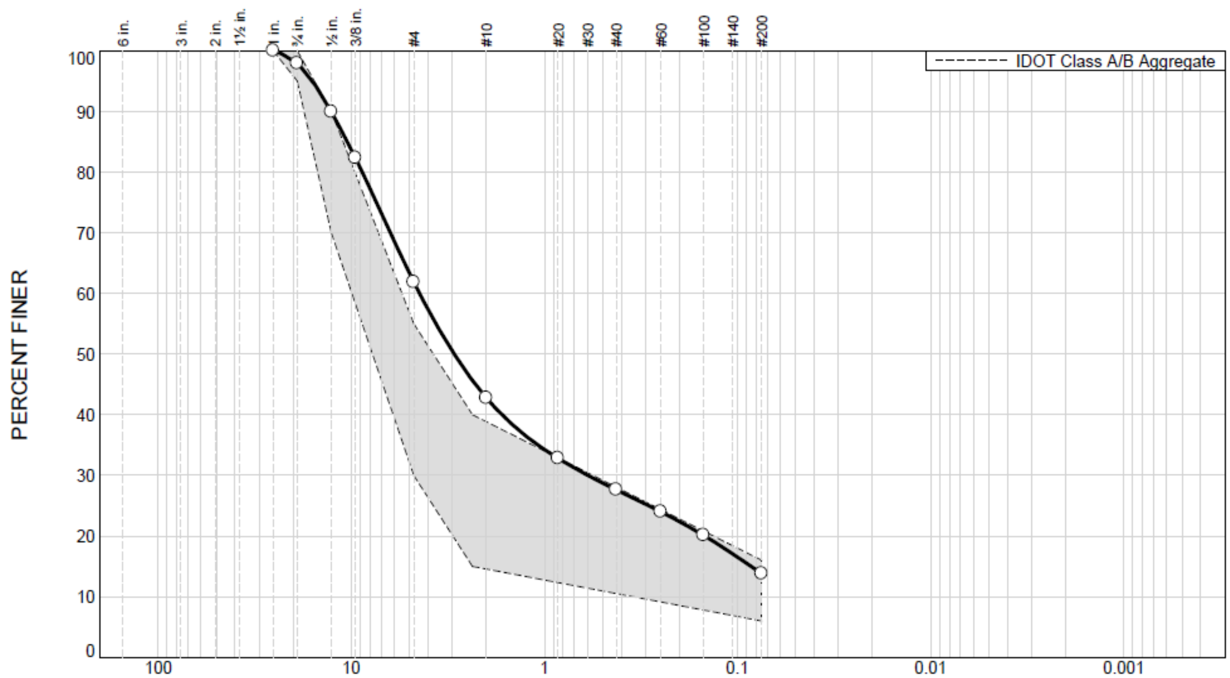
| Date | Location | CIV | CBR | Average CBR |
|---|---|---|---|---|
| | *1.05* | | | SB |
| Jun.2012 | 280ft S of AF01, SB | 36.4 | 94.8 | 54.1 |
| | 0.12mi S of AF01, SB | 21.4 | 37.7 | |
| | 0.23mi N of AF03. SB | 27.8 | 58.9 | |
| | 75ft N of AF03, SB | 16.7 | 25.1 | |

**Location 2.01_MP226.2-226.6**

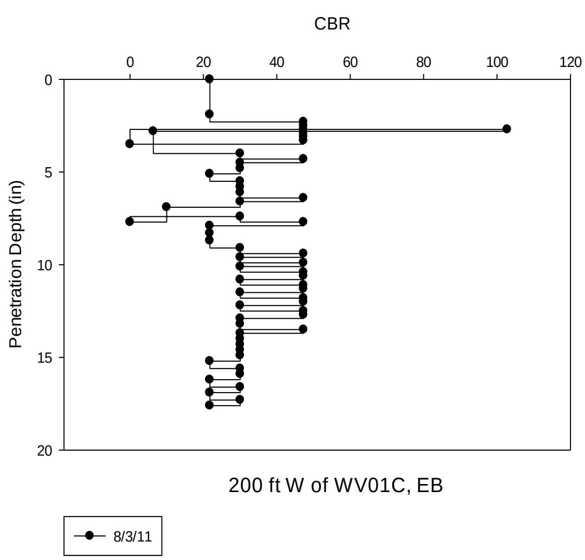
Description: IA 3, east of Waverly, shoulders on both sides, sprayed 1192ft long and 4ft wide on westbound, 1930ft long and 4ft wide on eastbound, applied 2nd coat for 596ft long and 4ft wide on westbound, 965ft long and 4ft wide on eastbound

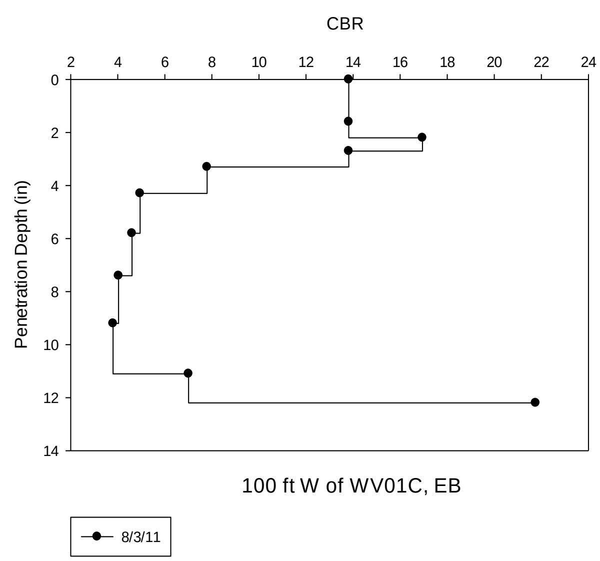
GPS: West end: N 42 42.892, W 92 22.675

East end: N 42 42.892, W 92 22.276

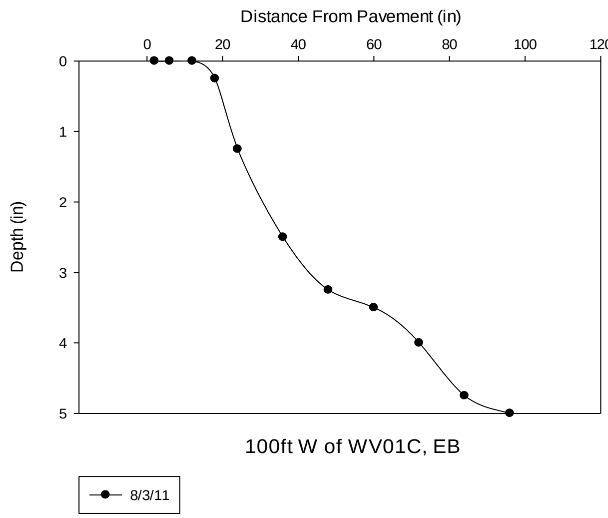


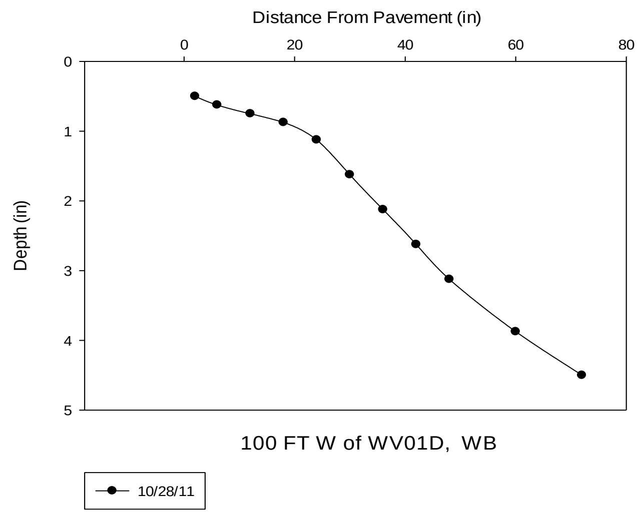

DCP Plots

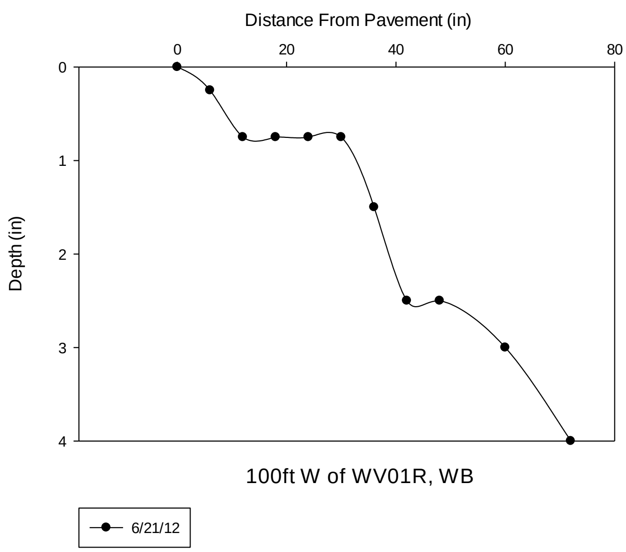


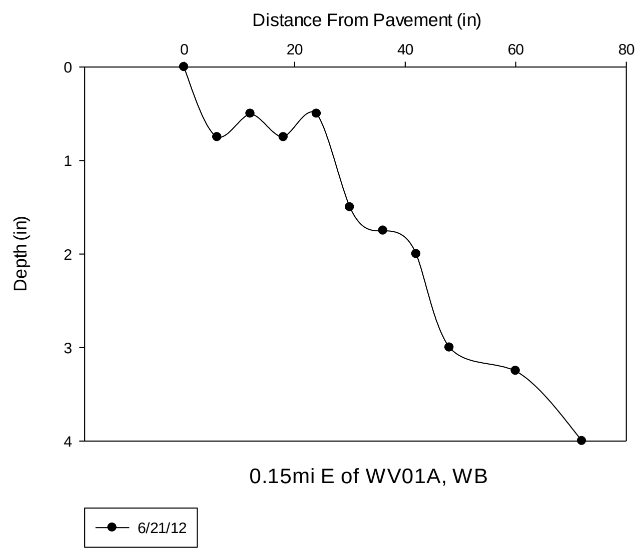



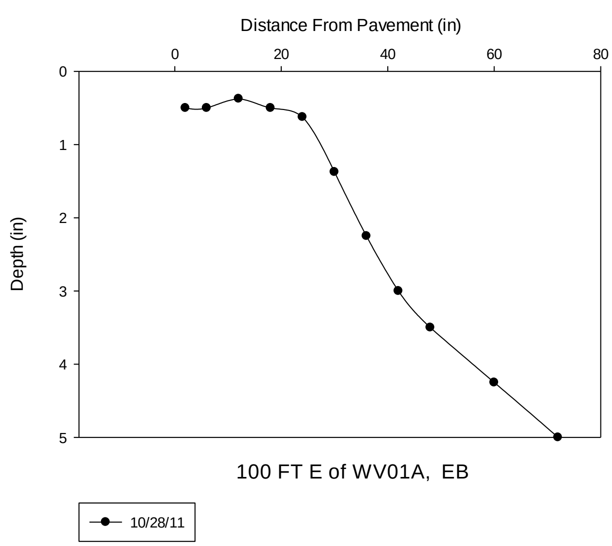
# Elevation Profiles



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 W of WV01C, EB | 20.1 | 33.9 | 26.1 | |
| | 200 ft W of WV01C, EB | 13.6 | 18.2 | | |
| | 100 ft E of WV01A, WB | 22.7 | 41.6 | | 47.2 |
| | 150 ft E of WV01A, WB | 33.7 | 82.6 | | |
| | 250 ft E of WV01A, WB | 13.2 | 17.4 | | |
| | | | | | |
| Jun.2012 | 0.15mi E of WV01A, WB | 18.9 | 30.6 | | 31.6 |
| | 90ft E of WV01R, WB | 20 | 33.6 | | |
| | 100ft W of WV01R, WB | 23.7 | 44.7 | | |
| | 225ft E of WV01A, WB | 13.2 | 17.4 | | |
| | 230 ft W of WV01C, EB | 20.2 | 34.2 | 30.1 | |
| | 75ft E of WV01C, EB | 17.1 | 26.1 | | |

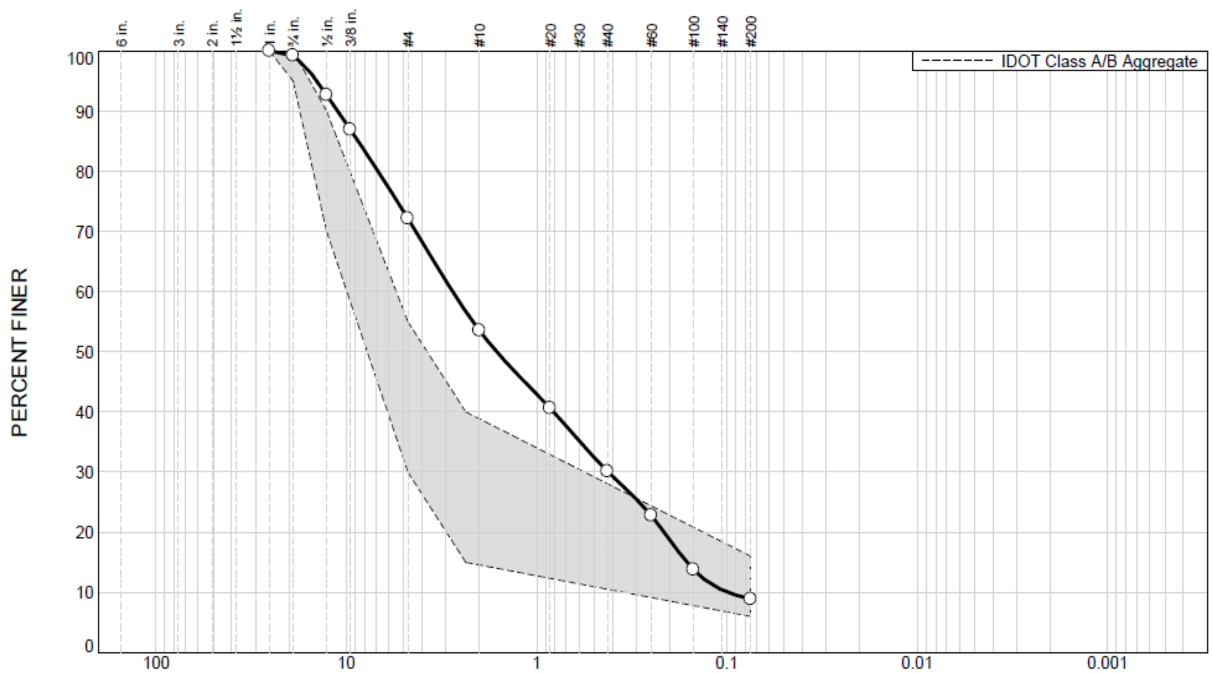
**Location 2.02_MP174.6-177**

Description: US 63, 4-lane divided highway, Denver, outside and inside shoulders on both sides, each shoulder is 11080ft long, sprayed at whole length and 4ft wide except for driveways or bridges, outside shoulders applied 2nd coat for 1584ft long and 4ft wide on southbound, 3168ft long and 4ft wide on northbound

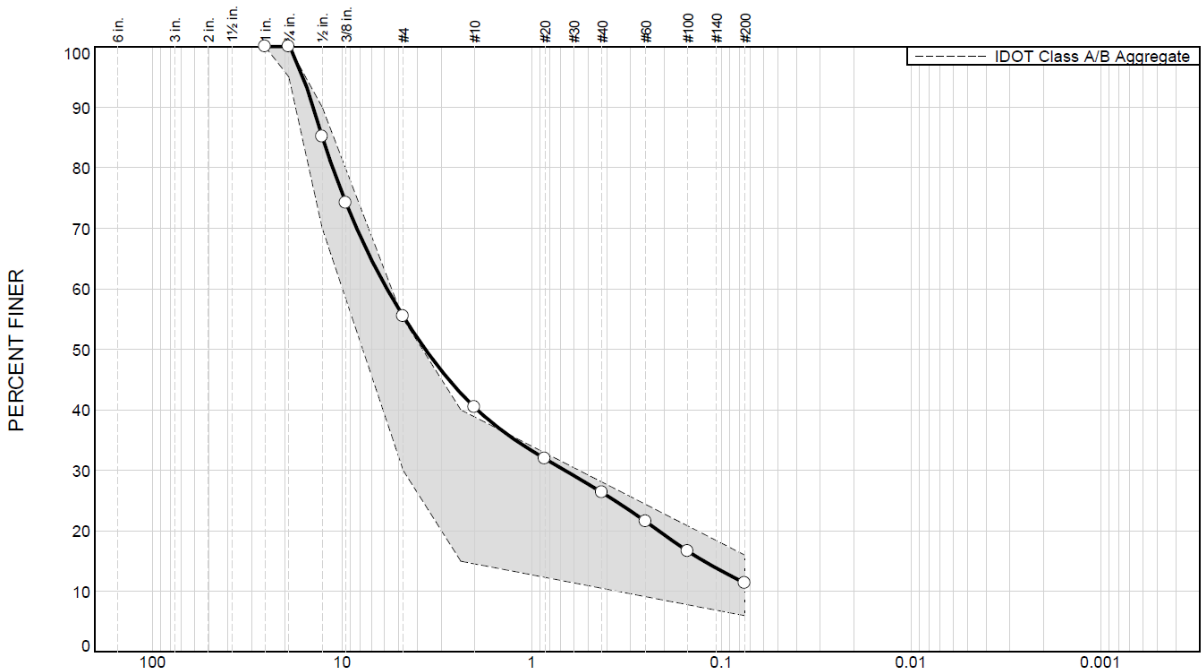
GPS: South end: N 42 39.311, W 92 20.251

North end: N 42 41.146, W 92 20.267

Gradation Distribution

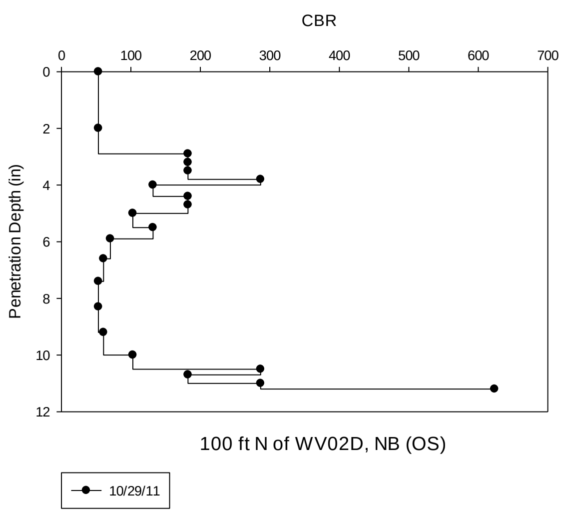



Outside shoulders on northbound and southbound

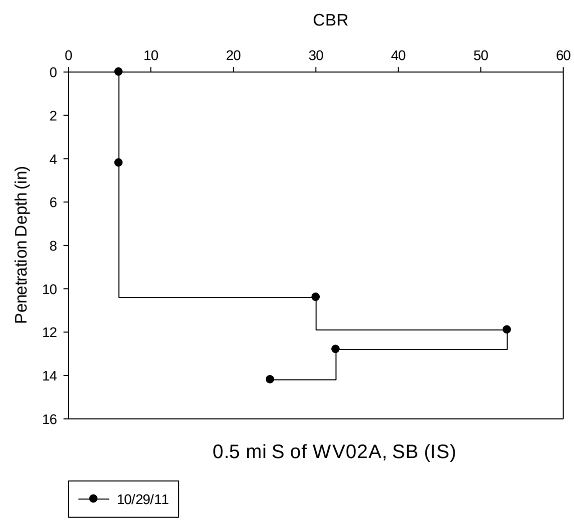



Inside shoulders on northbound and southbound

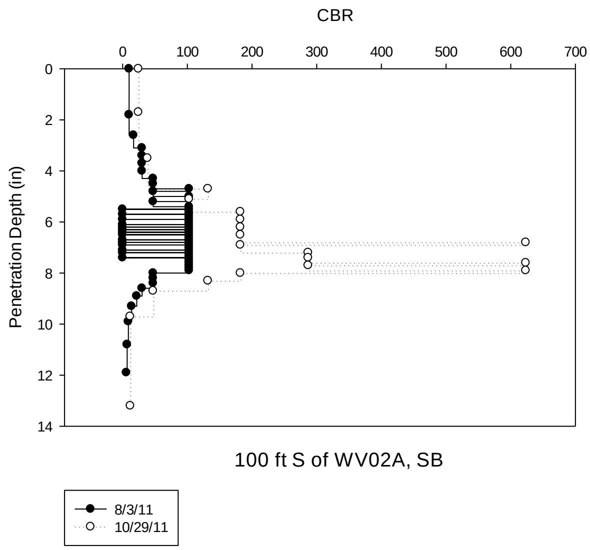
## DCP Plots



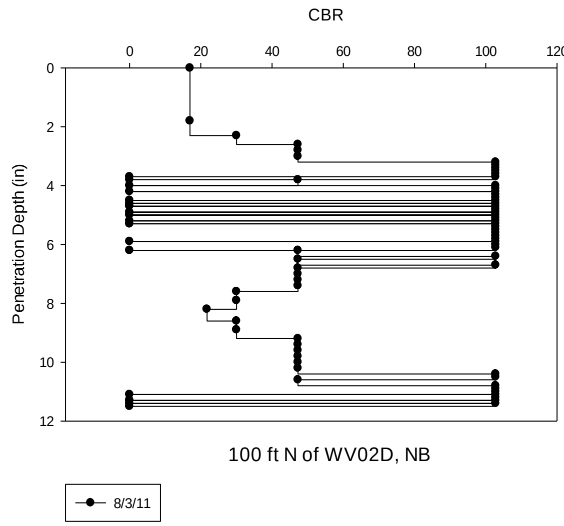

100 ft N of WV02D, NB (OS)




0.5 mi S of WV02A, SB (IS)

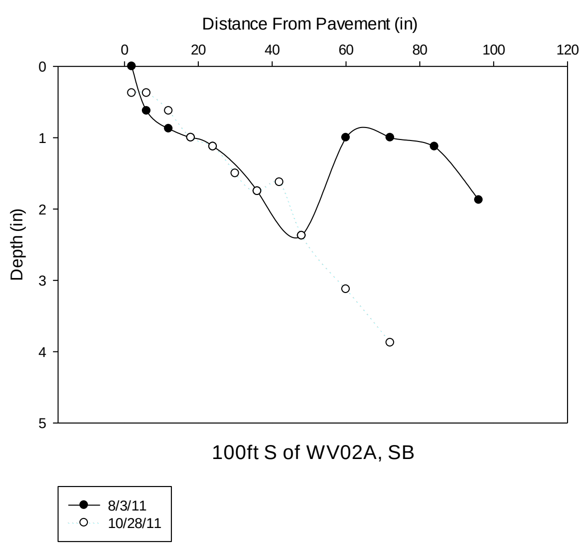


100 ft S of WV02A, SB

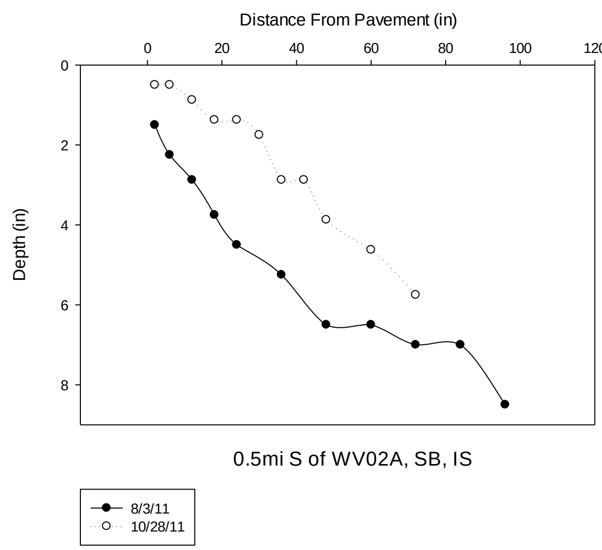


100 ft N of WV02D, NB

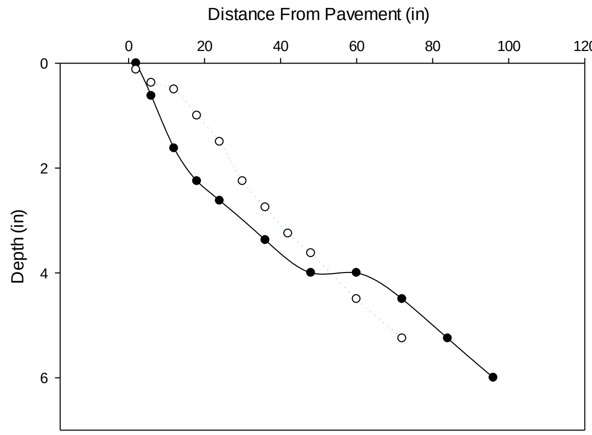
# Elevation Profiles



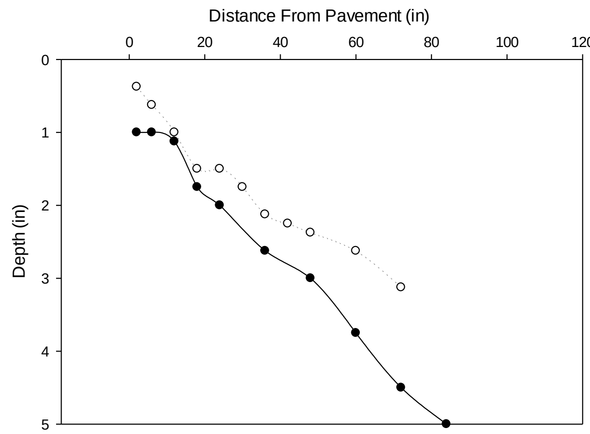
100ft S of WV02A, SB



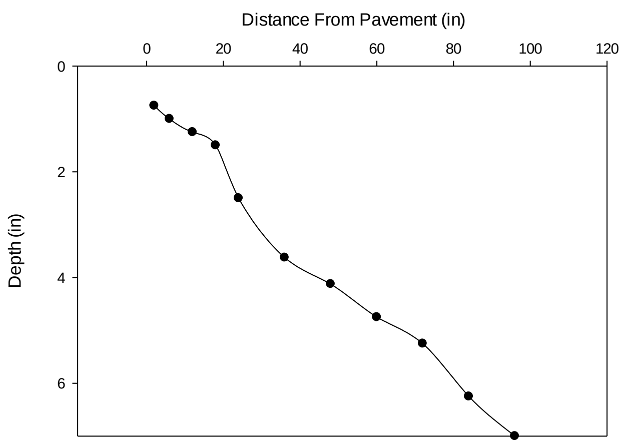
0.5mi S of WV02A, SB, IS



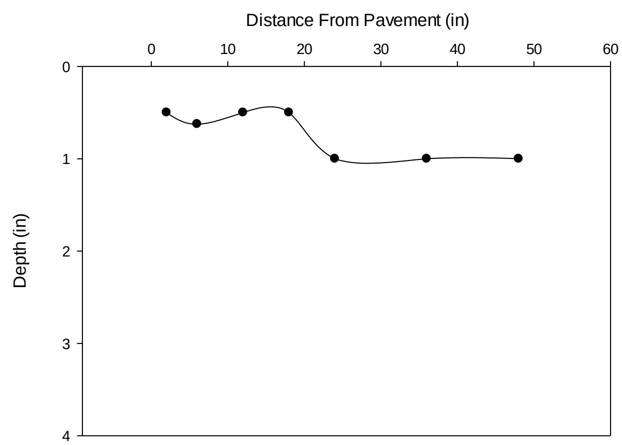

0.5mi S of WV02A, SB



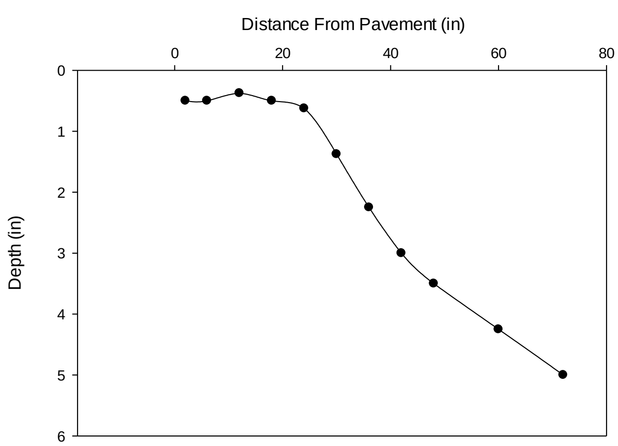

100ft S of WV02A, SB



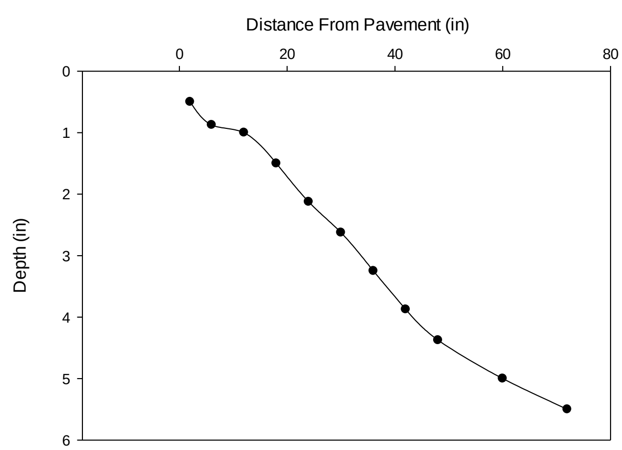

0.85mi N of WV02D, NB



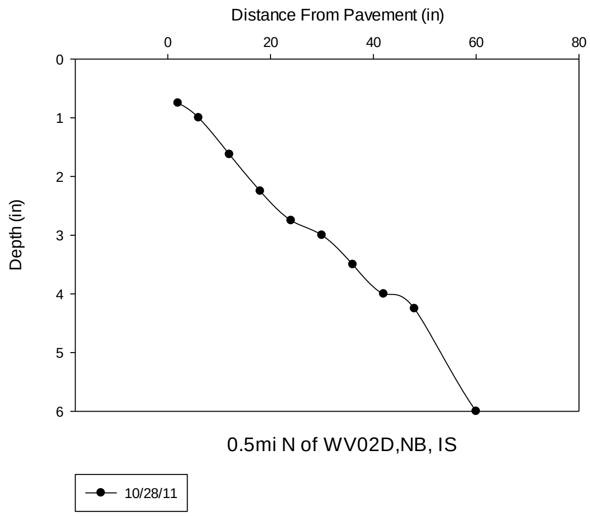

200ft S of WV02B, NB

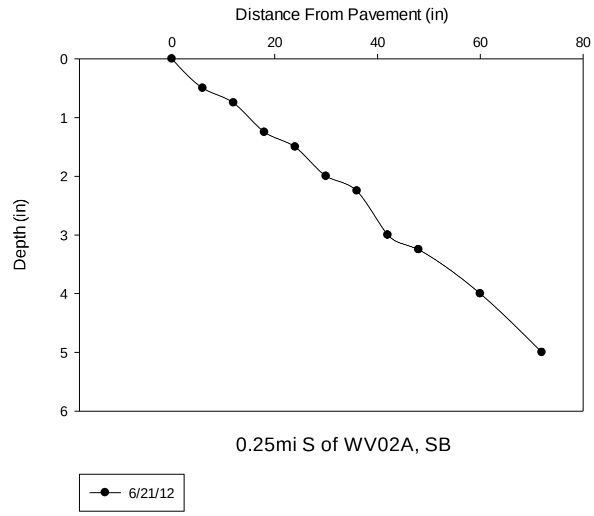


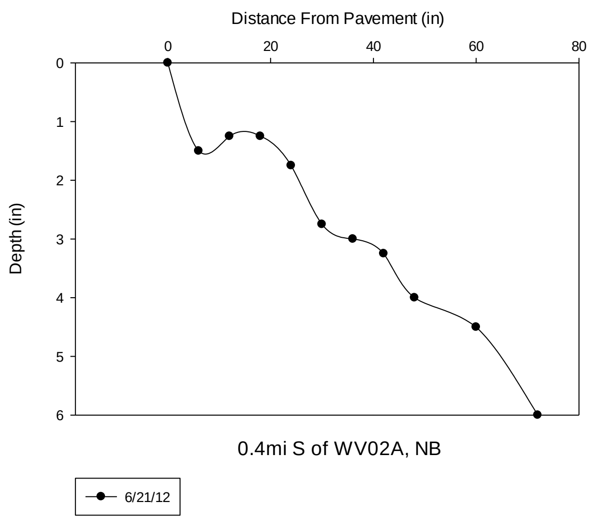

200ft S of WV02B, NB, IS




0.5mi N of WV02D, NB


Distance From Pavement (in)
0
20
40
60
80
Depth (in)
0
1
2
3
4
5
6
0.5mi N of WV02D,NB, IS
10/28/11


Distance From Pavement (in)
0
20
40
60
80
Depth (in)
0
1
2
3
4
5
6
0.25mi S of WV02A, SB
6/21/12


Distance From Pavement (in)
0
20
40
60
80
Depth (in)
0
1
2
3
4
5
6
0.4mi S of WV02A, NB
6/21/12

CBR Values

**Table 34. Clegg hammer data for section 2.02**

<table>
<tr><th>Date</th><th>Location</th><th>CIV</th><th>CBR</th><th colspan="4">Average CBR</th></tr>
<tr><td></td><td>2.02</td><td></td><td></td><td>SB (OS)</td><td>SB (IS)</td><td>NB (OS)</td><td>NB (IS)</td></tr>
<tr><td rowspan="9">Aug.2011</td><td>100 ft S of WV02A, SB, OS</td><td>14.9</td><td>20.9</td><td>20.7</td><td></td><td></td><td></td></tr>
<tr><td>0.5 mi S of WV02A, SB, OS</td><td>13.6</td><td>18.2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>300 ft N of WV02C, SB, OS</td><td>15.8</td><td>23.0</td><td></td><td></td><td></td><td></td></tr>
<tr><td>0.5 mi S of WV02A,SB, IS</td><td>5.4</td><td>5.3</td><td></td><td>9.1</td><td></td><td></td></tr>
<tr><td>0.5 mi + 50 ft S of WV02A, SB, IS</td><td>10.8</td><td>12.9</td><td></td><td></td><td></td><td></td></tr>
<tr><td>100 ft N of WV02D, NB, OS</td><td>15.2</td><td>21.6</td><td></td><td></td><td>16.9</td><td></td></tr>
<tr><td>0.85 mi N of WV02D,NB, OS</td><td>12.2</td><td>15.4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>200 ft S of WV02B, NB, OS</td><td>11.3</td><td>13.8</td><td></td><td></td><td></td><td></td></tr>
<tr><td>200 ft S of WV02B, NB, IS</td><td>9.8</td><td>11.2</td><td></td><td></td><td></td><td>11.2</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="9">Jun.2012</td><td>100 ft S of WV02A, SB, OS</td><td>19</td><td>30.9</td><td rowspan="4">29.6</td><td></td><td></td><td></td></tr>
<tr><td>0.25 mi S of WV02A, SB, OS</td><td>16.1</td><td>23.7</td><td></td><td></td><td></td></tr>
<tr><td>0.5 mi S of WV02A,SB, OS</td><td>18.9</td><td>30.6</td><td></td><td></td><td></td></tr>
<tr><td>WV02C, SB, OS</td><td>19.9</td><td>33.4</td><td></td><td></td><td></td></tr>
<tr><td>0.25 mi S of WV02A, SB, IS</td><td>13.2</td><td>17.4</td><td></td><td rowspan="2">12.9</td><td></td><td></td></tr>
<tr><td>0.5 mi S of WV02A, SB, IS</td><td>7.9</td><td>8.4</td><td></td><td></td><td></td></tr>
<tr><td>0.4 mi S of WV02B,NB, OS</td><td>12.7</td><td>16.4</td><td></td><td></td><td rowspan="2">21.3</td><td></td></tr>
<tr><td>WV02B, NB, OS</td><td>17.2</td><td>26.3</td><td></td><td></td><td></td></tr>
<tr><td>0.4mi S of WV02B, NB, IS</td><td>7.7</td><td>8.1</td><td></td><td></td><td></td><td>8.1</td></tr>
</table>

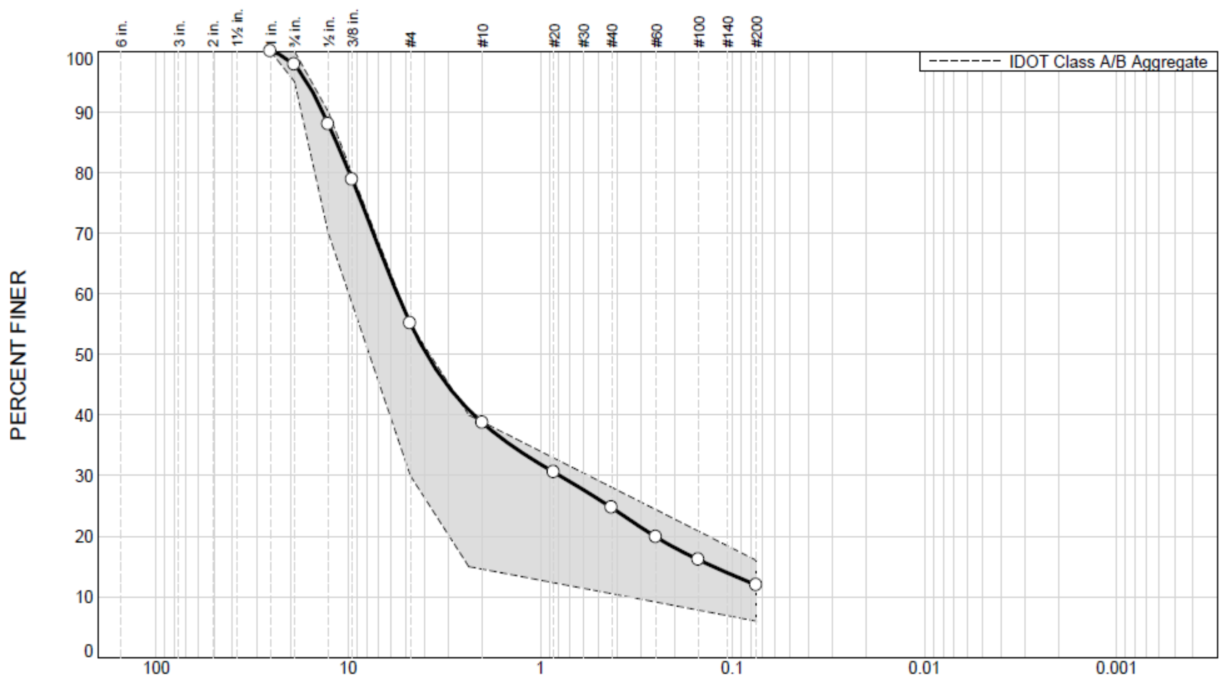
**Location 2.03_MP220**

Description: IA 3, Waverly, shoulder on westbound, sprayed 1491ft long and 4ft wide

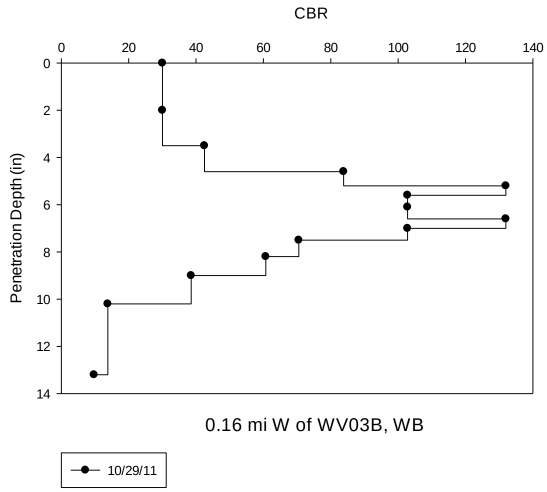
GPS: West end: N 42 43.155, W 92 29.796

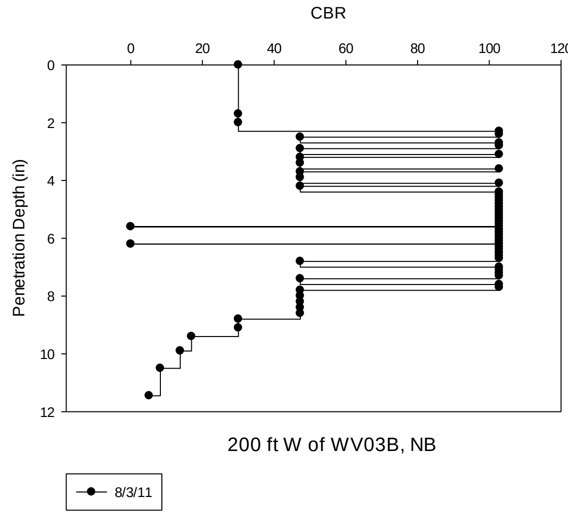
East end: N 42 43.382, W 92 29.715

Gradation Distribution

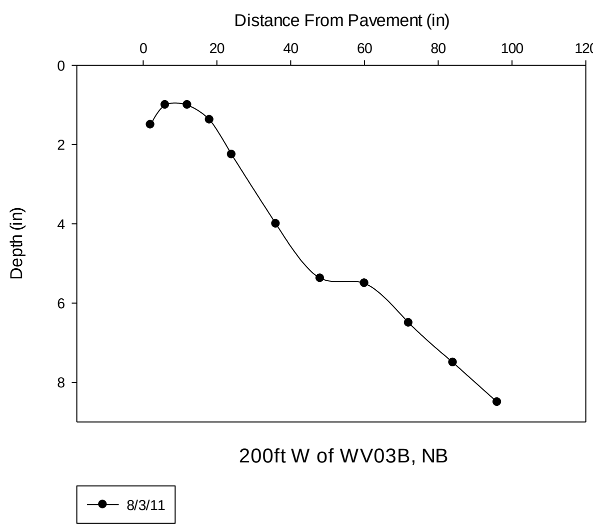


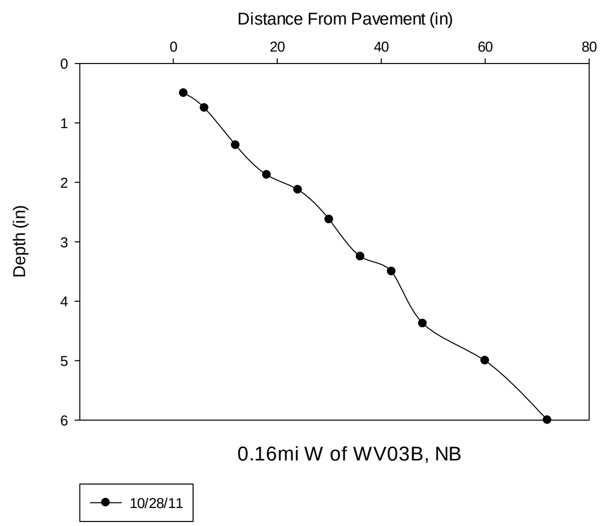
## DCP Plots

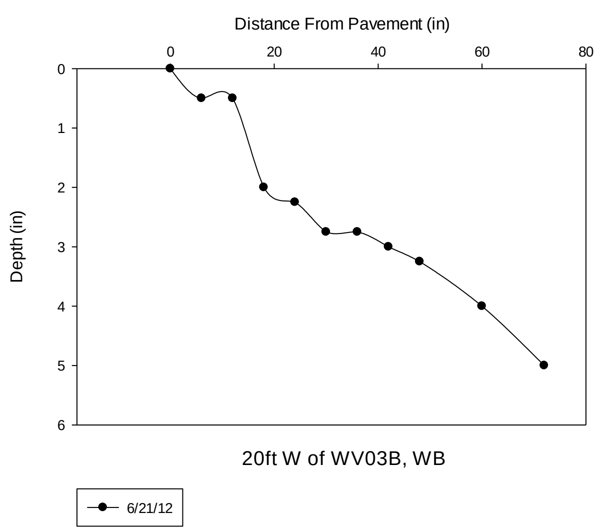


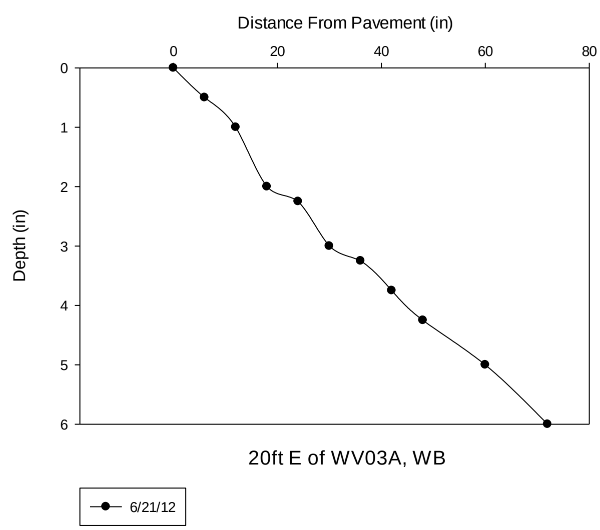




## Elevation Profiles



CBR Values

**Table 35. Clegg hammer data for section 2.03**

| Date | Location | CIV | CBR | Average CBR |
|---|---|---|---|---|
| | *2.03* | | | WB |
| Aug.2011 | 200 ft W of WV03B, WB | 16.5 | 24.6 | 24.6 |
| | | | | |
| Jun.2012 | 20 ft W of WV03B, WB | 25.3 | 50.0 | 43.2 |
| | 200ft W of WV03B, WB | 26 | 52.4 | |
| | 20ft E of WV03A, WB | 17.5 | 27.0 | |

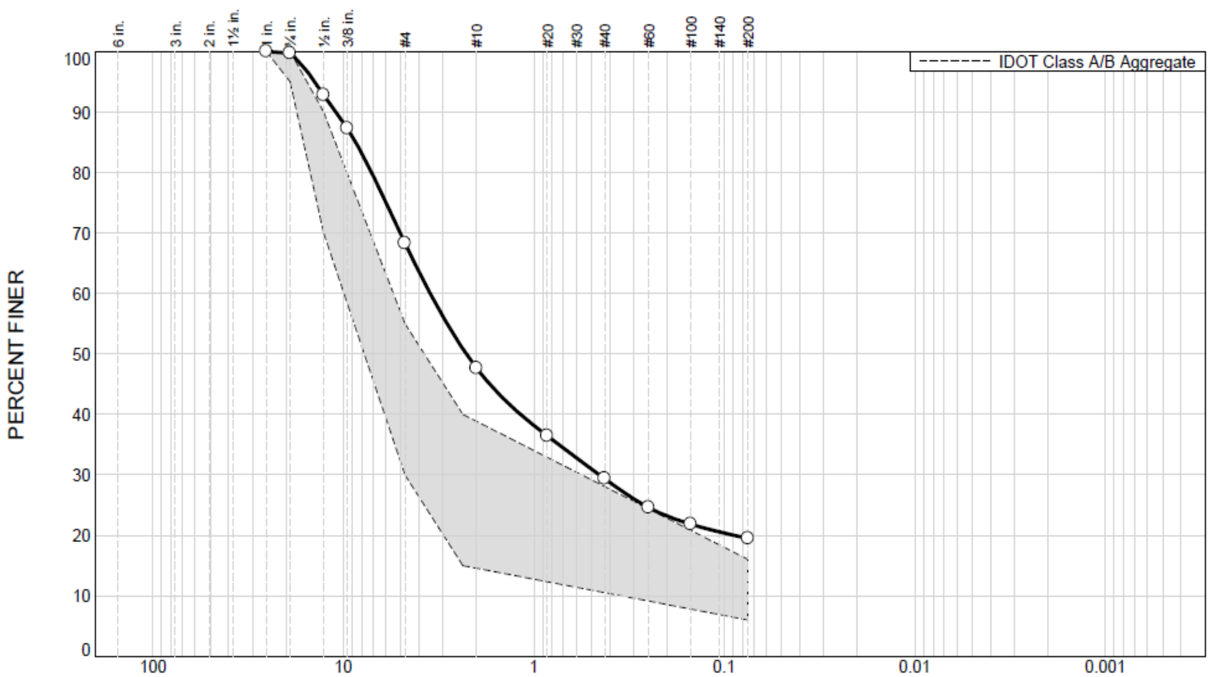
**Location 2.04_MP215-216**

Description: IA 3, Shell Rock, shoulders on both sides, sprayed 11170ft long and 4ft wide

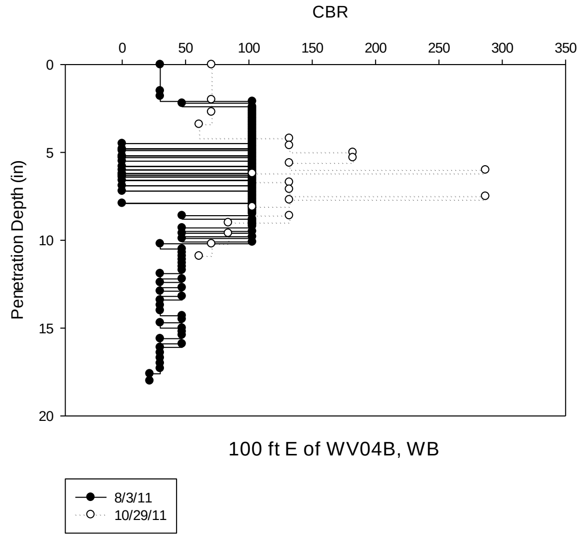
GPS: West end: N 42 43.252, W 92 35.022

East end: N 42 42.889, W 92 33.952

Gradation Distribution

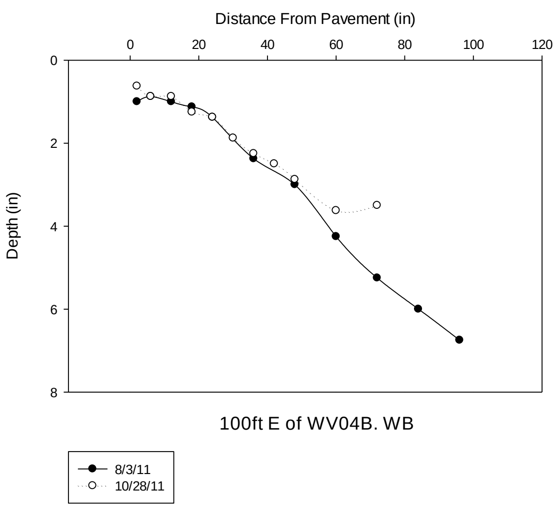


## DCP Plots

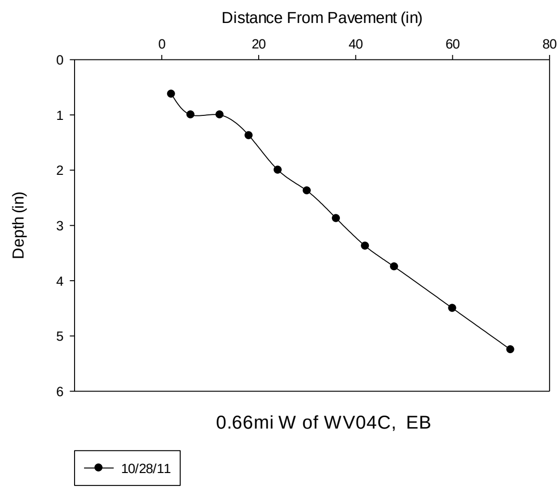



100 ft E of WV04B, WB

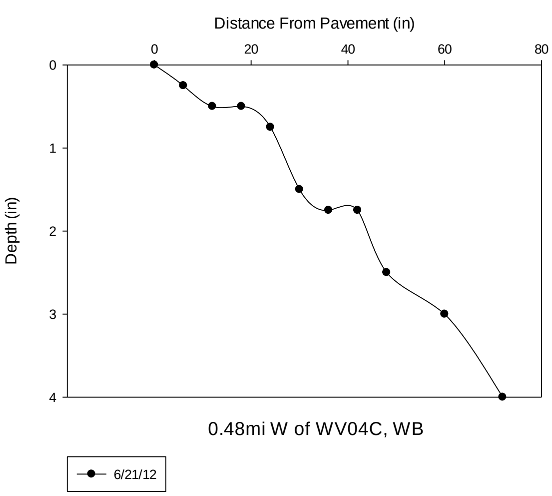
## Elevation Profiles



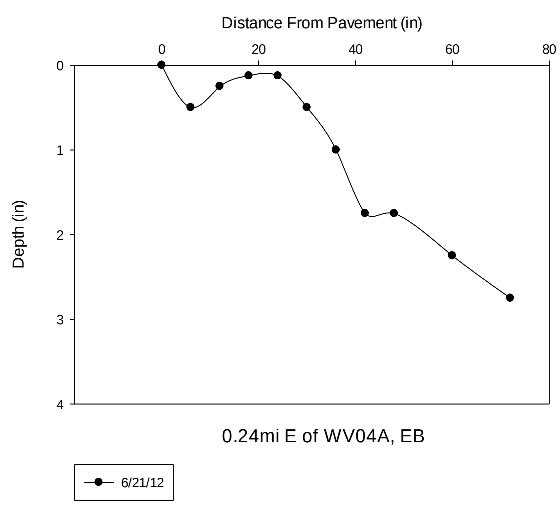

100ft E of WV04B. WB




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 W of WV04C, EB | 18.8 | 30.4 | 38.9 | |
| | 200 ft W of WV04C, EB | 18.5 | 29.6 | | |
| | Near middle, EB | 27.2 | 56.7 | | |
| | 100 ft E of WV04B, WB | 34 | 83.9 | | 58.2 |
| | Near middle, WB | 19.6 | 32.5 | | |
| | | | | | |
| Jun.2012 | 60 ft E of WV04A, EB | 28.6 | 61.8 | 60.4 | |
| | 0.24mi E of WV04A, EB | 27.6 | 58.1 | | |
| | 0.39mi W of WV04C, EB | 27.4 | 57.4 | | |
| | 70ft W of WV04C, EB | 29.2 | 64.1 | | |
| | 0.48mi W of WV04C, WB | 37.6 | 100.5 | | 80.0 |
| | 100ft E of WV04A, WB | 28 | 59.6 | | |

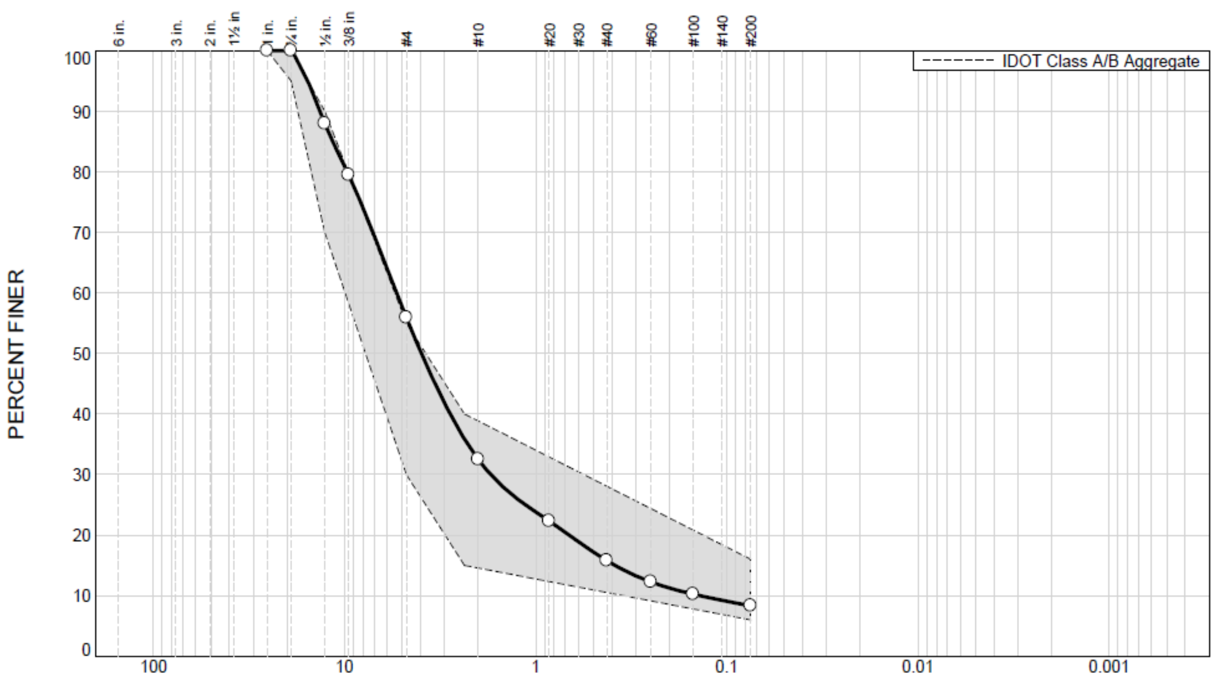
**Location 2.05_MP205.1-305.7**

Description: IA 3, east of Allison, shoulder on both sides, sprayed 8280ft long and 4ft wide

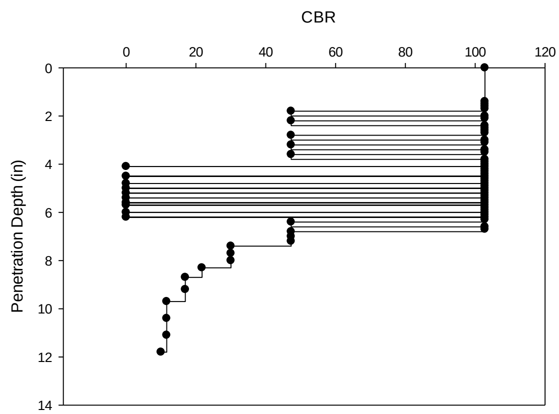
GPS: West end: N 42 44.685, W 92 47.184

East end: N 42 44.674, W 92 46.308

Gradation Distribution

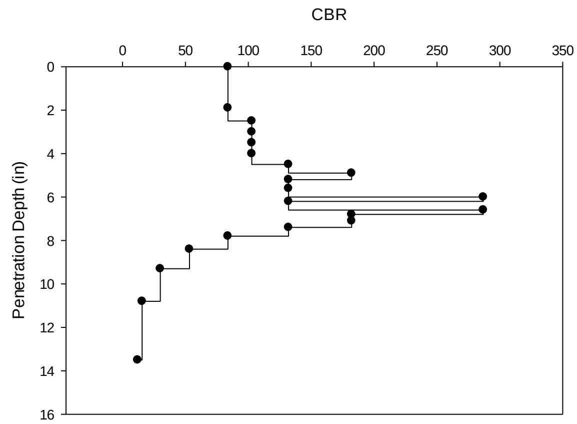


## DCP Plots




50 ft W of WV05C, EB

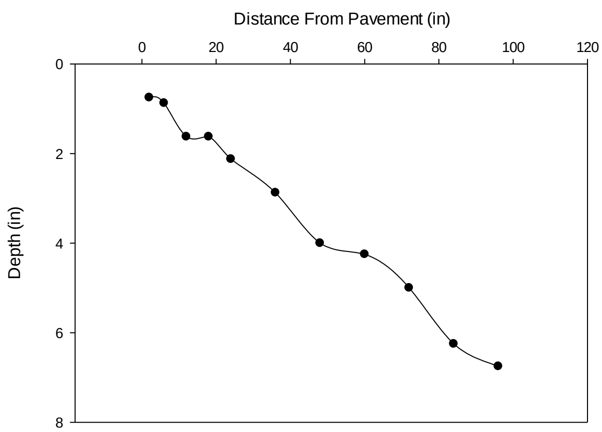
8/3/11




440 ft E of WV05A, EB

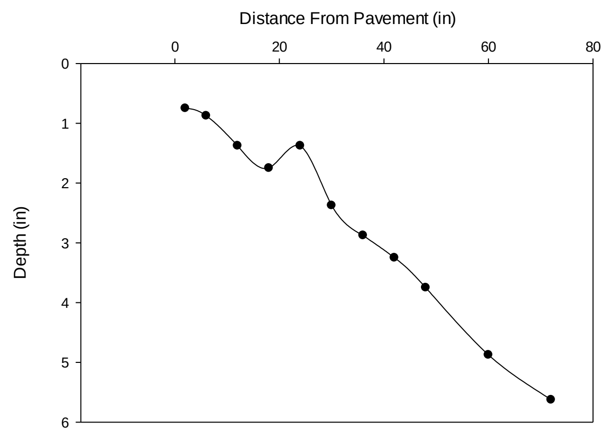
10/29/11

## Elevation Profiles



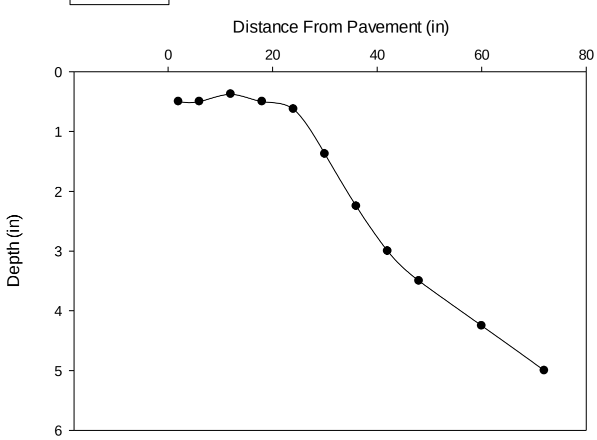

50ft W of WV05C, EB

8/3/11



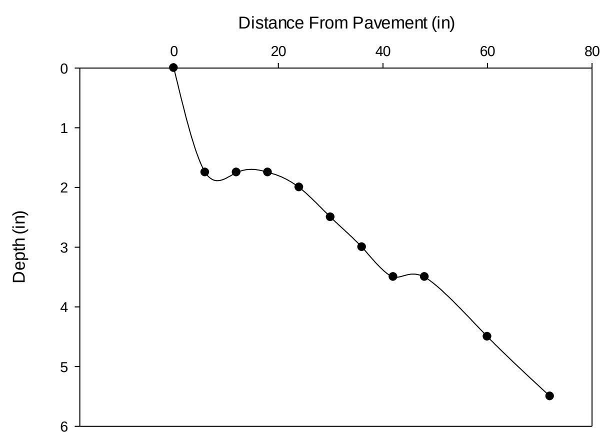

440 FT East of WV05A, EB

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 W of WV05C, EB | 23.1 | 42.8 | 42.8 | |
| | | | | | |
| Jun.2012 | 455 ft E of WV05A, EB | 32.2 | 76.2 | 72.6 | |
| | 0.24mi E of WV05A, EB | 35.4 | 90.2 | | |
| | 0.4 mi W of WV05C, EB | 31.4 | 72.9 | | |
| | 40ft W of WV05C, EB | 25.7 | 51.4 | | |
| | 0.45mi W of WV05C, WB | 31.9 | 74.9 | | 74.5 |
| | WV05A, WB | 31.7 | 74.1 | | |

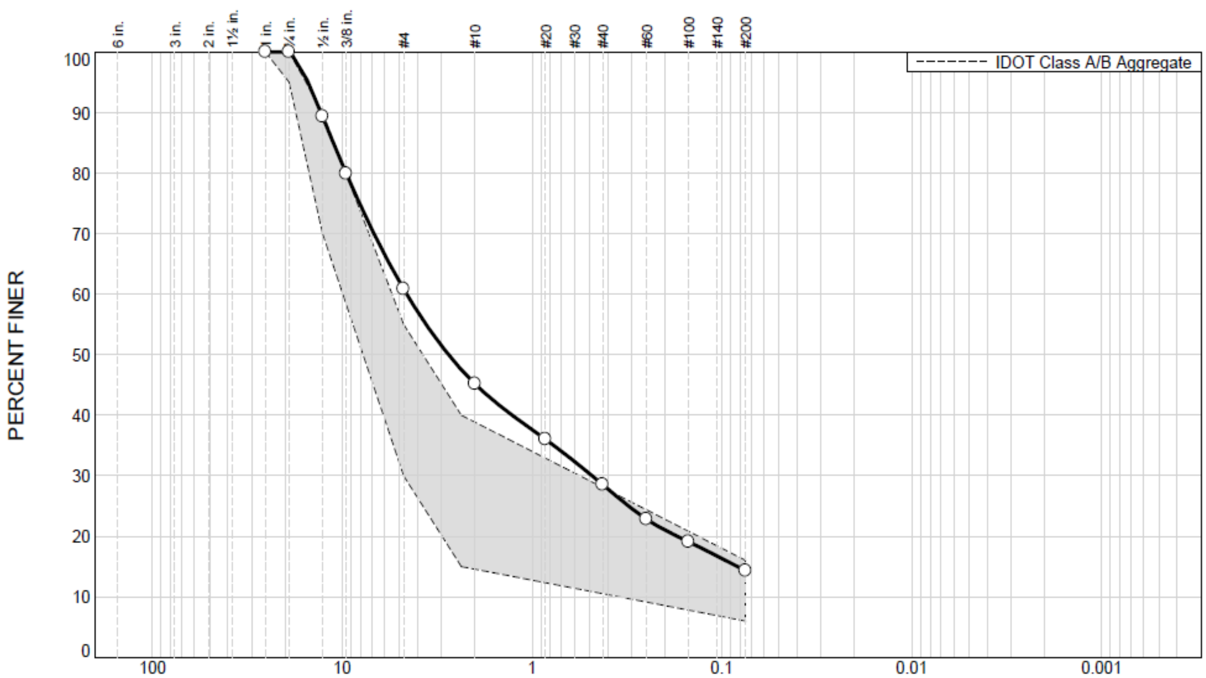
**Location 3.01_MP264.5-265**

Description: US 18, east of West Union, shoulder on both sides, sprayed 3048ft long and 4ft wide

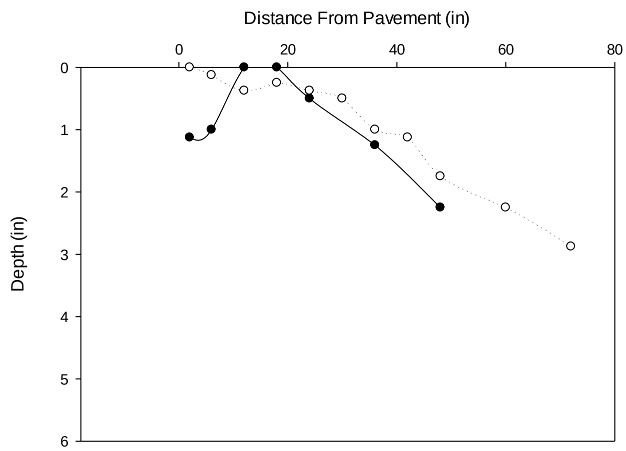
GPS: West end: N 42 57.840, W 91 47.823

East end: N 42 57.996, W 91 47.450

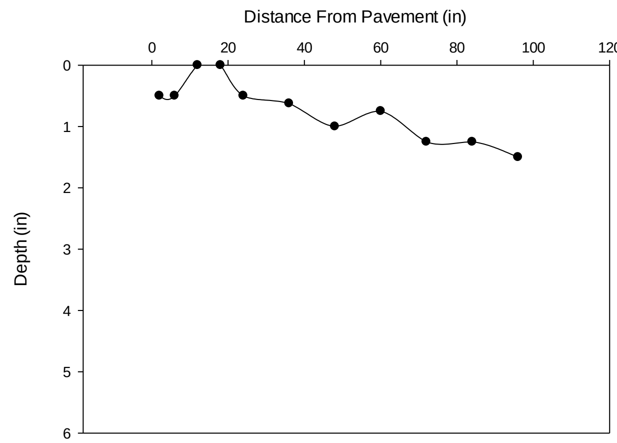
Gradation Distribution



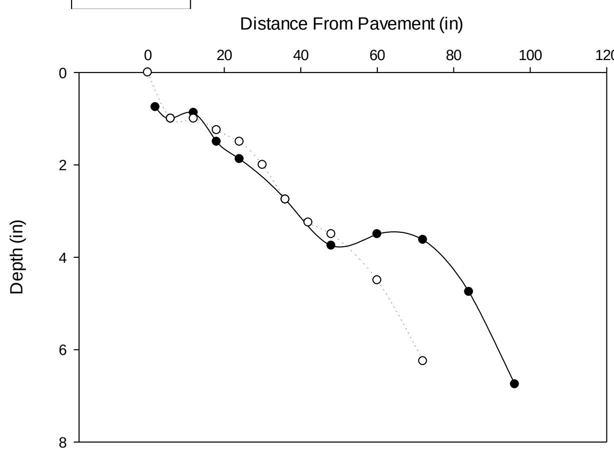
## Elevation Profiles



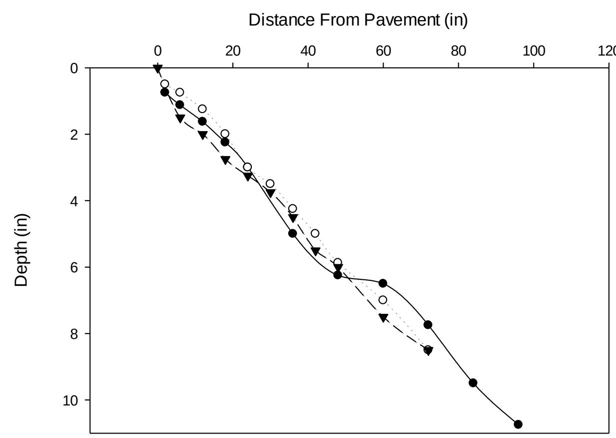

UN01A, EB



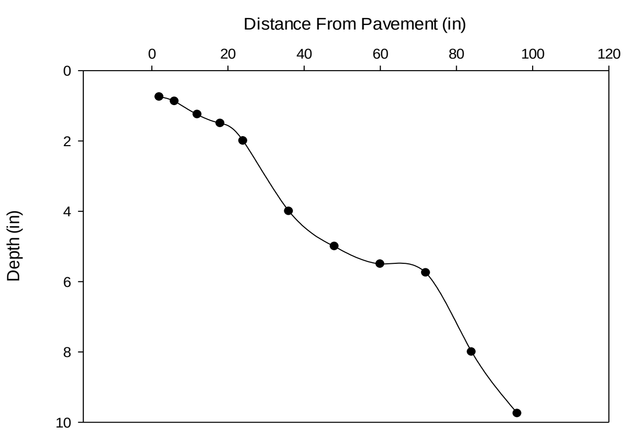

300 FT E of UN01A, EB



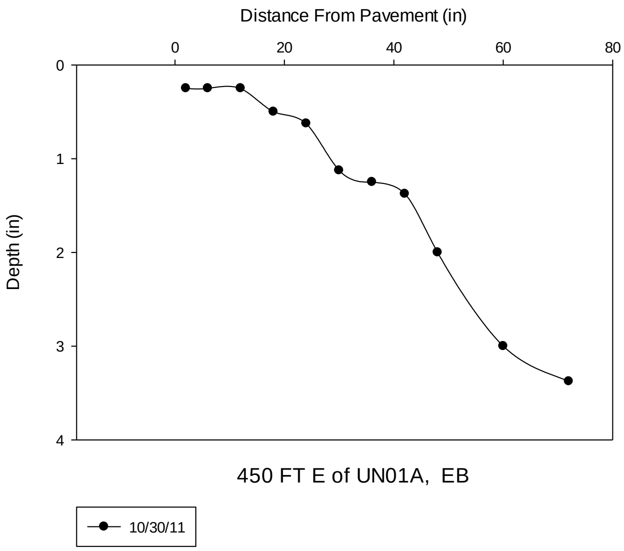

215 FT W of UN01B, EB

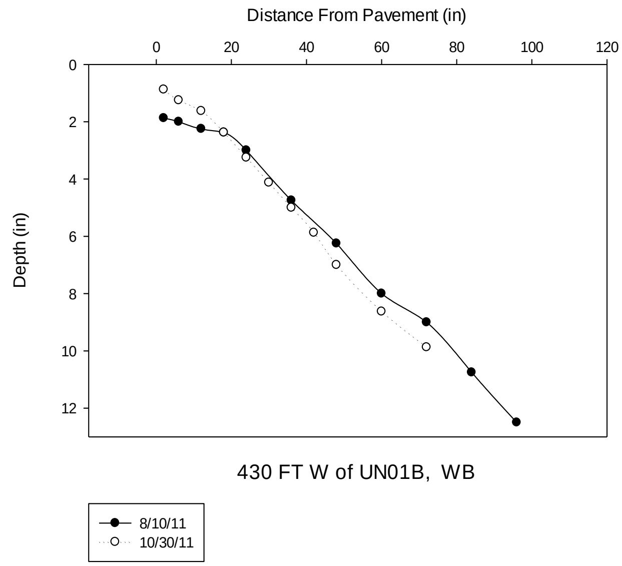



215 FT W of UN01B, WB




0.19mi W of UN01B, WB




CBR Values

## Table 38. Clegg hammer data for section 3.01

| | Location | CIV | CBR | Average CBR | |
|---|---|---|---|---|---|
| | *3.01* | | | EB | WB |
| Aug.2011 | Right at UN01A, EB | 27.3 | 57.0 | 57.6 | |
| | 300 ft E of UN01A, EB | 31.1 | 71.6 | | |
| | 490 ft E of UN01A, EB | 20.8 | 35.9 | | |
| | 215 ft W of UN01B, EB | 29.6 | 65.7 | | |
| | 215 ft W of UN01B, WB | 26.5 | 54.2 | | 44.0 |
| | 0.19 mi W of UN01B, WB | 20.1 | 33.9 | | |
| | | | | | |
| Jun.2012 | UN01A, EB | 16.6 | 24.8 | 41.5 | |
| | 215 ft W of UN01B, EB | 27.6 | 58.1 | | |
| | 215 ft W of UN01B, WB | 30 | 67.2 | | 64.9 |
| | 430 ft W of UN01B, WB | 28.8 | 62.6 | | |

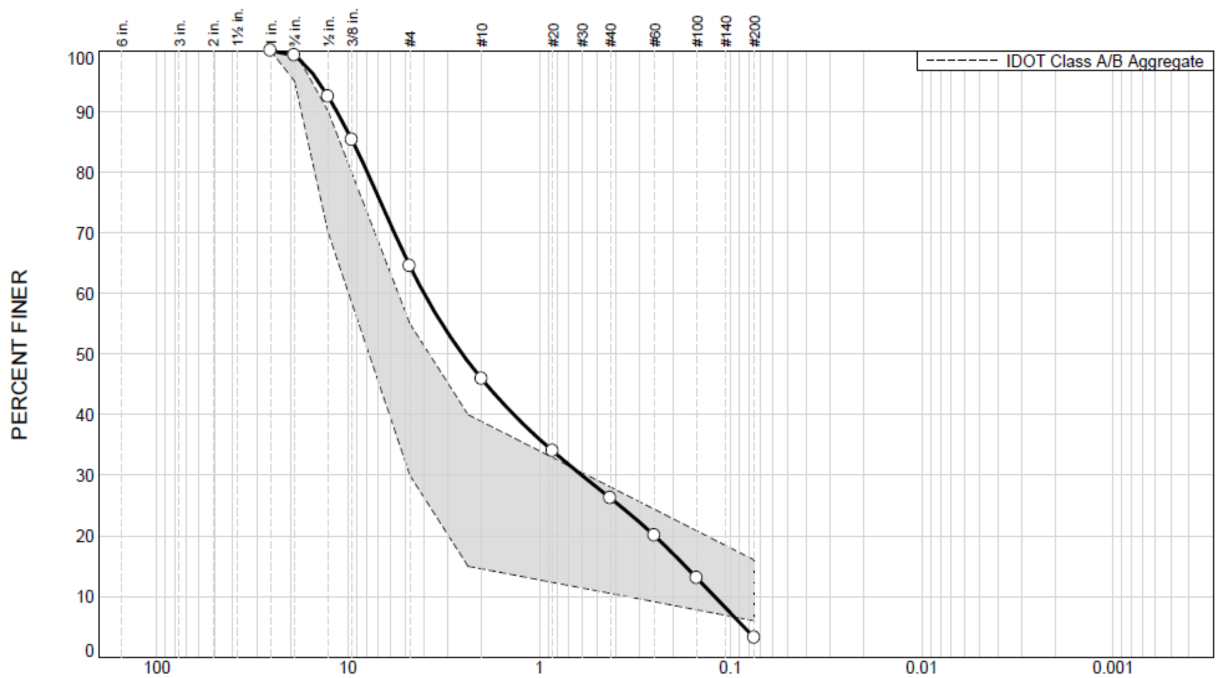
**Location 3.02_MP269.8-271**

Description: US 18, west of Clermont, shoulder on both sides, sprayed 8900ft long and 4ft wide

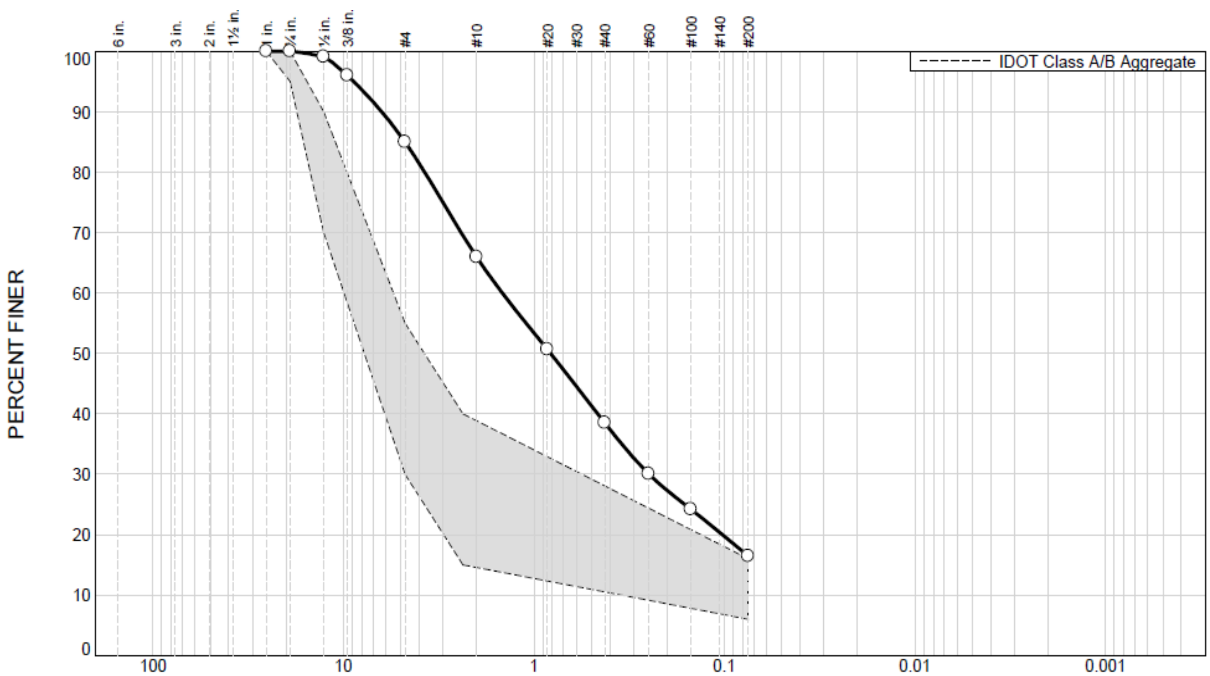
GPS: West end: N 42 59.086, W 91 42.442

East end: N 42 59.354, W 91 41.483

Gradation Distribution

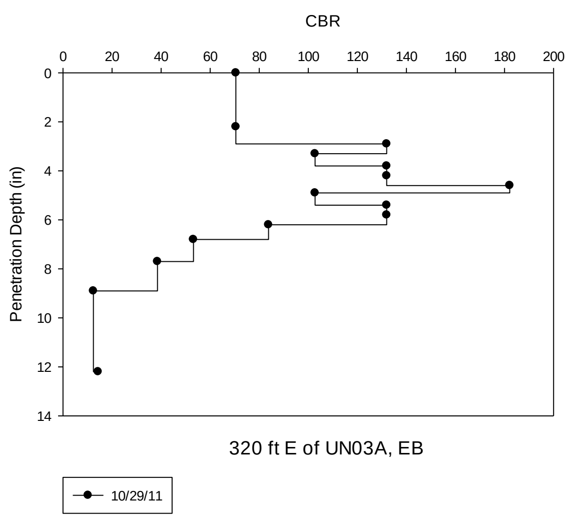



Shoulder on eastbound



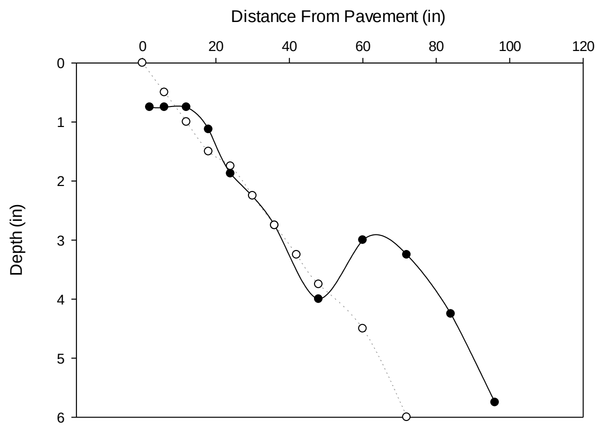

Shoulder on westbound

DCP Plots

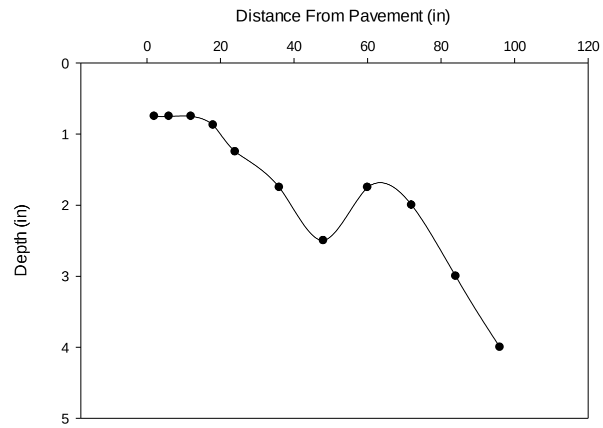



320 ft E of UN03A, EB

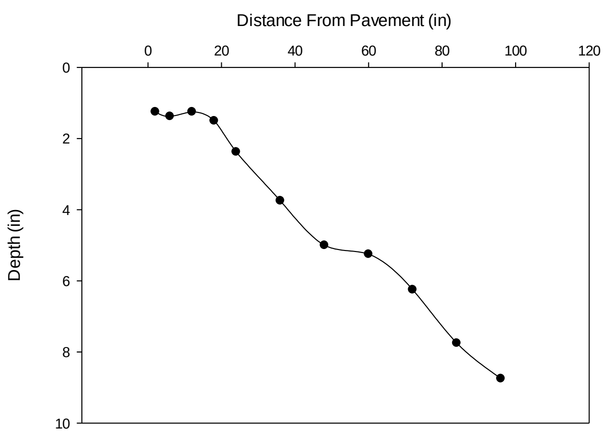
# Elevation Profiles



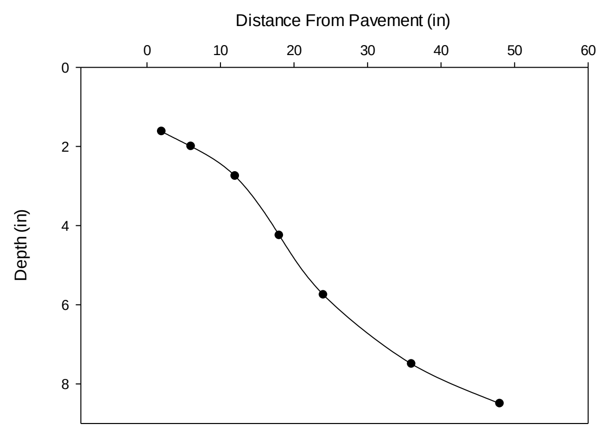

UN02A, EB



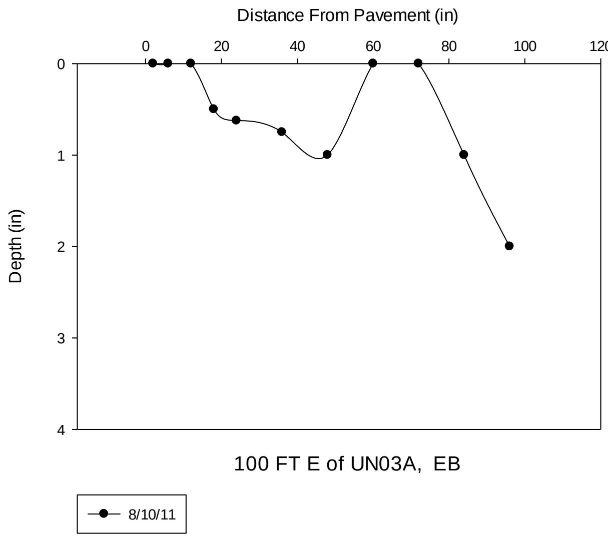

300 FT E of UN02A, EB



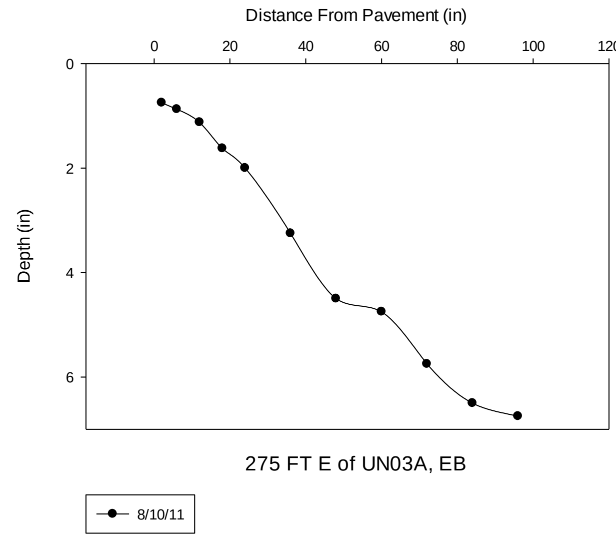

100 FT W of UN02B, WB



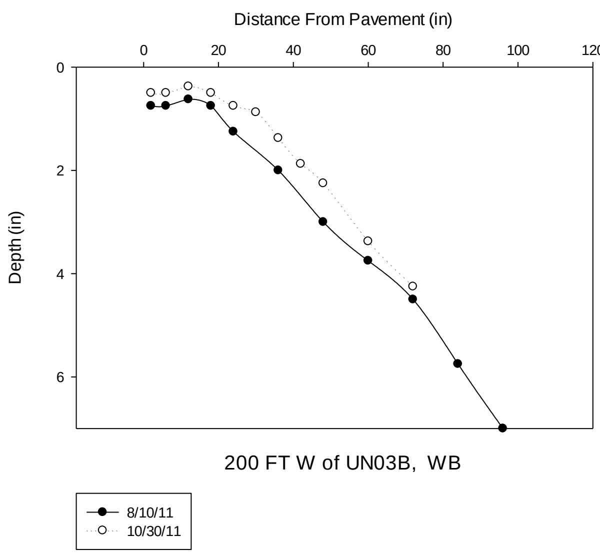

300 FT W of UN02B, WB



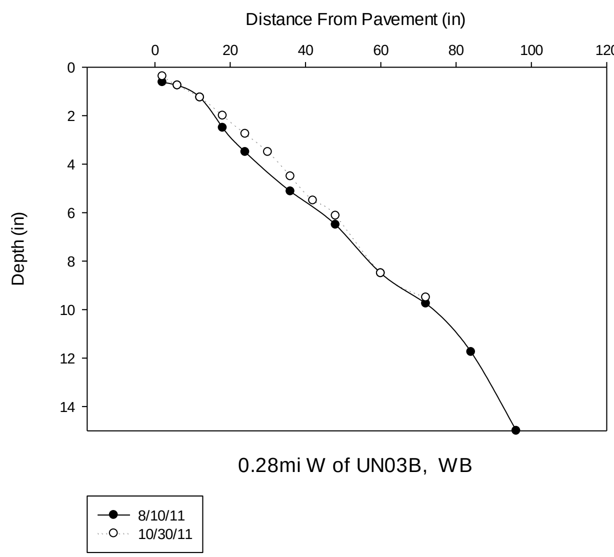

100 FT E of UN03A, EB



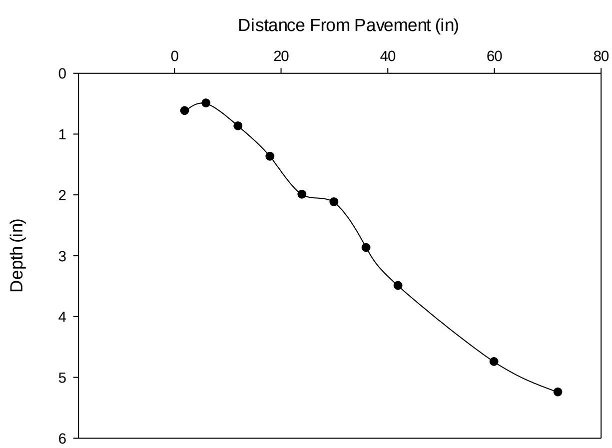

275 FT E of UN03A, EB



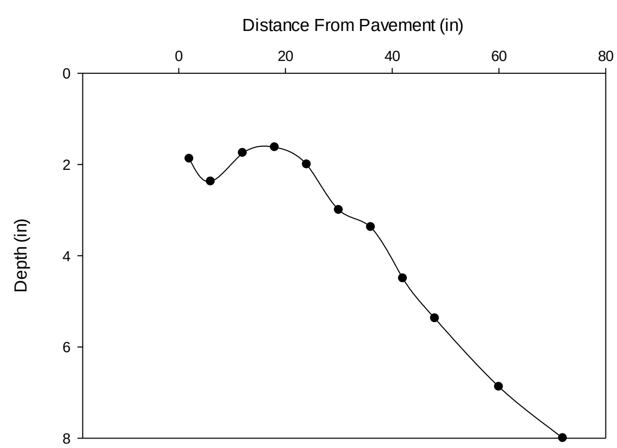

200 FT W of UN03B, WB



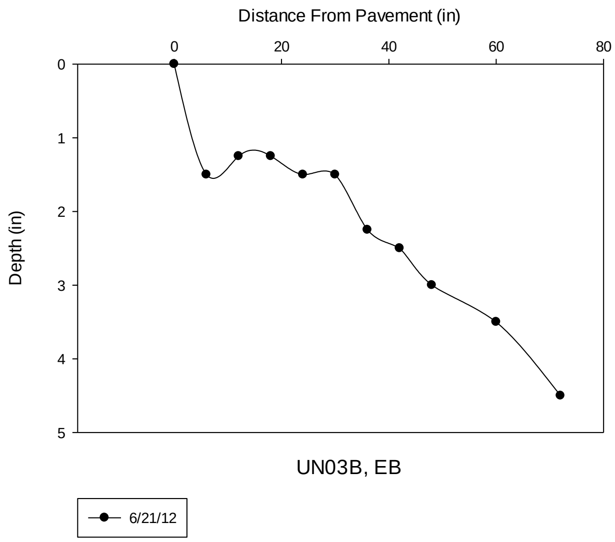

0.28mi W of UN03B, WB

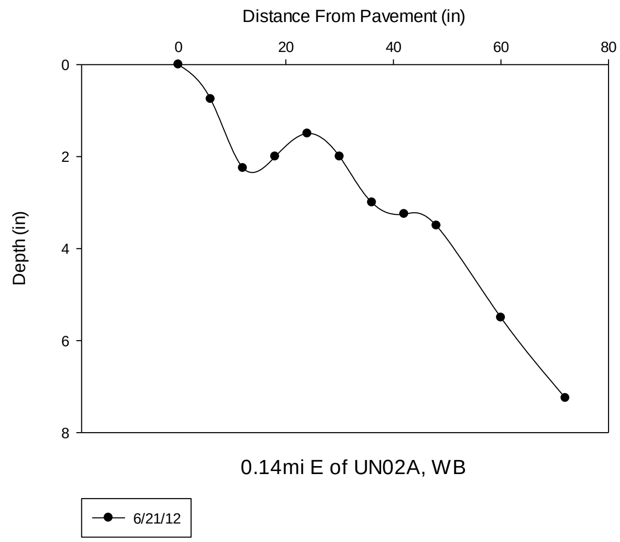



320 FT E of UN03A, EB




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 |
| | Right at UN02A, EB | 32.2 | 76.2 | | |
| | 300 ft E of UN02A, EB | 25.3 | 50.0 | | |
| | 90 ft W of UN02B, EB | 30.8 | 70.4 | 66.9 | |
| | 100 ft E of UN03A, EB | 30.8 | 70.4 | | |
| Aug.2011 | 275 ft E of UN03A, EB | 30.1 | 67.6 | | |
| | 100 ft W of UN02B, WB | 28.3 | 60.7 | | |
| | 300 ft W of UN02B, WB | 23.1 | 42.8 | | |
| | 200 ft W of UN03B, WB | 28.8 | 62.6 | | 51.5 |
| | 0.28 mi W of UN03B, WB | 22.2 | 40.0 | | |
| | | | | | |
| | UN02A, EB | 32.2 | 76.2 | | |
| | 300 ft E of UN02A, EB | 25.3 | 50.0 | 66.8 | |
| | 0.31mi W of UN03B, EB | 30.8 | 70.4 | | |
| Jun.2012 | 65 ft E of UN03B, EB | 30.8 | 70.4 | | |
| | 0.33mi W of UN03B, WB | 30.1 | 67.6 | | |
| | 0.14mi E of UN02A, WB | 28.3 | 60.7 | | 57.1 |
| | 60 ft E of UN02A, WB | 23.1 | 42.8 | | |

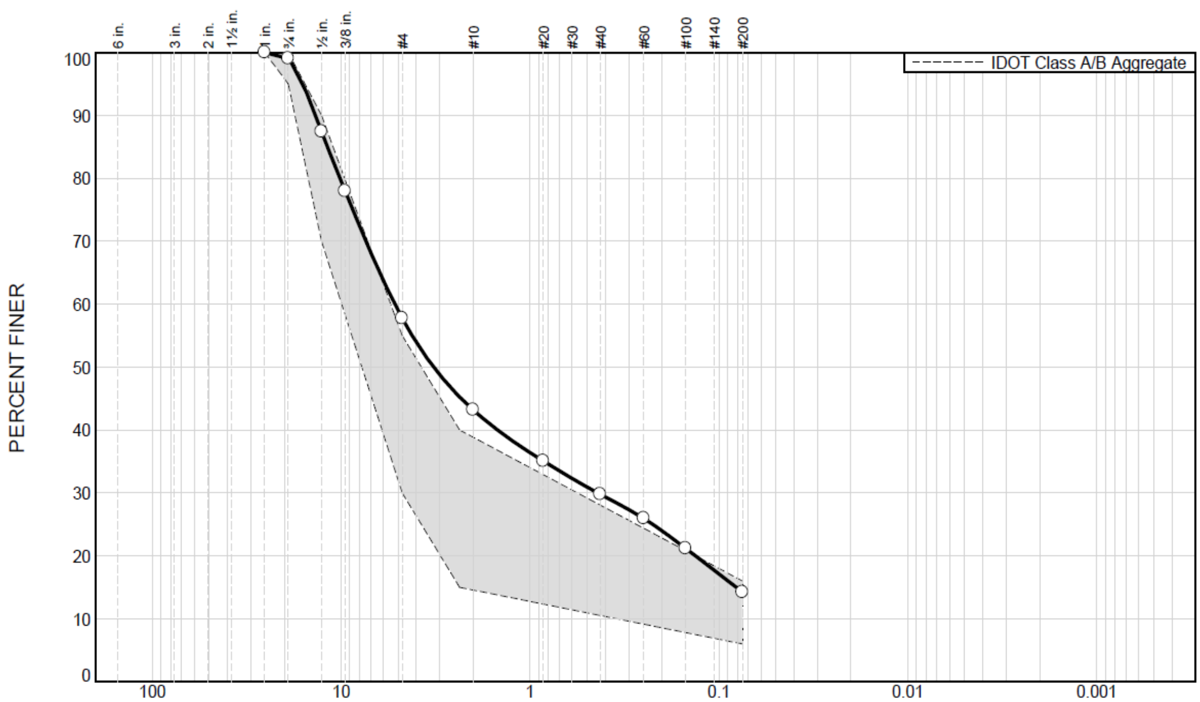
**Location 3.03-3.04_MP75-75.7**

Description: IA 13, Elkader, Location 3.03 (MP75-75.7): shoulder on northbound, sprayed 3090ft long and 12ft wide; Location 3.04 (MP75-75.2): shoulder on southbound, sprayed 1330ft long and 12ft wide

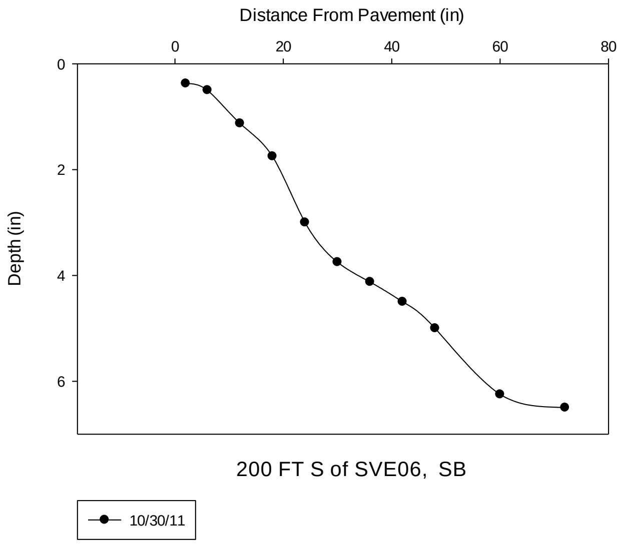
GPS: South end: N 42 51.210, W 91 23.566

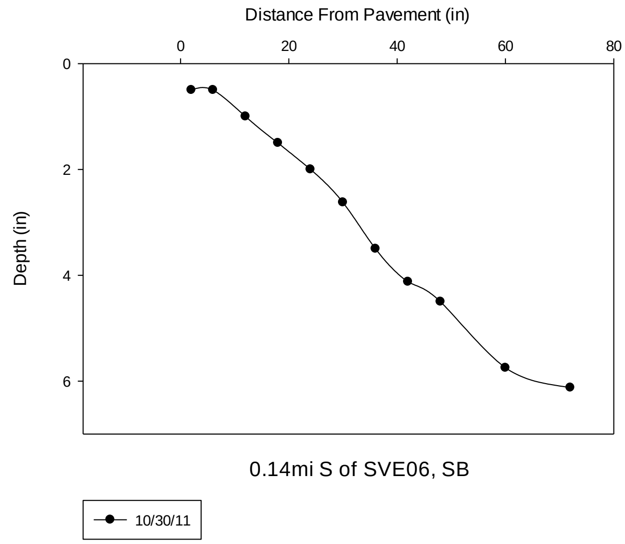
North end: N 42 51.711, W 91 23.634

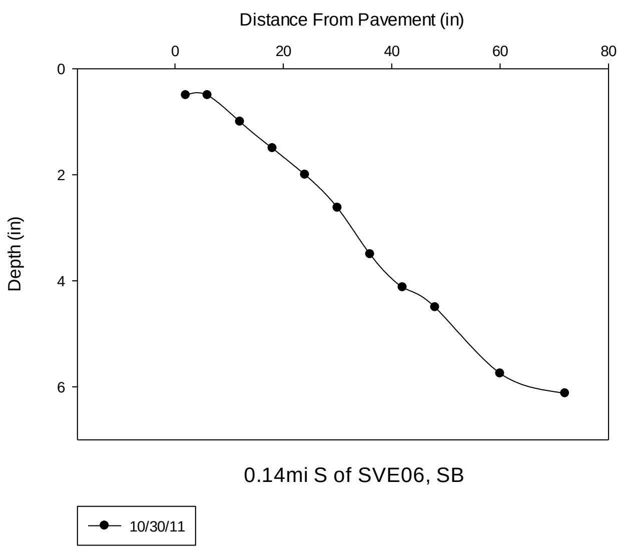
Gradation Distribution

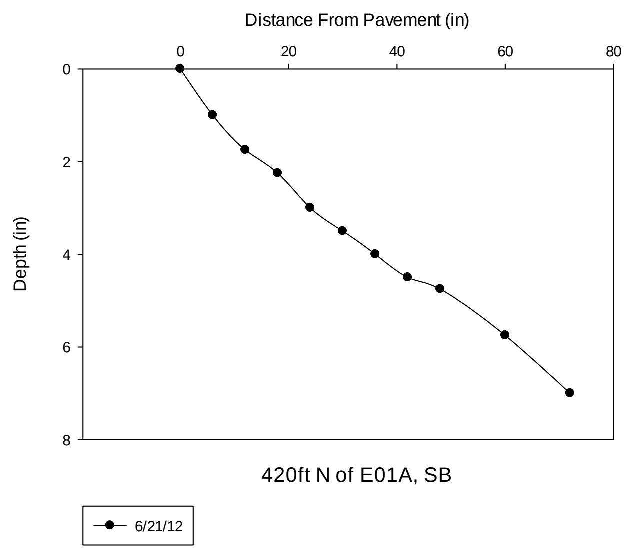


Elevation Profiles




CBR Values

**Table 40. Clegg hammer data for section 3.03-3.04**

<table>
<tr><th>Date</th><th>Location</th><th>CIV</th><th>CBR</th><th colspan="2">Average CBR</th></tr>
<tr><td></td><td>3.03-3.04</td><td></td><td></td><td>SB</td><td>NB</td></tr>
<tr><td rowspan="5">Jun.2012</td><td>330ft N of E01A, NB</td><td>31</td><td>71.2</td><td></td><td rowspan="3">58.1</td></tr>
<tr><td>0.18mi S of E01B, NB</td><td>27</td><td>56.0</td><td></td></tr>
<tr><td>E01B, NB</td><td>24.4</td><td>47.0</td><td></td></tr>
<tr><td>30ft S of E01C, SB</td><td>19.2</td><td>31.4</td><td rowspan="2">35.3</td><td></td></tr>
<tr><td>420ft N of E01A, SB</td><td>21.9</td><td>39.1</td><td></td></tr>
</table>

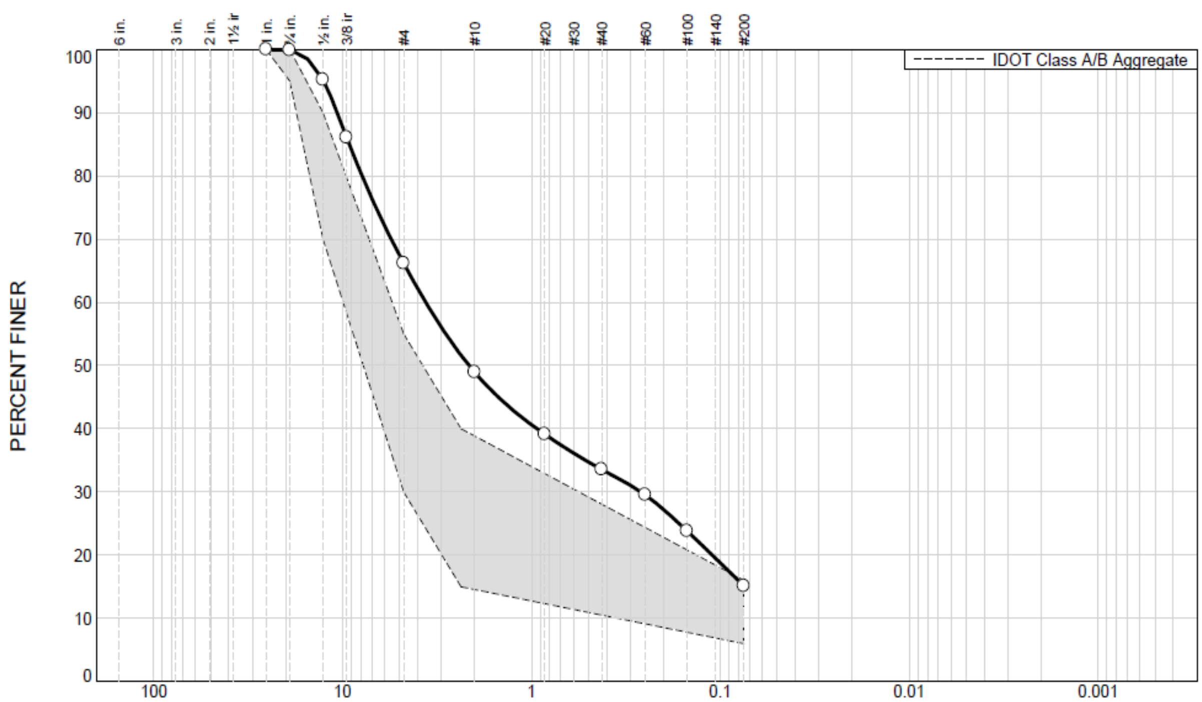
**Location 3.05-3.07_MP69.3-74**

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

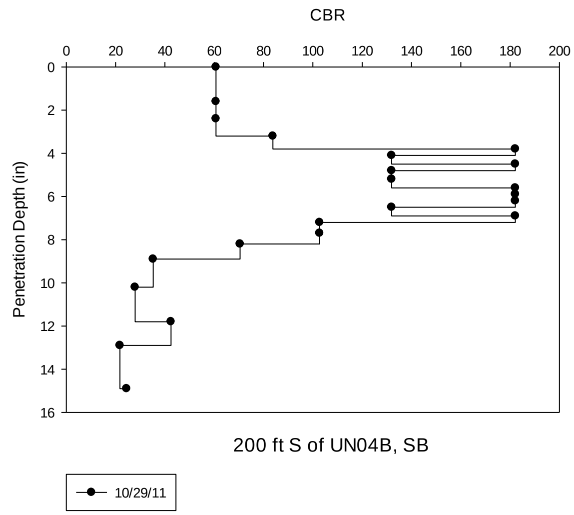
GPS: South end: N 42 47.876, W 91 26.148

North end: N 42 50.557, W 91 24.083

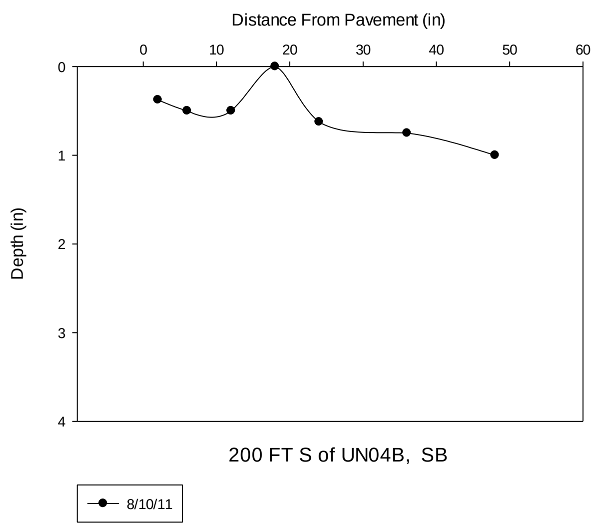
Gradation Distribution

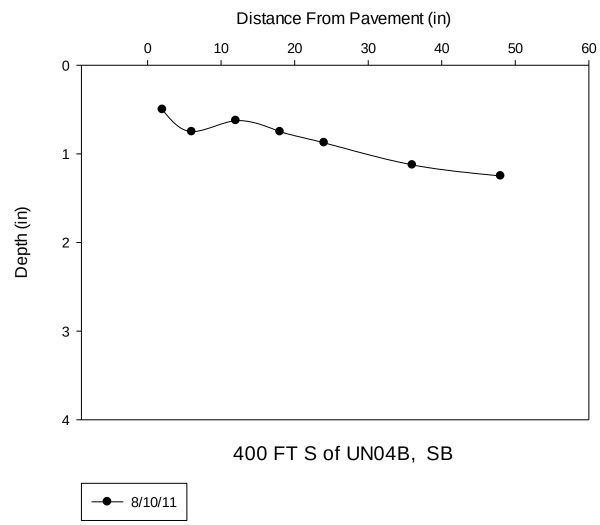


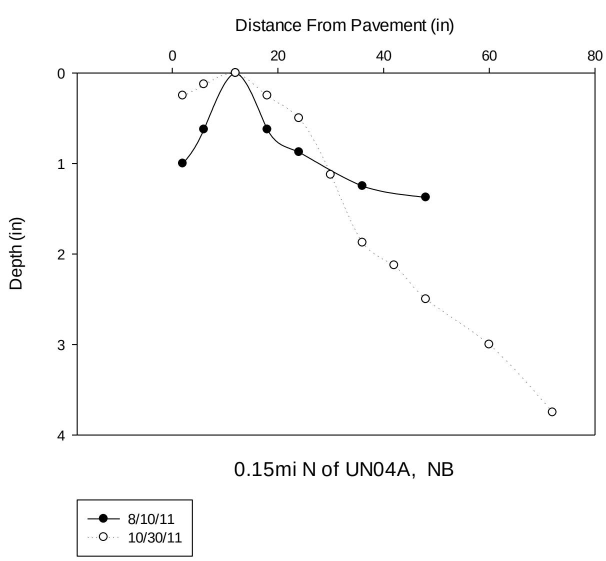
# DCP Plots

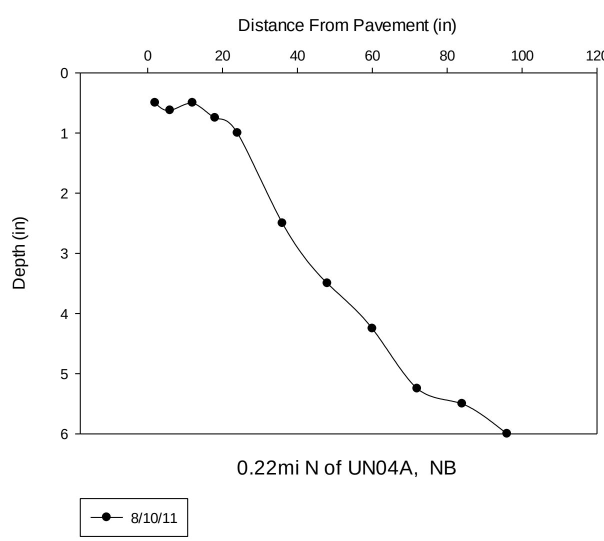


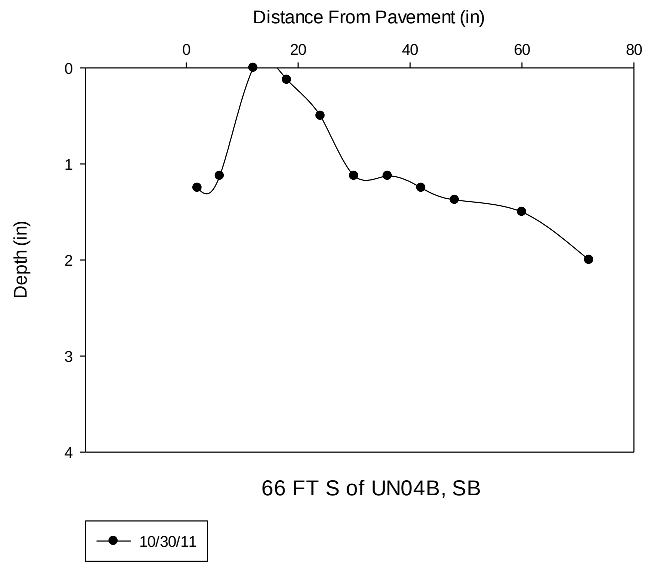

# Elevation Profiles

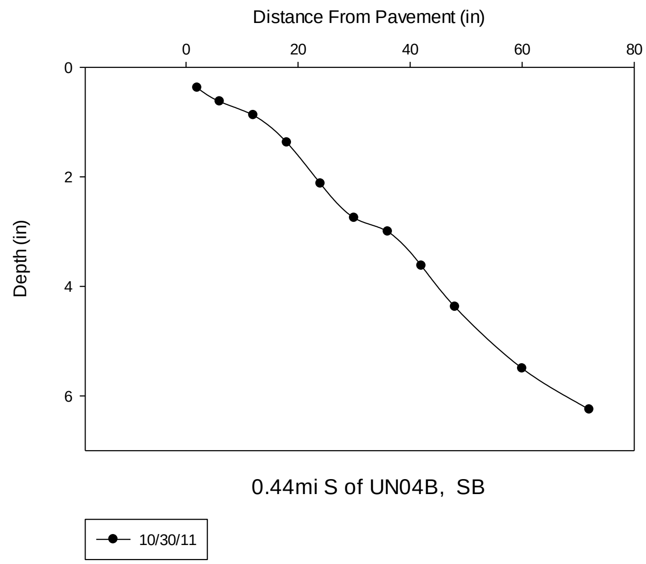


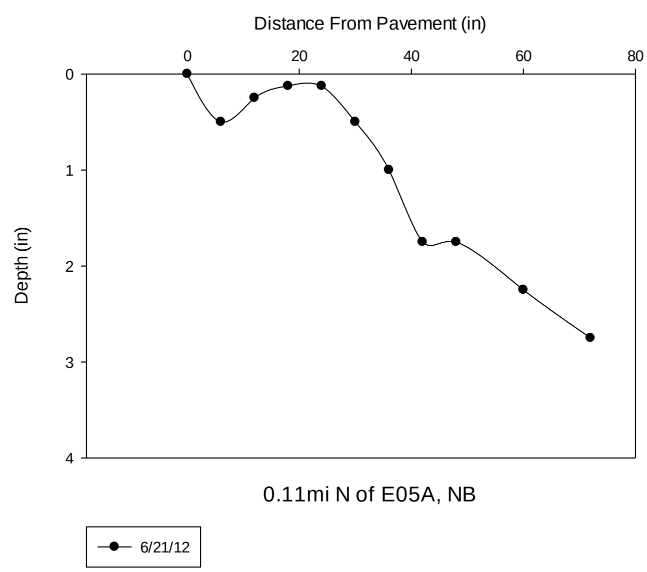



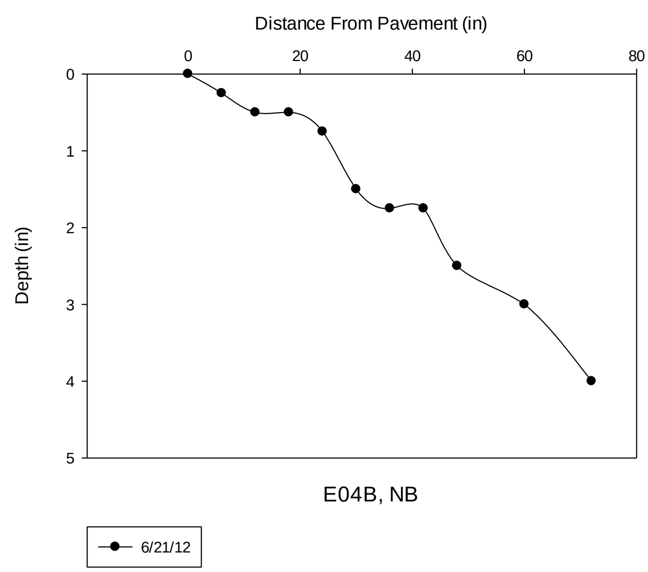



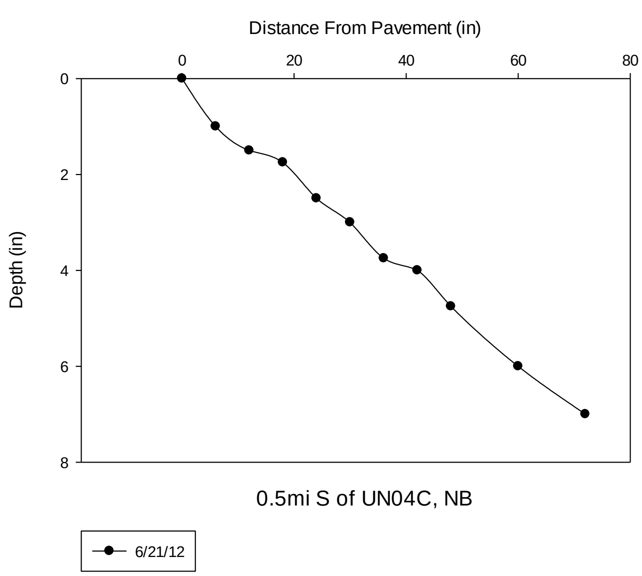




Distance From Pavement (in)
0 20 40 60 80
Depth (in)
0 1 2 3 4
66 FT S of UN04B, SB
10/30/11


Distance From Pavement (in)
0 20 40 60 80
Depth (in)
0 2 4 6
0.44mi S of UN04B, SB
10/30/11


Distance From Pavement (in)
0 20 40 60 80
Depth (in)
0 1 2 3 4
0.11mi N of E05A, NB
6/21/12


Distance From Pavement (in)
0 20 40 60 80
Depth (in)
0 1 2 3 4 5
E04B, NB
6/21/12


Distance From Pavement (in)
0 20 40 60 80
Depth (in)
0 2 4 6 8
0.5mi S of UN04C, NB
6/21/12

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 N of UN04A, NB | 26.3 | 53.5 | 58.0 |
| | 0.22 mi N of UN04A, NB | 28.8 | 62.6 | |
| | | | | |
| Jun.2012 | 20ft N of E05A, NB | 13.8 | 18.6 | 35.5 |
| | 0.11mi N of E05A, NB | 21.9 | 39.1 | |
| | 30ft S of E05B, NB | 19.7 | 32.8 | |
| | E04B, NB | 18.8 | 30.4 | |
| | 0.5mi S of UN04C, NB | 26.3 | 53.5 | |
| | 220ft S of UN04C, NB | 21.7 | 38.5 | |

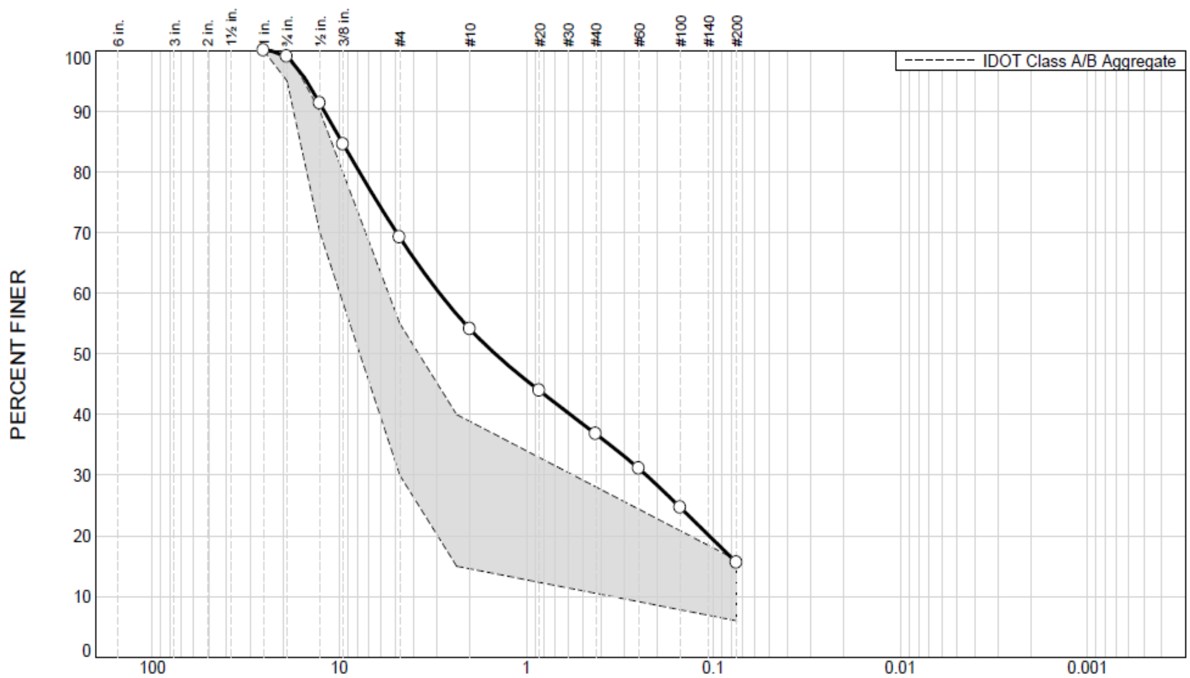
**Location 3.08-3.10_70ft south of Intersection W51&215th St. to 4460ft south of Intersection W51&215th St.**

Description: W 51, south of Elgin, Location 3.08 (3600ft S. of Int. W51&215th St. to 4460ft S. of Int. W51&215th St.): shoulder on northbound, sprayed 860ft long and 2ft wide; Location 3.09 (70ft S. of Int. W51&215th St. to 1050ft S. of Int. W51&215th St.): shoulder on northbound, sprayed 980ft long and 2ft wide; Location 3.10 (1760ft S. of Int. W51&215th St. to 4000ft S. of Int. W51&215th St.): shoulder on southbound, sprayed 2240ft long and 2ft wide

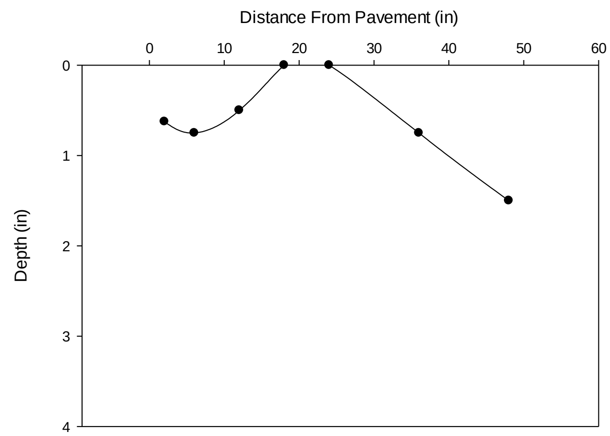
GPS: South end: N 42 56.152, W 91 39.063

North end: N 42 56.774, W 91 38.711

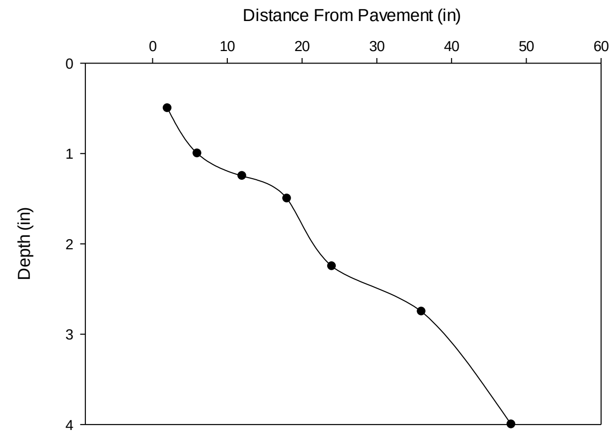
Gradation Distribution



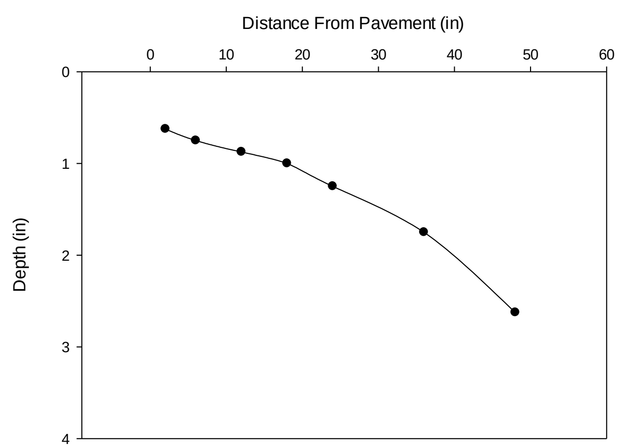
## Elevation Profiles



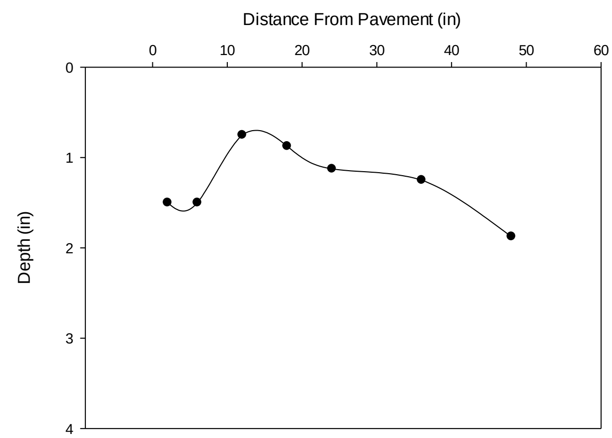

312 FT S of UNC01B,NB



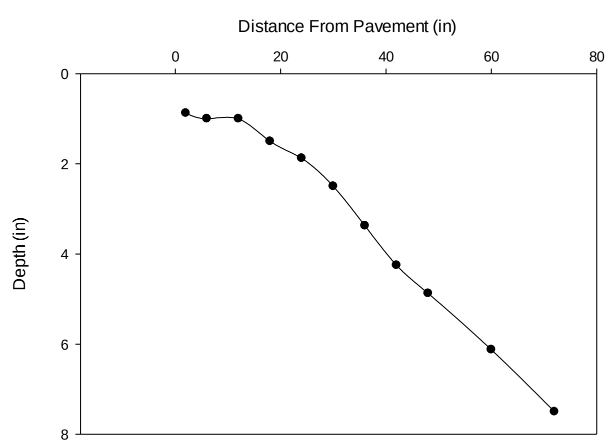

312 FT S of UNC01B, SB



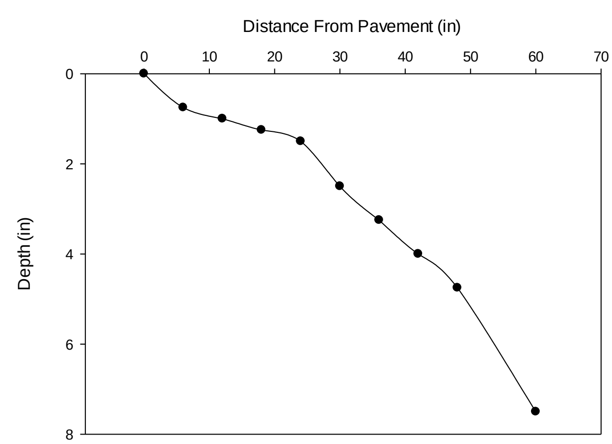

35 FT N of UNC01A, SB



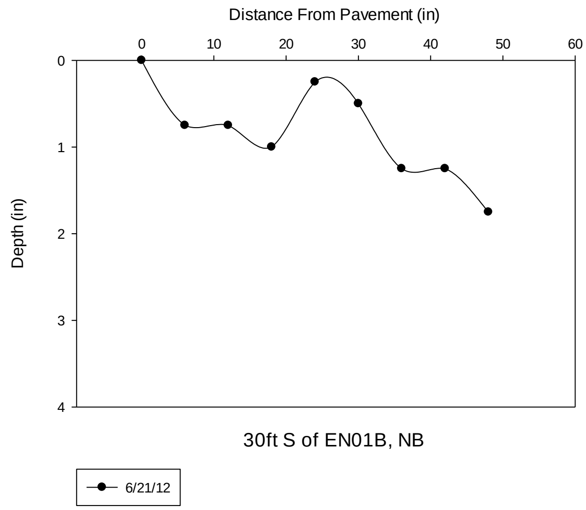

35 FT N of UNC01A, NB




0.1mi N of EN01B, SB




340ft N of EN02A, NB




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 |
| | Right at UNC01B, SB | 26 | 52.4 | | |
| | 312 ft S of UNC01B, SB | 21.6 | 38.2 | 39.9 | |
| Aug.2011 | 35 ft N of UNC01A, SB | 18.3 | 29.1 | | |
| | 312 ft S of UNC01B, NB | 21.9 | 39.1 | | 38.2 |
| | 35 ft N of UNC01A, NB | 21.3 | 37.4 | | |
| | | | | | |
| | 50ft S of ES01B, SB | 20.1 | 33.9 | | |
| | 0.15mi N of ES01A, SB | 21.7 | 38.5 | 31.5 | |
| | ES01A, SB | 15.4 | 22.1 | | |
| | 340ft N of EC02A, NB | 21.4 | 37.7 | | |
| Jun.2012 | 400ft S of EN02B, NB | 17.7 | 27.5 | | |
| | EN02B, NB | 18.9 | 30.6 | | 39.5 |
| | EN01A, NB | 30.7 | 70.0 | | |
| | 430ft N of EN01A, NB | 18.9 | 30.6 | | |
| | 30ft S of EN01B, NB | 22.3 | 40.3 | | |