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Foundation Design of Low Volume Roads: Evaluation and Performance

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FOUNDATION DESIGN OF LOW VOLUME ROADS:

EVALUATION AND PERFORMANCE

BY

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FOUNDATION DESIGN OF LOW VOLUME ROADS:

EVALUATION AND PERFORMANCE

This thesis is approved as a creditable and independent investigation by a candidate for the Masters of Science in Civil Engineering degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidates are necessarily the conclusions of the major department.

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ABBREVIATIONS

AASHTO: American Association of State Highway and Transportation Officials

AC: Asphalt Concrete

ADT: Average Daily Traffic

ADTT: Average Daily Truck Traffic

ASCE: American Society of Civil Engineers

ASTM: American Society of Testing and Materials

CBR: California Bearing Ratio

DCP: Dynamic Cone Penetrometer

DOT: Department of Transportation

DPI: Dynamic Penetration Index

ESAL: Equivalent Single Axle Load

GN: Grading Number

FHWA: Federal Highway Administration

FWD: Falling Weigh Deflectometer

HMA: Hot-Mixed Asphalt

HWY: Highway

IDOT: Illinois Department of Transportation

LL: Liquid Limit

LOS: Level of Service

LTAP: Local Transportation Assistance Program

LVR: Low Volume Road

MC: Moisture Content

MnDOT: Minnesota Department of Transportation

NP: Non-plastic

PCC: Portland Cement Concrete

PI: Plasticity Index

PLT: Plate Loading Test

PR: Penetration Rate

QA/QC: Quality Assurance / Quality Control

SD: South Dakota

SDDOT: South Dakota Department of Transportation

SDLTAP: South Dakota Local Transportation Assistance Program

SDSU: South Dakota State University

SN: Structural Number

USACE: United State Army Corps of Engineers

USCS: Unified Soil Classification System

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ABSTRACT

FOUNDATION DESIGN OF LOW VOLUME ROADS:

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ALYSSA CLEMEN

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A majority of roads in the state of SD are low volume roads (LVRs). The SDDOT has developed simplified methods for LVR pavement thickness selection. These guides allow users to obtain recommended asphalt surfacing and base course layer thickness based on the subgrade support and the average daily traffic (ADT) of the road. The main objective of this study is to relate the surface condition of LVRs to their ADT, layer thicknesses, foundation material properties, and maintenance. A secondary objective was to evaluate if the Dynamic Cone Penetrometer (DCP) is an acceptable tool in determining the subgrade support by using it to measure the penetration resistances of the foundation layers.

A total of 16 different asphalt surfaced LVRs across SD were tested. The construction and maintenance histories of the roads was obtained. The performance of the roads was evaluated based on the surface condition of the pavement. Field tests were performed to obtain the layer thicknesses, DCP Penetration Index, and samples were obtained for laboratory testing. The laboratory testing included moisture content, liquid limit, plastic limit, and gradation tests. The results of the tests were used to compare the layer thicknesses and material properties to both the performance of the roads and the suggested thicknesses and material specifications from the SDDOT guides.

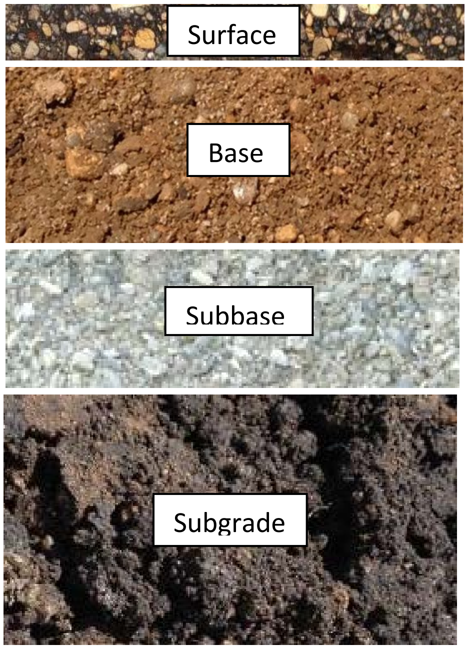
Based on the analysis, it was determined that the DCP test did not provide an adequate measure of the subgrade soil support to be used in the SDDOT Rural Road

Design Guide. It was also determined that the layer thicknesses, material quality, and maintenance schedule all contribute to the performance of asphalt surfaced LVRs. They have the greatest positive impact on a road's performance when all three of these components satisfy the guidelines in the SDDOT Rural Road Design Guide.

1. Introduction

1.1 Background and Problem Description

Low volume roads (LVRs) are of great importance to the state of South Dakota. The American Association of State Highway and Transportation Officials (AASHTO) defines a very low volume road as a road that has an average daily traffic (ADT) less than 400 vehicles per day (AASHTO, 2001). According to Sebaaly most of the roads under county, town, and township jurisdiction in South Dakota are LVR (Sebaaly et al., 2003). Out of approximately 82,500 miles of roadway in the state, almost 91% (75,000 miles) of them are owned by these local agencies. A majority of these 75,000 miles are LVRs (SDDOT, 2014). LVRs generally have thinner surface thicknesses than roads designed for greater traffic volumes. Therefore, in order for a pavement to adequately support traffic, it must be supported by its foundation, which is the base course, subbase, and subgrade. A pavement cross-section with the typical layer materials is shown in Figure 1.1. The surface is the top material in the pavement structure and is the material that is in direct contact with the traffic. The base course is the layer of aggregate material immediately below the pavement surface. For the purposes of this study, the base course layer and its materials will simply be referred to as “base”. The subbase, when present, is the layer beneath the base layer and above the subgrade. It can be made of either aggregate material or stabilized subgrade soil. The subgrade is the in-place material beneath the pavement structure.



very strong, durable, impermeable, manufactured

strong, free-draining, manufactured

moderate strength, free-draining, natural material

weak, moisture sensitive, in-situ soil

Figure 1.1: Typical Pavement Cross-Section

The primary factors influencing road design include traffic volume, surface type, material properties, environmental factors, and geometry. These design parameters are significantly affected by the strength of the materials and the ADT. If these variables are not taken into account, the resulting roadway design could be either overly conservative or inadequate. In many cases the layer thicknesses ad materials used in LVRs may have been selected based on experience with materials and thicknesses used on previously constructed roads. However, these other roads may have different design variables than the roads being designed, resulting in a design that may not be appropriate (Beckemeyer and McPeak, 1995). This is a major reason why low volume roads require different design guidelines than roads with higher volumes (AASHTO, 2001). It is imperative to understand the design components in order to develop the most effective design of a LVR.

There are several different design methods for LVRs, including the AASHTO method, DCP method, U.S. Army Corps of Engineers method, National Stone Association method, and the Asphalt Institute method. These methods require several inputs, such as 18-kip Equivalent Single Axle Load (ESAL), roadbed soil resilient modulus, and layer California Bearing Ratio (CBR) values. However, local agencies may not always know these variables or have the resources, such as money and equipment, to obtain them. The South Dakota Department of Transportation (SDDOT) has developed simplified guides based on the AASHTO design method to assist local agencies when their resources cannot provide an engineered design for a road. These SDDOT guides provide suggested material properties and layer thicknesses based on the amount of traffic and the subgrade support.

Construction inspection of low volume roads, when conducted, typically requires the measurement of the in-place density of the subgrade and base. However, the strength of a soil or aggregate is determined by more than just its density. The strength is affected by the gradation and plasticity of the material. These components of strength are significant factors in the design of the LVR. Therefore, the use of in-place density testing may not be an adequate indication of the support a subgrade and base provide for the pavement. The dynamic cone penetrometer (DCP) is a device used to determine the in-situ support and stiffness of the soil and aggregate by correlating the results to the CBR value. Therefore, this device may be used for construction inspection.

An increased interest in LVR design has evolved due to changes in agricultural and construction equipment over the past few decades. Equipment now is larger and heavier than it has ever been in order to increase efficiency of agricultural and construction operations. Increases in agricultural yields have also resulted in significantly higher crop output per acre of land. This increase in yield results in larger and heavier loads and more trips required by farmers to transport their crops. This can greatly affect the performance of LVR, especially since considerable agricultural, construction and commodity related traffic occurs on LVR. As traffic demands on low volume roads increases, local agencies must place increased emphasis on applying appropriate design methodologies to ensure that roads can withstand traffic loadings without experiencing significant distress. Therefore, it is necessary to determine if the current layer thicknesses and material quality used for LVR in SD provides adequate performance for the current traffic loads.

In general, all of the LVR's in South Dakota have either a gravel or asphalt surface. The asphalt surfaces include hot-mixed asphalt (HMA) mats and thin bituminous surface treatments, also known as blotters. Based on the ADT and life cycle costs, the most cost-effective surface can be chosen for a road. Once constructed, a gravel road can be reshaped at relatively low cost with the use of a motor grader. The surface condition and road performance can change rapidly from one day to the next thereby requiring more frequent maintenance to maintain consistent performance. Asphalt surfaced roads, however, may require less frequent maintenance but repairs may be more extensive once they exhibit signs of deterioration. When compared to asphalt surfaced roads, the surface condition and performance of gravel roads are highly variable with respect to time. Therefore, the scope of this investigation will be limited to asphalt surfaced roads.

The varying use of LVR roadway layer thicknesses and material quality throughout South Dakota has resulted in a variety of pavement performance levels. At this time, little research has been conducted to correlate observed pavement performance with specific LVR layer thicknesses and material selection.

1.2 Objectives and Scope

The objective of this study is to relate the surface condition of LVRs to their ADT, maintenance, layer thicknesses, and foundation material properties. Penetration resistance will be evaluated using the dynamic cone penetrometer to evaluate the support of the subgrade underneath the roads being studied. It is envisioned that this data will yield correlations between the primary factors influencing road design and their actual performance.

The main objectives of this study:

1. Review literature concerning the DCP, road foundation material selection, LVR design methods and guides, and asphalt surface performance.
2. Conduct field and laboratory evaluations of the foundation properties of asphalt surfaced LVRs.
3. Use the correlation between DCP Penetration Index and CBR value to determine subgrade support from the DCP test results. Determine if this DCP-CBR correlation is more suitable for estimating subgrade support than using the Liquid Limit or AASHTO soil classification.
4. Compare the layer thicknesses, material properties, ADT, and maintenance of the LVR roads to their surface performance to determine how these factors may influence the surface performance.

The foundations of several LVRs located primarily throughout the state of South Dakota were evaluated. As stated previously, only foundations under asphalt surfaced LVR were considered. The evaluation included:

1. Determining the surface performance of the pavement surface.
2. Measuring the thickness of the pavement surface and the base.
3. Testing base and subgrade strength with the DCP.
4. Obtaining base aggregate and subgrade soil samples to use for determining moisture content, gradation, liquid limit, and plastic limit of each material.
5. Determining the age, maintenance, and ADT of the road.

This research will provide some guidance to those who construct and maintain LVRs on the effectiveness of certain thickness and material selection guides. It will also present the factors that caused some roads that were evaluated to perform successfully and the factors that caused other roads to fail.

2. Literature Review

Many pieces of research literature relating to this study are summarized in this review. Definitions of low volumes are established, and several LVR design methods and guides are presented and those most applicable to the roads evaluated in this study are explained more in depth. The different design components of a LVR are defined and discussed along with the use of the DCP. Finally, the method for surface condition assessment of roads is summarized.

2.1 Low Volume Roads

A low volume road is a road that experiences a low level of traffic. According to AASHTO, the traffic throughout the design life for a LVR is from 50,000 to 1,000,000 18-kip ESAL's (Equivalent Single Axle Load) for both flexible and rigid pavements (AASHTO, 2011). AASHTO also has a sub-category of LVR's called very low volume roads. These are roads subjected to an ADT of 400 or less. Many LVRs are local roads, which are defined as roads whose primary function is to provide access to residences, farms, businesses, or other adjacent property, compared to serving through traffic (AASHTO, 2001).

2.2 Low Volume Road Design Methods and Guides

There are several different methods and guides for designing LVRs. Some of these methods, such as the AASHTO method for very low volume roads and the guide from the SDDOT Rural Road Design, Maintenance, and Rehabilitation Guide, are specifically for roads with low traffic volume and ADT of 400 or less. Other design methods, such as the Asphalt Institute's and the National Stone Association's procedures, are used for the design of roads with any traffic volume including low volumes.

2.2.1 Low Volume Road Design Methods & Guides Summaries

This section will briefly describe a few of the different methods for designing LVRs: the AASHTO method, DCP method, U.S. Army Corps of Engineers method, and the National Stone Association method. The inputs required for each of these methods will be discussed. The basis and inputs of the two SD design guides (Rural Road Guide and Local Road Plan) will also be summarized.

AASHTO

Low Volume Roads – Design of Pavement Structures

AASHTO's *Guide for Design of Pavement Structures* (AASHTO, 2011) has a chapter that specifically addresses the design of low volume roads. This section is for roads that have 18-kip ESAL traffic levels between 50,000 and 1,000,000 throughout their design life. 18-kip ESAL takes into account the number of vehicles as well as the axle configurations of the vehicles. The inputs for this design method include the season lengths for the climatic region, roadbed soil resilient modulus, design reliability, standard deviation, 18-ESAL, base course elastic modulus, layer coefficients for the structural number, and design serviceability loss. For this procedure, the relative quality of the roadbed soil is determined from a table based on the soil resilient modulus and the climate. Using the relative quality of the roadbed soil, the traffic level and the climatic region, a range of values for the structural number (SN) can be determined from a table. The layer coefficients for the different layers of materials can be determined from charts. The chart for the asphalt layer coefficient is based on the elastic modulus of the asphalt. The charts for the granular base and subbase can be used with the resilient modulus, Texas triaxial value, R-value, or CBR value for the material. These respective layer coefficients are then used with the SN to determine the thicknesses of the different layers (AASHTO, 2011).

Very Low Volume Local Roads –Geometric Design of Very Low Volume Local Roads

The *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)* (AASTHO, 2001) can be less stringent than those for roads with higher traffic volumes because a majority of the motorists using these roads are familiar with them and there are few encounters between vehicles. With the few encounters between vehicles, there are less chances for collisions, particularly multiple-vehicle crashes. Even though this design may be less stringent than for higher volume roads, it is still conservative with a "margin of safety". For this design method, the safety of motorist and the cost are the most important factors instead of the LOS (Level of Service), travel time savings, and driver comfort and convenience. This design method is a method for the geometric design of roads which includes horizontal curves, vertical curves, and roadway width. However, it does not address the pavement structure (AASHTO, 2001).

DCP Method – Republic of Malawi Ministry of Transport and Public Works

The Ministry of Transport and Public Works in Malawi (south eastern Africa) has developed a design manual (Ministry of Transport and Public Works, 2013) for the design of low volume sealed roads using the Dynamic Cone Penetrometer (DCP). The DCP is discussed further in Section 2.4. It can be used for both the design of new roads and the upgrading of existing roads. One of the goals of this method is to make maximum use of the local in-situ materials. For upgrading existing roads, the materials in the existing road may have undergone compaction from years of traffic loading. This compaction is more typical in regions with drier climates. With this compaction, these base and subgrade layers are typically stronger than when the road was first built. The DCP is used to determine the strength of the in-situ material. This in-situ strength is then compared to the strength needed to support the traffic. The difference between these two strengths indicates what needs to be added to reach the design strength for the road. Because this design method was developed for the sub-tropical climate of Malawi, Africa it may be ineffective for use in the continental climate of South Dakota. The design method was developed specifically for roads in Africa for their climate, materials, and traffic. Applying it to the conditions in South Dakota could result in inadequate quality or thickness of pavement layers (Ministry of Transport and Public Works, 2013).

U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers (USACE) pavement design procedure is also sometimes referred to as the “CBR procedure”. The inputs for this procedure are traffic in terms of 18-kip ESAL, CBR of the base and subgrade, subgrade soil classification, and whether the soil is frost susceptible or not. The resulting design thickness for each layer has to be great enough to distribute the traffic load stresses so that these stresses do not cause excessive shear deformation in the underlying layers. It is suggested that the proposed design criteria for a particular area should be confirmed based on the performance of existing pavements on similar local subgrade over a period of at least five years. There are a couple of limitations with the USACE design procedure. One limitation is that varying environmental effects and other uncertainties may not be adequately accounted for in the design. Also, the material of the thickness that was determined with the design procedure must have a greater CBR strength than the underlying material (Hall and Bettis, 2000).

In this USACE design procedure, the magnitude of the traffic loading is more significant to the design than the number of load repetitions. Therefore, the traffic is categorized into one of five different categories based on the distribution of the types of vehicles. The design CBR value for the base is based on the type of materials that compose the base. The resulting design CBR and the Design Index are then used to determine the minimum thicknesses of the pavement and base course. These thicknesses determined with this procedure can also be adjusted for the use of stabilized soil layers (Joint Departments of the Army and Air Force, 1992).

National Crushed Stone Association Design Procedure

The National Crushed Stone Association Procedure is an adaptation of the USACE design method. Therefore, it is also a CBR based method. The inputs are ADTT, subgrade soil classification, and CBR of base, subbase and subgrade layers. For this procedure, the soil support is categorized based on the soil's classification and CBR value. The traffic intensity is used to determine the Design Index. Then the thickness, which is the total combined thickness of the crushed stone base and the bituminous surface, is selected from the table. This design thickness is checked for its resistance to severe conditions, such as frost damage and drainage problems. If necessary, a thicker section is used to avoid results of those severe conditions. A limitation of this method is that is only considers asphalt surfaced roads that are on a good crushed stone base (Hall and Bettis, 2000).

Asphalt Institute

The Asphalt Institute design method is a mechanistic-empirical design procedure and is based on elastic layer analysis. The inputs for this method are the resilient modulus of the subgrade and the 18-kip ESAL for the traffic. This methods also specifies the CBR, LL, PI, gradation, and sand equivalent of the base and subbase layers. The Asphalt Institute design procedure only considers full depth asphalt, asphalt over an emulsified asphalt stabilized base, and asphalt over granular base types of pavements. It cannot be used directly for any other types of stabilized layers or for subbase layers (Hall and Bettis, 2000).

SDDOT Rural Road Design, Maintenance, and Rehabilitation Guide

The *Rural Road Design, Maintenance, and Rehabilitation Guide* (Beckemeyer and McPeak, 1995) provides suggested pavement and base layer thicknesses based on the ADTT (Average Daily Truck Traffic) and the subgrade support. The CBR (California Bearing Ratio) used to determine the subgrade support conditions may be estimated two different ways: with the DCP dynamic penetration index (DPI) or with the liquid limit. The layer thicknesses were determined using the AASHTO method for rural roads with less than 200 heavy trucks per day, 20 year design life, design reliability of 75%, and structural coefficients of 0.10 for the aggregate layer and 0.36 for the asphalt concrete layer. With these assumptions, the Rural Road Manual provides a simplified version of the AASHTO design method for users (Beckemeyer and McPeak, 1995).

SD Local Roads Plan

The SDDOT developed the SD Local Roads Plan (SDDOT, 2011) as a guideline for counties and cities in the state. It serves as an aid in the planning, design, and construction of the roads and bridges on their local systems. The SDDOT describes the goal of the document as “to provide a product that will fit local needs and safety considerations at the most reasonable cost possible.” This method takes into consideration safety, existing and future needs, economy, reasonable maintenance costs, and available funding for the local entities. The selection criteria in the Local Roads Plan is for a 20 year design life and is in accordance with AASHTO's *A Policy on Geometric Design of Highways and Streets* (AASHTO, 2011) and is intended to be used with that manual. The guidelines for roads with ADT $\leq$ 400 are in accordance with AASHTO's *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT $\leq$ 400)* (AASHTO, 2001).

The Local Roads Plan presents typical cross-sections for low volume roads. It also recommends minimums for layer thicknesses of asphalt surfaced roads for different ranges of ADT (Average Daily Traffic). This is the simplest method because the only input is the ADT. However, because of the simplicity, this method may not result in an adequate or economical road design.

2.2.2 Selected Design Guides

Most local governments do not have information on or the ability to test in-situ materials for several parameters used in many design methods such as the resilient modulus and CBR. However, they are usually able to obtain ADT, ADTT, material gradations and Atterberg Limits. With only this available information to use in the design of their roads, they do not have the parameters needed for many design methods. However, the two guides previously discussed that would allow these local governments to obtain a design with the information that they do have and can measure: the SDDOT Rural Road Design, Maintenance, and Rehabilitation Guide and the SD Local Roads Plan. Therefore, only these two design guides will be used in this study.

SDDOT Rural Road Design, Maintenance, and Rehabilitation Guide

The *Rural Road Design, Maintenance, and Rehabilitation Guide* provides suggested pavement and base layer thicknesses based on the ADTT and the quality of the subgrade support. Throughout the remainder of this study, the *Rural Road Design, Maintenance, and Rehabilitation* Guide will be referred to as “Rural Road Guide”. Typical layer thicknesses in SD are 6-10” aggregate base for blotters and 2-6” AC on top of 6-10” aggregate base course for AC (Asphalt Concrete) pavements. The suggested layer thicknesses are shown in Table 2.1 and Table 2.2 for blotters and AC pavements, respectively. Although Table 2.1 is for gravel roads, it is also used for blotter surfaced roads because the blotter provides no additional support for the traffic load. In this case, the suggested minimum gravel layer thickness in Table 2.1 would be the suggested minimum base course layer thickness under the blotter.

Table 2.1: Suggested gravel layer thicknesses for new or reconstructed rural roads

Estimated daily no. of heavy trucks	Subgrade support condition[1]	Suggested minimum gravel layer thickness, mm (in)
0 to 5	Low	165 (6.5)
	Medium	140 (5.5)
	High	115 (4.5)
5 to 10	Low	215 (8.5)
	Medium	180 (7.0)
	High	140 (5.5)
10 to 25	Low	290 (11.5)
	Medium	230 (9.0)
	High	180 (7.0)
25 to 50	Low	370 (14.5)
	Medium	290 (11.5)
	High	215 (8.5)

Notes. [1] Low subgrade support: average CBR ≤ 3 percent; medium subgrade support: 3 percent < average CBR ≤ 10 percent; high subgrade support: average CBR > 10 percent. [2] CBR = California Bearing Ratio of the in-place subgrade soils. Methods of estimating CBR are discussed in section 7 of this document.

Table 2.2 shows the suggested corresponding AC surface layer thickness for a range of base course layer thicknesses at each ADTT range and subgrade support condition. These thickness were determined using the AASHTO method for rural roads with less than 200 heavy trucks per day, 20 year design life, design reliability of 75%, and structural coefficients of 0.10 for the aggregate layer and 0.36 for the asphalt concrete layer.

Table 2.2: Suggested AC-Surfaced Pavement Thicknesses

Road classification and estimated daily truck traffic	Subgrade support conditions[1]	AASHTO structural number	Aggregate base thickness (in)	Corresponding AC layer thickness (in)
Light truck traffic (0 to 15 heavy trucks per day in design lane)	Low Medium High	2.89 2.42 1.88	6.0, 8.0, or 10.0 6.0, 8.0, or 10.0 6.0, 8.0, or 10.0	6.5, 6.0, or 5.5 5.0, 4.5, or 4.0 3.5, 3.0, or 2.5
Medium truck traffic (15 to 50 heavy trucks per day in design lane)	Low Medium High	3.44 2.90 2.27	8.0, 10.0, or 12.0 8.0, 10.0, or 12.0 8.0, 10.0, or 12.0	7.5, 7.0, or 6.5 6.0, 5.5, or 5.0 4.0, 3.5, or 3.0
Heavy truck traffic (50 to 200 heavy trucks per day in design lane)	Low Medium High	4.19 3.55 2.82	10.0, 12.0, or 14.0 10.0, 12.0, or 14.0 10.0, 12.0, or 14.0	9.0, 8.5, or 8.0 7.0, 6.5, or 6.0 5.0, 4.5, or 4.0

Notes. [1]Low subgrade support: average CBR[2] ≤ 3%; medium subgrade support: 3% < average CBR ≤ 10%; high subgrade support: average CBR > 10%. [2]CBR = California Bearing Ratio (CBR) of the in place subgrade soils. Methods of estimating the CBR of a subgrade soil are provided in section 7 of this document.

The CBR used to determine the subgrade support conditions in Table 2.1 and Table 2.2 can be estimated two different ways: with the DCP Dynamic Penetration Index(DPI) and with the Liquid Limit (LL). The following equation is used to estimate CBR from the DPI: $\log(CBR) = 0.84 - 1.26*\log(DPI)$. The approximate CBR values are listed in Table 2.3 for five different ranges of the liquid limit (Beckemeyer and McPeak, 1995).

Table 2.3: Summary of Relationship Between Liquid Limit and CBR of Typical South Dakota Soils

Liquid Limit, %	Approximate CBR, %
0 to 30	> 8.5
30 to 40	5.0 to 8.5
40 to 50	3.3 to 5.0
50 to 75	1.5 to 3.3
> 75	< 1.5

SD Local Roads Plan

The Local Roads Plan has recommended design minimums for layer thicknesses of asphalt surfaced roads for different ranges of ADT. These values shown in Table 2.4 are based on a life cycle of 20 years (SDDOT, 2011).

Table 2.4: Local Road Plan Surfacing Design Minimums for a 20 Year Life Cycle

ADT	Base	Surface
<400	8" to 10"	Asphalt Surface Treatment *
401 to 750	10"	3" Asphalt Concrete
>750	**	**

*Asphalt surface treatments need to be repeated @ every 4-5 years for optimum performance

** Base and surface shall be designed according to current SDDOT Standards

2.3 Review of Low Volume Asphalt Road Design Components

There are several components that are essential in the design of roadways. The design of low volume roads is slightly different than the design of higher volume roads. The components that are especially important in the design of low volume roads are the surfacing, base course, subbase, and subgrade soil. In order for a pavement to adequately support traffic, it must be supported by its foundation, which is the base, subbase, and subgrade. This is especially true for many LVRs, which generally have thinner surface thicknesses than roads designed for greater traffic volumes.

Designing a road includes selecting the surface material, surface thickness, and base aggregate material and thickness, among other roadway characteristics. A typical cross-section of a road and its foundation was previously shown in Figure 1.1. These design parameters are significantly dependent upon the strength of the base aggregate, subgrade soil, and the traffic load. If these variables are not taken into account, the resulting roadway design could be either overly conservative or inadequate. Many times LVRs have been designed based on previously built roads. However, these other roads may have different conditions than the roads being built. Therefore, the resulting design may not be appropriate (Beckemeyer and McPeak, 1995). It is imperative to understand the design components in order to develop the most effective design of a LVR.

2.3.1 Asphalt Surfacing

The surfacing is the top layer of a pavement structure that the vehicles ride on. For a surface layer to be effective, it should distribute the loads from the traffic to the underlying layers, resist fatigue cracking, and resist permanent deformation (ASCE, 1992). Asphalt pavements are flexible pavements which reduce the load of traffic on the subgrade by distributing the traffic loads over larger and larger areas, through the depth of the pavement structure. The loads are reduced to a level at which the subgrade can support based on its bearing capacity (Mannering and Washburn, 2013). The distribution of the loads as they are reduced and spread to the subgrade is shown in Figure 2.1 for both an asphalt road with and without a subbase. Most of the roads in South Dakota are built without a subbase, and therefore have the stress distribution shown in Figure 2.2-B.

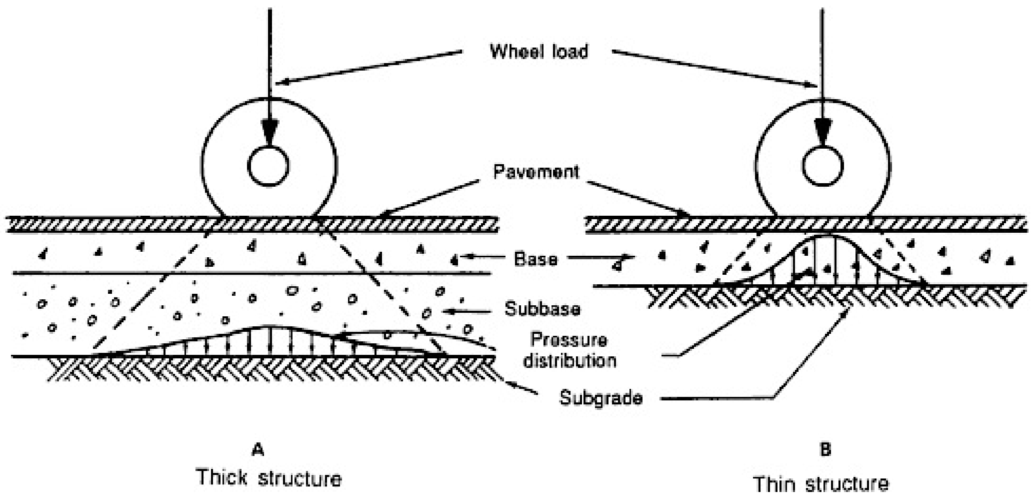


Figure 2.1: Distribution of pressures from traffic throughout thick (with a subbase) and thin (without a subbase) asphalt surfaced roads.

There are two types of asphalt surfacing commonly used for LVRs: asphalt concrete and asphalt surface treatments. Asphalt concrete is usually placed as a hot-mixed asphalt mat. For asphalt concrete pavement structures, the stronger, higher quality materials are placed towards the top of the structure where the loads are greater. The weaker, lower quality materials are placed towards the bottom of the structure where the loads are more distributed (Beckemeyer and McPeak, 1995). The second asphalt surface is an asphalt surface treatment, which is also called a blotter. Blotters consist of a layer of aggregate chips embedded in a thin layer of asphalt, which is placed on top of an aggregate base. This thin surface layer provides a smoother surface than gravel and prevents water from getting into the base course (Beckemeyer and McPeak, 1995). Ideally, the aggregate used in blotters are as clean, cubical shaped, and one-sized as possible. Any dust on the aggregate can prevent good cohesion to the asphalt (ASCE, 1992). The use of an asphalt concrete or asphalt surface treatment may be determined by the anticipated Average Daily Traffic (ADT). The SDDOT guidelines for surface type based on ADT are presented in Figure 2.4 in Section 2.3.7 (SDDOT, 2011).

The thickness of a pavement surface depends of the type of asphalt surface being used, the traffic volume, and the thickness and strength of the subgrade, and the strength of the subgrade (AASHTO, 2011). Pavement structures with asphalt concrete usually consist of 2-6 inches of asphalt concrete over a 6-12 inch aggregate base. The total thickness of a blotter surface is approximately ¼-1 inch (Beckemeyer and McPeak, 1995). The SDDOT guidelines for base and surface thicknesses were presented in Section 2.2.2 in Tables 2.1 & 2.2 (Beckemeyer and McPeak, 1995).

2.3.2 Base Course

The base course is an essential component of a roadway. The main purpose of a base course is to support the traffic load. Especially in asphalt surfaced roads, this layer distributes most of the traffic load to provide some structural support. A second purpose of the base course is to act as a drainage layer that permits water entering the pavement structure to drain. The base course is composed of aggregate granular material such as crushed stone, crushed gravel, and sand (AASHTO, 2011). The South Dakota state specifications for base course and subbase are shown in Table 2.5. The specification includes limits for gradation, liquid limit, plasticity index, and fractured faces (SDDOT, 2004). Limits on the percentage of fines, as well as the liquid limit and plasticity index also exist to ensure the base material as adequate permeability to permit drainage. If the available materials for a base course do not provide adequate support, there is the option of stabilizing the base layer to increase its strength. This can be accomplished with the use of Portland cement, asphalt, and lime among other materials. A properly stabilized base reduces the amount of pavement or quality of the aggregate needed to support the traffic loading. This can result in a reduction in cost of the pavement structure construction (AASHTO, 2011).

2.3.3 Subbase

The subbase is an optional layer in a LVR, depending on the demands of the traffic and the materials available for construction of the road. This layer is below the base course and above the subgrade soil. The subbase can provide additional support for the traffic loads, if needed. When the use of an adequate thickness of base is too expensive, a portion of the base layer may be replaced by a thicker but potentially less expensive subbase material. It is also useful in providing a barrier so the fines from the subgrade do not pump up into the base course, which would weaken it. In states such as South Dakota where frost occurs, the subbase may minimize the effects of frost action. The material used for the subbase material is usually either a granular material or a treated soil (AASHTO, 2011). The subbase specifications for South Dakota are shown in Table 2.5 (SDDOT, 2004).

Table 2.5: SDDOT Specifications for Aggregate Base Course and Subbase

Requirement	Aggregate Base Course	Subbase
Sieve	Percent Passing	
2” (50 mm)		100
1” (25.0 mm)	100	70-100
¾” (19.0 mm)	80-100	
½” (12.5 mm)	68-91	
No. 4 (4.75 mm)	46-70	30-70
No. 8 (2.36 mm)	34-58	22-62
No. 40 (425 µm)	13-35	10-35
No. 200 (75 µm)	3.0-12.0	0.0-15.0
Liquid Limit Max	25	
Plasticity Index	0-6	0-6
L.A. Abra. Loss, max.	40	50
Foot Notes	1, 2	
Processing Required	Crushed	Crushed

FOOTNOTES:

1. The fraction passing the No. 200 (75 µm) sieve shall not be greater than 2/3 of the fraction passing the No. 40 (425 µm) sieve. In no case shall the upper limit specified for the No. 200 (75 µm) sieve be exceeded.
2. Requirements include quarried ledge rock.

2.3.4 Subgrade Soil

The support of the subgrade soil is essential in a proper pavement design. The amount of pavement needed for a given traffic load depends on the strength of the in-situ material, which is the subgrade soil. Weaker subgrade soils require thicker and stronger bases and/or surfaces (ASCE, 1992). If the strength of the subgrade is underestimated, the resulting pavement will be overdesigned and, therefore, more expensive. On the other hand, if the strength is overestimated, the pavement could be under-designed and experience premature failure, which could also be very costly. There are a few different values used to describe the support offered by the soil: the CBR value and resilient modulus. Both of these measures are used for flexible pavement design. Relationships developed between the liquid limits of common SD soils to CBR and of DPI to CBR can be used to quickly estimate the subgrade soil support (Beckemeyer and McPeak, 1995). The support can vary significantly with the change in moisture content. Some soils can experience frost heave or are weakened by the freeze-thaw process, especially silty soils. (ASCE, 1992).

2.3.5 Geometry

The geometry along the width of the roadway is also important in creating a pavement structure with the strength to support the traffic load. The different aspects of this geometry can be seen in Figure 2.2. The primary functions of this geometry are to prevent water from saturating the road's foundation and to provide lateral support to the pavement and foundation.

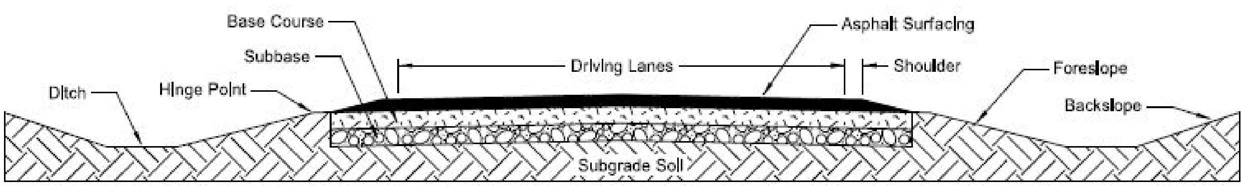


Figure 2.2: Typical Roadway Geometry

The cross-slope is the slope across road from the crown (center) of the roadway to the shoulder. This should be at around 2% for asphalt surfaced roads to allow the surface water to runoff. The hinge point is the point outside of the shoulder at which the slope of the roadway changes from the cross-slope to the foreslope. The foreslope runs from the hinge point down to the ditch (AASHTO, 2011).

It is ideal for the foreslope to be as flat as practical for several different reasons. One reason is that a flatter foreslope is safer by allowing area for drivers to maneuver with control in emergencies or when they leave the pavement surface. The foreslope also provides support for the subgrade soils. The flatter the slope, the more support that it provides. The maximum foreslope depends on the stability of the existing soils. A less steep foreslope also helps to ease maintenance and establish plant growth, which provides erosion control. The foreslope assists the ditch in moving surface runoff from the roadway away from the pavement (Beckemeyer and McPeak, 1995).

The shoulder is essentially an extension of the traveled roadway that provides lateral support for the base course and an area for emergency stopping of vehicles. The shoulder material can be the same as the pavement surfacing or a different material, such as gravel for an asphalt surfaced road. Truck and agricultural equipment that encroach onto the shoulder can cause serious distress. Therefore, methods, such as contrasting shoulder color and texture with the traveled way, can be implemented (AASHTO, 2011).

2.3.6 Drainage

Since moisture can have a significant effect on the strength of aggregate and soil materials, proper drainage is essential for a road to function adequately. Saturation causes base and subgrade materials to lose much of their strength. This loss in strength can lead to premature failure of a road. Even just a few large loads can potentially create much damage to a road with reduced strength (ASCE, 1992). In addition to reducing the strength of the granular base and subgrade soils, poor drainage can contribute to frost heave and pump fines from the subgrade up into the base. Because fines have less strength than the coarser materials used in the base course, the pumping of fines into the base also decreases the strength that the base provides. There are a number of different ways in which water can enter the pavement structure. It can seep in through cracks or joints in the pavement or through pavement infiltration. Water can also come up into the pavement system as groundwater from interrupted aquifers, springs, or high water tables (AASHTO, 2011). Most of the drainage issues can be solved by constructing good drainage into the road. A proper cross slope is necessary to provide a way for the surface to shed the water that falls onto it instead of letting the water sit and infiltrate into the base. Adequate foreslope and ditch grade separation is also essential to getting the runoff from the surface away from the pavement. (Beckemeyer and McPeak, 1995).

2.3.7 Traffic Volume

The primary function of a pavement structure is to carry the loads of the traffic travelling on it. Therefore, the traffic is a critical part of the design and performance of roads. In the geometric design (vertical curves, horizontal curves, etc.) of roads, the main traffic parameters used are average daily traffic (ADT) and peak hour volume. For the design of the pavement structure (surfacing, base, etc.), the amount and type of truck loads are commonly used in addition to ADT (ASCE, 1992). The greater the amount of traffic and the heavier the traffic is, the stronger the pavement structure has to be in order to support the load. Studies of the life cycle costs for different surfacing have shown which surface type is most cost effective at specific ADT's. An example of this for gravel, blotter, and HMA surfaces is shown in Figure 2.3 from the *Local Road Surfacing Criteria* (Zimmerman and Wolter, 2004). Using this chart, it can be seen that for roads with an ADT of 0 – 150, a gravel surface is most cost effective. However, blotter surfaces are most cost effective for roads with ADT's between 150 and 675, and HMA surfaces are for roads with over 675 ADT (Zimmerman and Wolter, 2004).

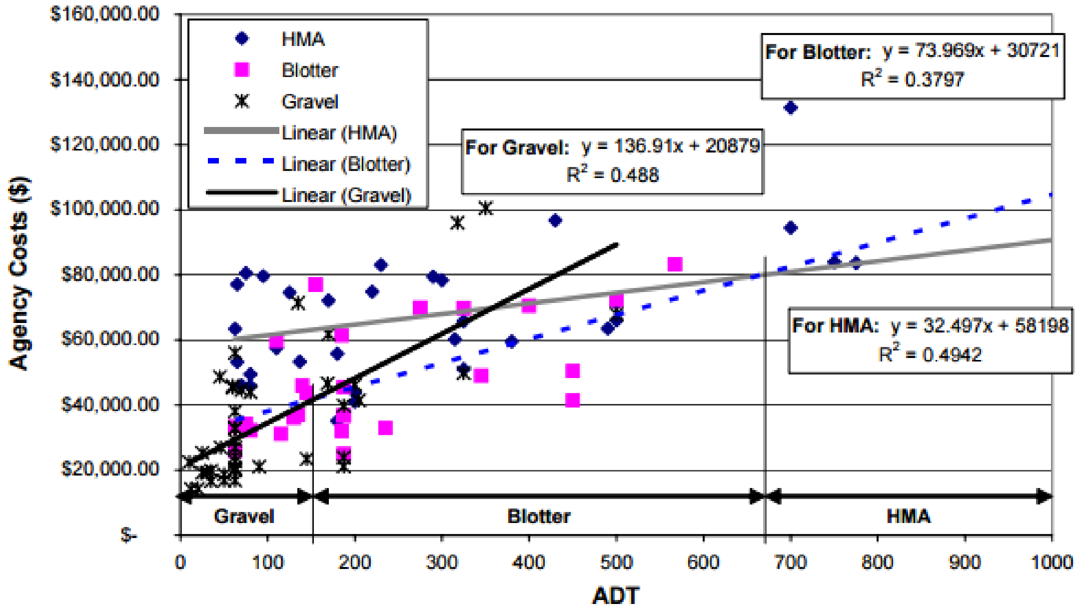


Figure 2.3: Default 20-Year Agency Cost Models (Per Mile), (Zimmerman and Wolter, 2004)

2.4 Dynamic Cone Penetrometer

The dynamic cone penetrometer (DCP) is a tool used to determine the support of a soil material. This section provides a description of the device and describes how it can be used. It also discusses the reliability of the DCP device and how the readings are affected by the tested material's gradation and moisture.

2.4.1 Description

The dynamic cone penetrometer (DCP) is a testing device used to determine the penetration resistance of a pavement, base course, or soil. This penetration resistance correlates to the strength of the material. The DCP originates from Australia, where it was invented by Scala in the 1950's. It was then further developed by Dr. D.J. Van Vuuren from South Africa in the 1960s for in-situ pavement evaluation. The current DCP device consists of a 17.6 lb hammer that falls from a height of 22.6 inches to strike an anvil that drives the shaft with a 60° cone on the end of it into the ground. This apparatus is shown in Figures 2.4 & 2.5 (ASTM, 2009).

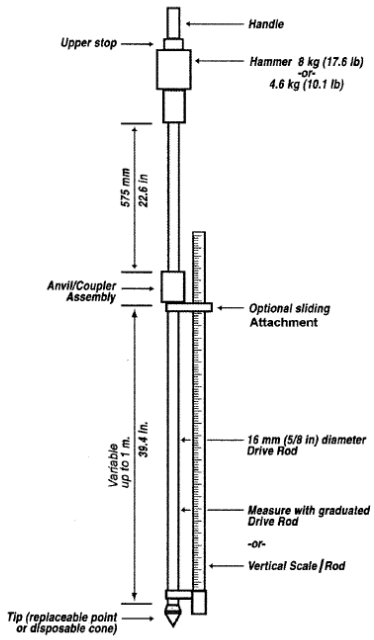


Figure 2.4: DCP Device Schematic

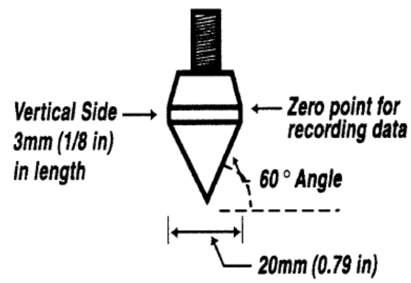


Figure 2.5: DCP Replaceable Point Tip

The vertical distance the cone penetrates into the ground for each blow is measured and recorded. This penetration per blow is the number used in analysis to determine the strength of the material. There are a variety of different names for the penetration per blow, depending on the agency. A summary of these names is listed in Table 2.6 for reference. In this study, the penetration per blow will be referred to as the Dynamic Penetration Index (DPI). This is the same terminology that the Minnesota Department of Transportation (MnDOT) uses (Dai and Kremer, 2006).

Table 2.6: DCP Penetration Index by Reference

Abbreviation	Name	Reference
PR	Penetration Rate	(Abu-Farsakh et al., 2004) & (Wu and Sargand, 2007)
DCPI	DCP Penetration Resistance	(Amini, 2003)
DCP	DCP Index	(ASTM, 2009)
DPI	Dynamic Penetration Index	(Dai and Kremer, 2006) & (Siekmeier et al., 2009-12)
DCP	DCP Value	(Livneh et al., 1995)
N/A	Penetration	(Paige-Green, 2011)
DN	DCP Number	(Ministry of Transport and Public Works, 2013)

2.4.2 Use in Analyzing Roads

The DCP is a simple and quick device that can be used to test the in-situ characteristics of an aggregate or soil. There are several different applications in which the DCP is used. From the results of the DCP test, the thickness of the layers can be determined, providing a continuous strength profile throughout the depth tested (Amini, 2003). Another application is in gravel pavement design, a method developed by Kleyn from South Africa in 1975. Also, in South Africa, the DCP is used in pavement rehabilitation design and evaluation and in the design of LVR's (Paige-Green, 2011).

One of the most common uses of the DCP is evaluation of aggregate bases, subgrade soils, and unbound pavement layers for Quality Assurance / Quality Control (QA/QC) in construction. The DOT's of several states, including Mississippi, Pennsylvania, and Kansas, use the DCP for this reason and to estimate other material parameters such as resilient modulus and California Bearing Ratio (CBR). In addition, the Iowa DOT has adopted a simple soil classification system for road design based on the DPI (Dai and Kremer, 2006).

MnDOT has used the DCP for over 20 years in several applications: identifying high strength layers in pavement structures and weak spots in constructed embankments, measuring the uniformity of in-situ base material, testing foundations to aid design, and ensuring proper compaction of backfill in edge drain trenches (Burnham, 1997). Within the past ten years, MnDOT has developed DPI limits for the inspection and quality control of base layer and subgrade compaction in road construction (Amini, 2003).

2.4.3 Reliability

The DCP has proven itself as a reliable testing device. The numerous strong correlations that have been developed between the DCP and CBR, resilient modulus, unconfined compression strength, and static plate load test values support this claim (Wu and Sargand, 2007). Abu-Farsakh tested and compared the resilient modulus calculated from the results of the DCP test with the results from the Falling Weight Deflectometer (FWD), Plate Load Test (PLT), and CBR tests. They found strong correlations between the DCP and these other tests (Abu-Farsakh, 2004). In the research performed to improve and validate the MnDOT DCP specifications, the DCP tests were duplicated. The results from the duplicated tests were very close or even the same as the results of the original tests. Therefore, it was concluded that the DCP test is repeatable and accurate (Dai and Kremer, 2006).

There are some variables that must be considered in analyzing the DCP data to ensure accurate and reliable results. The moisture content and the gradation of the material being tested can potentially vary the DPI greatly. These effects are discussed in more detail below. Another factor that could affect the results is the effect of vertical confinement on the tested material. Livneh addressed this issue in his research. He determined that there is some vertical confinement effect on the DPI of lower cohesive subgrade layers from rigid pavement and upper cohesive layers. This finding does not affect this study, since this study is concerned only with flexible pavements. Livneh also discovered that there was no effect on the DPI of cohesive subgrade from granular layers above it. Finally, he found that the DPI of granular base layers was affected by asphaltic layers above. In order to eliminate the significance of this effect of vertical confinement on the granular base, Livneh suggests boring a small hole in the asphalt layer to get to the granular layer instead of removing a large section of the asphalt (Livneh et al., 1995).

There are some instances in which it is not appropriate to use the DCP for accurate correlations. Although the DCP works well for estimating in-place density for properly compacted granular base materials, there can be too much variability when doing so for cohesive and selected granular materials (Abu-Farsakh, 2004). In addition, Van Vuuren from South Africa reports that the DCP was only effective for soils with CBR values in the range of 1 to 50 (Dai and Kremer, 2006).

2.4.4 Correlation to CBR

Many researchers have developed correlations of DPI to other values describing engineering properties, such as CBR, resilient modulus, and unconfined compression strength. One of the most common of the correlations is the one to CBR, since it is a well-known property that is used in pavement design. A multitude of researchers have established a correlation between DPI and CBR. One of the most accepted equations was developed by the U.S Army Corps of Engineers at the US Army Waterways Experiment Station (Abu-Farsakh, 2004):

$$\text{Log CBR} = 2.465 - 1.12 (\log \text{DPI}) \quad \text{or} \quad CBR = \frac{292}{DPI^{1.12}} \qquad \text{[Eqn. 1]}$$

----with DPI measured in mm/blow----

The effects of soil moisture content and dry density are considered negligible for this correlation since they both affect the DCP and CBR in similar ways.

2.4.5 Effects of Moisture

MnDOT has also performed research on the effect of moisture content on the results of the DCP test. Their research was used to modify their specification for aggregate base material to account for moisture and gradation. This specification is in terms of moisture relative to the material's optimum moisture content. This specification for fine grained material is in shown in Table 2.7 (Siekmeier et al., 2009). The results showed that, in general, as the moisture content increased, the DPI also increased. Most of the failing tests for the criterion in the specification in the research were a result of high moisture content (Dai and Kremer, 2006).

Table 2.7: MnDOT Target DPI Values for Fine Grained Soils

Plastic Limit	Estimated Optimum Moisture	Field Moisture as a Percent of Optimum Moisture	DCP Target DPI at Field Moisture
[%]	[%]	[%]	[mm/drop]
non-plastic	10-14	70-74	12
		75-79	14
		80-84	16
		85-89	18
		90-94	22
15-19	10-14	70-74	12
		75-79	14
		80-84	16
		85-89	18
		90-94	22
20-24	15-19	70-74	18
		75-79	21
		80-84	24
		85-89	28
		90-94	32
25-29	20-24	70-74	24
		75-79	28
		80-84	32
		85-89	36
		90-94	42
30-34	25-29	70-74	30
		75-79	34
		80-84	38
		85-89	44
		90-94	50

2.4.6 Effects of Gradation

The research that MnDOT did for the effect of moisture content on DCP results also included studying the effect of soil gradation (Dai and Kremer, 2006). In assessing the gradation, they developed the grading number (GN). This is a single number that represents the gradation of the material. It is calculated with the equation:

$$GN = \frac{25mm+19mm+9.5mm+4.75mm+2.00mm+425\mu m+75\mu m}{100} \qquad \text{[Equation 2]}$$

(25 mm represents the percent passing the 25mm sieve, etc.)

This equation is equivalent to:

$$GN(\%passing) = \frac{1"+3/4"+3/8"+No.4+No.10+No.40+No.200}{100} \qquad \text{[Equation 3]}$$

(1" represents the percent passing the 1" sieve, etc.)

A higher GN number represents a higher fine content, whereas a lower GN number represents a lower fine content. Their results showed that in general, as the GN increased, the DPI increased as well. A higher GN has more fines, which have less strength.

The MnDOT DCP specifications accounting for gradation are shown in Table 2.8. This table is used in construction inspection for quality assurance in Minnesota. These specifications help to ensure that a pavement foundation has been properly compacted so that the foundation provides the required support for traffic. It also was found that the interaction between GN and MC (Moisture Content) is statistically insignificant so the GN does not affect the MC and visa versa. The equation developed for DPI based on both moisture content and gradation is (Siekmeier et al., 2009):

$$DPI\ (mm/blow) = 4.76 * GN + 1.68 * MC - 14.4 \qquad \text{[Equation 4]}$$

Table 2.8: Current MnDOT DCP Specification

GN	MC (% dry)	Maximum Allowable SEAT (mm)	Maximum Allowable DPI (mm/blow)	GN	MC (% dry)	Maximum Allowable SEAT (mm)	Maximum Allowable DPI (mm/blow)
3.1-3.5	< 4.0	40	10	4.6-5.0	< 4.0	65	14
	4.1-6.0	40	10		4.1-6.0	75	17
	6.1-8.0	40	13		6.1-8.0	80	20
	8.1-10.0	40	16		8.1-10.0	90	24
3.6-4.0	< 4.0	40	10	5.1-5.5	< 6.0	90	19
	4.1-6.0	40	12		6.1-8.0	100	23
	6.1-8.0	45	16		8.1-10.0	110	26
	8.1-10.0	55	19		10.1-12.0	115	29
4.1-4.5	< 4.0	45	11	5.6-6.0	< 6.0	110	22
	4.1-6.0	55	15		6.1-8.0	120	25
	6.1-8.0	65	18		8.1-10.0	125	28
	8.1-10.0	70	21		10.1-12.0	135	32

2.5 Surface Condition Assessment

The condition of a pavement's surface, as determined by the extent of different distresses, can provide some indication of the overall pavement condition. There are many different methods that can be used to evaluate pavement surface condition including the Pavement Condition Index (PCI) and the FHWA method from "A Pavement Moisture Accelerated Distress Identification System", which is described in Appendix K of the AASHTO Green Book (AASHTO, 2011). Several states have their own methods, such as the Illinois Department of Transportation's (IDOT) Condition Rating Survey Program (IDOT, 2010) and the SDDOT's *Rural Road Condition Survey Guide* (Beckemeyer, 1995). The SDDOT *Rural Road Condition Survey Guide* is the method that will be used in this study since it was developed for use in South Dakota and in conjunction with the Rural Road Manual.

The different pavement conditions and distresses that were used to assess the pavement were weathering, oxidization, raveling, shoving, transverse cracks, longitudinal cracks, block cracks, alligator/fatigue cracks, rutting, patching, potholes, edge deterioration, and rideability. The frequency and severity of these distresses determined the rating that the pavement surface received. The pavement ratings were determined according to Table 3.1: Flexible Pavement Rating and Evaluation Scheme from the Rural Road Condition Survey Guide (Beckemeyer, 1995). This table (Table 3.1) is shown in Section 3.1.1.

2.5.1 Types of Distresses

There are two different types of failures that result in pavement distresses: structural failure and surface or functional failure. A structural failure is the loss of load carrying capacity of the pavement structure or the breakdown of at least one of the pavement's structural components or the subgrade to the degree that the pavement is unable to sustain the traffic loads. A surface failure is a failure that prevents the pavement from carrying its intended purpose without resulting in passengers' discomfort or high stresses in the vehicle from the pavement roughness. A surface failure may or may not occur along with a structural failure. Causes of the distresses can be the overload of the vehicular traffic, climatic and environmental conditions, and the freeze/thaw cycle (IDOT, 2010).

2.5.2 Selection of Distresses Considered

The IDOT manual describes several distresses that occur in flexible HMA pavements: alligator/fatigue cracking, block cracking, bleeding, centerline cracking, edge cracking, longitudinal cracking, permanent patch deterioration, potholes and localized distress, pumping and water bleeding, raveling, weathering, segregation, reflective "D" cracking, reflective widening cracking, rutting, shoving, and transverse cracking. The stresses that were considered in this study were the stresses that could be indicative of a structural failure because the structural failure could be the failure of the pavement's foundation. The distresses that could represent a structural failure are fatigue cracking, centerline cracking, edge cracking, longitudinal cracking, pavement patch deterioration, potholes and localized distresses, bleeding, pumping, reflective "D" cracking, reflective widening cracking, rutting, and transverse cracking. The reflective "D" cracking was not considered since none of the test sections were overlaid on top of a concrete pavement. Any level of severity of fatigue cracking and pumping can indicate a structural failure in the pavement. On the other hand, usually only high severity of centerline cracking, edge cracking, longitudinal cracking, potholes, reflective widening cracking, and transverse cracking indicate a structural failure. Pavement patch deterioration, potholes, rutting, and transverse cracking can all be indicative of impending localized structural failure (IDOT, 2010).

2.5.3 Description of Distresses Considered

Fatigue / Alligator Cracking: A series of interconnected cracks that create many-sided, sharp-edged pieces. This type of cracking occurs in the areas subject to repeated traffic loading, such as the wheelpaths. Initially, the cracks are fine and longitudinal. The cracking develops into a pattern that looks like chicken wire or alligator skin.

Centerline cracking: The cracking that occurs along the centerline in between two lanes of pavement.

Edge cracking: Crescent-shaped or fairly continuous cracks that are parallel to and within approximately 1-2 ft of the outer edge of the pavement. This type of cracking is usually load related and occurs more often in roads without paved shoulders.

Longitudinal cracking: Cracking that is approximately parallel to the centerline of the pavement.

Pavement patch deterioration: The deterioration of a patch that has been placed to repair or replace the original pavement.

Potholes and localized distresses: Holes of various sizes in the pavement formed when small pieces of the pavement surface have been removed by traffic.

Pumping: The ejection of water or fine-grained materials from the base or subgrade through cracks in the pavement surface. Pumping occurs from the pressure created from the traffic loads.

Rutting: Longitudinal surface depression that occurs in the wheelpaths.

Transverse cracking: Cracking that extends across the pavement approximately perpendicular to the pavement centerline.

(IDOT, 2010), (Beckemeyer, 1995)

3. Test Methods and Protocols

This chapter outlines the test methods and protocols used for both the field testing and lab testing done in this study. The field testing consisted of the surface condition assessment, the DCP test, and obtaining base course and subgrade samples. The laboratory testing included sample reduction and testing for moisture content, particle size/gradation, Atterberg Limits, and soil classification. In addition to testing, information about the age, ADT, ADTT, original design, and maintenance history of each road was obtained, if it was available.

3.1 Field Testing

This section details the testing that was performed in the field at each of the testing sites. The surface condition of the asphalt pavement was assessed to determine the performance of the pavement. The DCP test was performed on the base course and subgrade soil to obtain a penetration resistance of the soil. A boring was also done at each site so that the layer thicknesses could be measured and samples of the base and subgrade could be obtained for laboratory testing.

3.1.1 Surface Condition Assessment

The different pavement conditions and distresses that were used to assess the pavement were weathering, oxidization, raveling, shoving, transverse cracks, longitudinal cracks, block cracks, alligator/fatigue cracks, rutting, patching, potholes, edge deterioration, and rideability. The frequency and severity of these distresses determined the rating that the pavement surface received. The pavement ratings were determined according to Table 3.1: Flexible Pavement Rating and Evaluation Scheme from the Rural Road Condition Survey Guide.

Table 3.1: Flexible Pavement Rating and Evaluation Scheme (Beckemeyer, 1995)

	Rating	Surface Condition Description
Category 3	100 to 86 (excellent)	The pavement surface is in excellent condition. The pavement appears to be very smooth and is generally free of any distress. As the pavement nears a rating closer to the lower end of this category, some oxidation of the pavement surface may be present, and minimal amounts of low-severity hairline cracks or depressions may be visible.
Category 3	85 to 71 (very good)	The pavement surface is in very good condition, but surface deterioration is more evident. The pavement surface may be partially oxidized or weathered. Transverse and longitudinal cracks are visible, and crack widths are generally less than 3 mm (1/8 in) wide. Block cracking patterns may be appearing, but cracks have not deteriorated greatly. Some minor spalling or faulting may be present along the cracks. Additional types of surface deterioration may be present. Minor rutting may be noticeable in the outer wheel paths.
Category 2	70 to 56 (good)	The pavement surface is generally in good condition. The surface is noticeably oxidized and raveling may be present. Transverse and longitudinal cracks are between 6 and 12 mm (0.25 and 0.50 in) wide and may exhibit some deterioration (spalling). Depressions in cracked areas or around utility repairs may be noticeable. Alligator cracking may be evident in the wheel paths. Rutting is becoming more pronounced, and some shoving may occur at intersections. Minor patching may be present as a result of surface distresses or utility settlements.
Category 2	55 to 41 (fair)	The pavement surface is in fair condition. Pavement deterioration is much more advanced. Many reflective cracks are present on overlaid pavements. Block cracking is common and weathering is noticeable, with detrimental effects to the pavement. Some reflective cracks may be faulted or have medium- to high-severity spalls.
Category 1	40 to 26 (poor)	The pavement surface is in poor condition with poor rideability. Alligator cracking is severe, and potholes may be present. Rutting is common and, in some instances, is greater than 20 mm (0.75 in). The pavement edge may be deteriorated, and over 60 m (200 ft) of cracking per 90 square meters (1,000 sq ft) of pavement is present.
Category 1	25 to 0 (very poor to failed)	The pavement surface is in very poor to failed condition. The vast majority of the pavement surface is severely cracked and disintegrated. Traffic operations are severely affected.

For the purposes of this study, the six different rating categories from the Rural Road Condition Survey Guide were condensed into three different ratings categories. The three resulting categories were Category 1, Category 2, and Category 3. The "excellent" and "very good" categories from the Rural Road Condition Survey Guide made up Category 3 for this study, the "good" and "fair" categories made up the Category 2, and the "poor" and "very poor to failed" categories made up the Category 1. Each pavement surface was rated The following guidelines are provided by the Rural Road Condition Survey Guide for assessing the pavement surface (Beckemeyer, 1995).

Rating Guidelines:

- The pavement rating should not exceed 70 if more than 10% of the pavement area exhibits low-severity fatigue cracking.
- The pavement rating should not exceed 55 if more than 10% of the pavement area exhibits moderate-severity fatigue cracking.
- The pavement rating should not exceed 75 if minor rutting (0.25-0.50 in) is evident throughout the wheelpaths.
- The pavement rating should not exceed 60 if rutting in excess of 0.50 inches is present throughout the wheelpaths.
- The pavement rating should not exceed 90 if low-severity block cracking exists over more than 20% of the total pavement area.
- The pavement rating should not exceed 80 if medium- or high-severity block cracking exists over more than 20% of the total pavement area.

(Beckemeyer, 1995)

3.1.2 DCP Test

The Dynamic Cone Penetrometer (DCP) test was used to estimate the support of the base aggregates and the subgrade soils of the roads. The DCP test was performed at three locations for each test site: in the left lane outer wheel path, in the right lane outer wheel path, and on the centerline. For this test, the manual DCP apparatus was used. Before the DCP test was performed, a hole at least 2 inches in diameter was either axed or sawed into the pavement/surfacing to access the base aggregate. The DCP apparatus could be damaged if it was forced to penetrate the pavement.

The DCP test was then performed on the base and subgrade. The cone was driven up to a depth of 2 ft or until refusal, whichever was shallower. Refusal occurs when the cone penetration is less than 0.1 inch (3 mm) per blow for ten consecutive blows (Dai and Kremer, 2006).

The procedure for the DCP test is as follows:

1. The DCP apparatus was assembled.
2. The DCP was placed at the top of the base in the center of the hole in the pavement. The shafts were plumb and not touching the edge of the hole.
3. One hand dropped the hammer from partial height until the entire cone surface was below the reference surface. The other hand held the top handle. This step is called seating the cone.
4. The current shaft reading was recorded as the starting point for blow zero.
5. The hammer was raised to its upper limit and then dropped so that it freely fell to the anvil.

6. The reading on the shaft was recorded as the penetration for that blow. The shaft was read to the nearest millimeter.
7. Steps 6-7 were repeated up to a depth of 2 ft or until refusal.
8. The DCP was removed from the hole and disassembled.
9. The hole was filled, compacted, and patched.

The DCP penetration depth was plotted against the number of blows for each of the tests performed. The Penetration Resistance (PR), a measure of the depth of penetration of the DCP cone per blow, was determined for both the base and subgrade layers of each test site. All the PRs for each layer were averaged to obtain the layer PR. This PR value is what was used to estimate the CBR of the soil.

3.1.3 Aggregate Base and Subgrade Soil Samples

A boring of the base aggregate and subgrade soil was taken to obtain samples for laboratory testing. The boring was performed in the roadway near the location where the DCP tests were performed. Only one boring was performed for each test section to help minimize the destruction of the pavement surface. To obtain the boring, an auger attached to a skid loader was used. Care was taken to prevent contamination of the base aggregate and the subgrade soil with each other and the surfacing material. A bag of each the base aggregate and the subgrade soil was filled from the boring. These were the aggregate and soil samples brought back to the laboratory and used for the sieve analysis, Atterberg limits tests, and soil classification. Additional smaller samples of the base aggregate and the subgrade soil were immediately placed in plastic bags to be brought back to the laboratory. This small portion of the sample was used to determine the in-situ moisture content.

3.2 Laboratory Testing

Laboratory tests were performed on the samples of base course and subgrade soil that were obtained from the sites during field testing. These laboratory tests determine the in-situ engineering properties of the materials. These properties can be used to classify the soils and estimate their CBR value in order to determine their subgrade support. The gradation and plasticity index are the properties that defined in the state specification for the base course material.

3.2.1 Sample Reduction

In order to prepare the samples for testing, they had to be reduced in size to an appropriate size for the tests. This was performed in accordance with ASTM C702/702M-11: Standard Practice for Reducing Samples of Aggregate to Testing Size. A mechanical splitter (Method A) was used (ASTM, 2011-a).

3.2.2 Moisture Content

The moisture contents of the samples were determined by performing the moisture content test in accordance with the ASTM D2216-10: Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. Method A of this standard was used (ASTM, 2010).

3.2.3 Particle Size Analysis

The first particle size analysis test performed on the samples was washing the fines. This analysis followed Procedure A of ASTM C117-13: Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing (ASTM, 2013). Following the washing of the fines, a sieve analysis was performed according to ASTM C136-06: Standard Test Method for Sieve Analysis of Fine and Coarse

Aggregates (ASTM, 2006). For this analysis, a mechanical sieve shaker was used. The results of the two tests were combined for the final grain size distribution.

3.2.4 Atterberg Limits – Liquid Limit, Plastic Limit, Plasticity Index

The Atterberg Limits of the base aggregates and the subgrade soils were determined by performing ASTM D4318-10: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. The Multipoint Liquid Limit – Method A was used for determining the liquid limit (ASTM, 2010e1).

3.2.5 Soil Classification

After the results from the laboratory tests were determined, they were used to classify the subgrade soils. Upon completion of the laboratory tests, the gradation and Atterberg Limit data was then used for soil classification. Each soil was given two classifications: one according to ASTM D2487: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) (ASTM 2011-b) and one according to the AASHTO soil classification system. The AASHTO soil classification system from AASHTO M 145-91 is shown in Table 3.2 (MnDOT, 2015).

Table 3.2: AASHTO Classification of Soils and Soil-Aggregate Mixtures

CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES											
General Classification	Granular Materials (35% or less passing No. 200 (75µm) sieve)							Silt-Clay Materials (More than 35% No. 200 (75µm) sieve)			
Group Classification	A-1		A-3*	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis:											
Percent passing:											
No. 10 (2mm)	50 max.	---	---	---	---		---	---	---	---	---
No. 40 (425µm)	30 max.	50 max.	51 min.	---	---	---	---	---	---	---	---
No. 200 (75µm)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. (40No. 425µm) sieve:											
Liquid Limit	---		---	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity Index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min**
Usual Types of Significant Constituent Materials	Stone Fragments Gravel and Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as Subgrade	Excellent to Good							Fair to Poor			

*The placing of A-3 before A-2 is necessary in the "left to right elimination process" and does not indicate the superiority of A-3 over A-2.

**The plasticity index of A-7-5 is equal to or less than the liquid limit minus 30. The plasticity index of the A-7-6 subgroup is greater than the liquid limit minus 30.

3.3 Road History

Information on each road and its history was obtained from the respective county and/or the SDDOT so that the analysis of this study would be as accurate as possible. For many roads, not all of the information is known, but the information that is known was obtained. The desired information included the age, original design, ADT, ADTT, and maintenance history for each road. All of these can affect the performance of a pavement.

4. Methodology

The selection of low volume roads to be used for testing and sampling was based upon sites that would provide the necessary data for this study, as well as offer a collection of roads with varying surface qualities. Another consideration was that the locations needed to be in areas where the necessary equipment could be provided. Finally, the research team also needed to have access and permission to cut out pieces of pavement surface to allow for DCP testing and the removal of base and subgrade samples.

4.1 Testing Locations

All of the roads tested were located in the state of South Dakota, except for one road in Bowman County, ND. An effort was made to select roads from a variety of counties and locations around the state. Only asphalt surfaced roads with low traffic volumes (ADT < 2000) were included in this study. The specific sites were chosen in order to provide a variety of age and surface conditions among the different roads for the study. A limitation in the selection of test sites was that the county of the road undergoing testing had to be able to provide the auger and skidloader necessary to cut through the asphalt and sample the base, as well as traffic control during testing, in order for testing to occur.

For each of the selected test sites, the specific location for testing and sampling also had to be determined. If possible, the testing location was not on the top or bottom of a hill. This was done in order to avoid the possible fill sections at the top of a hill and sections that could be uncharacteristically weak due to excess moisture at the bottom of a hill. The testing location also had to be in an area that was a fairly average representation of the whole site in terms of the surface performance.

The roads that were used for evaluation were:

1. Harding County, SD: Route 867 (Camp Crook Road)
2. Bowman County, ND: 154th Avenue
3. Miner County, SD: South Railroad Street
4. Miner County, SD: Railroad Street (Canova)
5. Aurora County, SD: 262nd Street (Stickney)
6. Aurora County, SD: 389th Avenue (Plankinton)
7. Deuel County, SD: 311 (Astoria)
8. Codington County, SD: Old Highway 81 (Watertown)
9. Clay County, SD: Saginaw Road
10. Lincoln County, SD: 135 (Canton)
11. Pennington County, SD: Rockerville Road (Rockerville)
12. Pennington County, SD: Bombing Range Road (Scenic)
13. Brown County, SD: Highway 14 (Aberdeen)
14. Brown County, SD: Highway 17 (Aberdeen)

The following map (Figure 4.1) indicates with red stars the testing site locations. More detailed maps for each individual location can be found in Appendix A. At each of the testing locations, the field and laboratory testing was conducted as presented in Ch. 3.

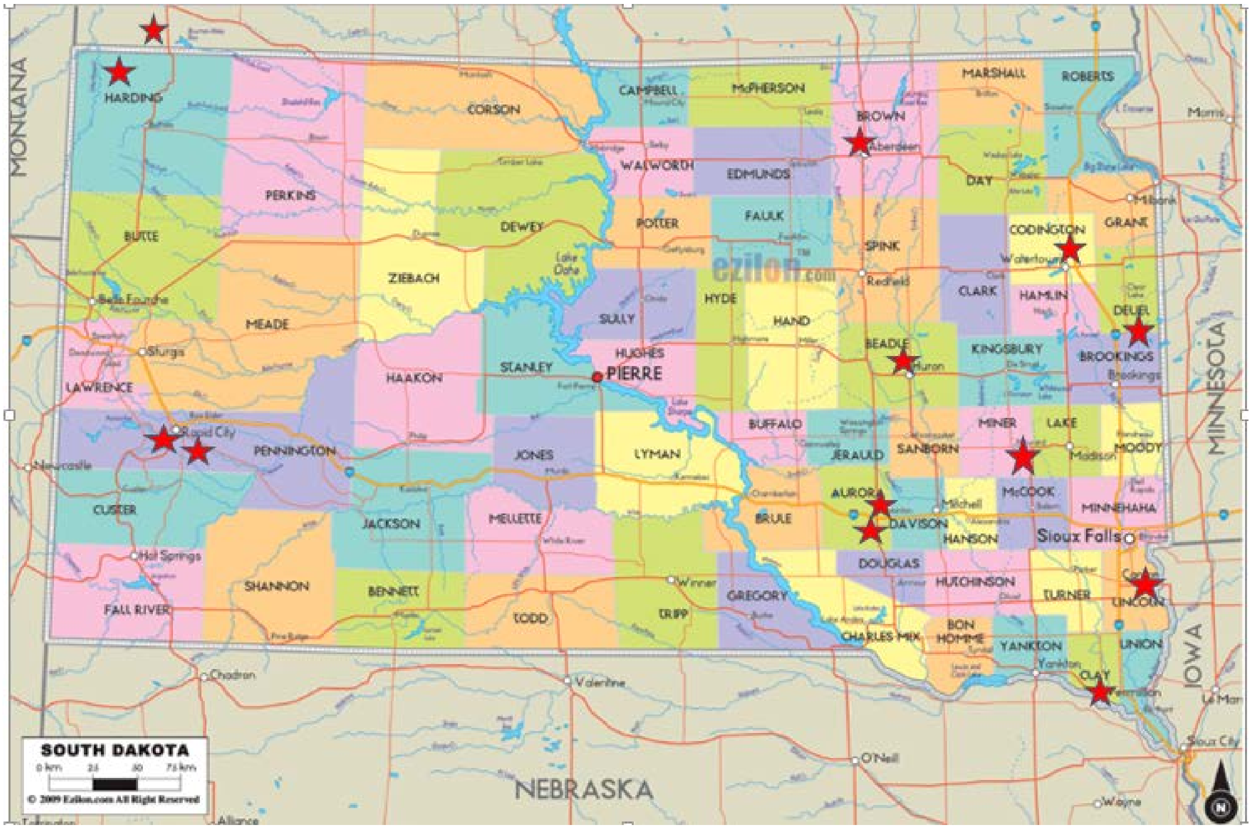


Figure 4.1: Map of Testing Locations

4.2 Testing Parameters

There were several parameters that were determined for each of the sample locations. Some of these parameters were obtained through research and the assistance of the county highway superintendents. This included ADT, ADTT, age of the road, and maintenance history. The other data was obtained through observation and measurements of the roads in the field and the results of laboratory tests. This data consisted of surface type, surface condition, surface and base thicknesses, base course gradation and plasticity index, base and subgrade moisture contents, and base and subgrade DCP penetration resistances.

4.3 Process of Comparing Road Performance Assessment to Recommended Design

The field and laboratory testing provides the necessary information to determine the required road thickness using the methods presented in the SDDOT Rural Road Design, Maintenance, and Rehabilitation Guide and in the SD Local Road Manual. This first design method uses the subgrade support and the ADTT to determine the required layer thicknesses. The latter design method depends only on the ADT. Both methods use the SDDOT base course specification. The following steps describe how the data was used to validate the effectiveness of the design methods by determining the recommended design thicknesses and relating the design to the road performance.

1. Laboratory data was used to determine the material properties (gradation, PI, LL).
2. Base course material properties were used to determine if the materials met the state specification.
3. Subgrade material properties and DCP results were used to establish the subgrade support.

4. Subgrade support and traffic data were applied to the design methods to determine the required layer thicknesses.
5. Design layer thicknesses were compared to the in place layer thicknesses to determine the adequacy of the existing pavement layer thicknesses.
6. Surface condition data was assessed to determine the road rating.
7. Analysis was conducted to assess how layer thicknesses and material properties influence observed road performance.
8. The effectiveness of the design methods were validated based on how the determination of design thickness and material properties influenced road performance.

The result of this process will subsequently be used to evaluate the effectiveness of the LVR design methods.

5. Results

Fourteen roads were tested during the summer of 2014, followed by another two roads in the summer of 2015. The field evaluations were conducted during the months of May through September. This chapter presents a summary of the data collected in both the field and laboratory testing.

5.1 Surface Condition

The surface condition assessment was performed as presented in Section 3.1.1 and Table 3.1, according to the SDDOT Rural Road Condition Survey Guide. Table 5.1 lists each road under the category that indicates its pavement condition. The detailed surface condition assessments for each of the roads are presented in Appendix E, Tables E.1 – E.16. Figures 5.1 – 5.3 are pictures from three different roads that demonstrate examples of the three different surface condition categories.

Table 5.1: Surface Condition Assessment Summary

Category 1	Category 2	Category 3
Harding – Hwy 867	Deuel – Hwy 311 original	Lincoln – Hwy 135
Bowman – 154th Ave	Aurora – W. 262nd St (Stickney)	Miner – Railroad St
Beadle – Broadland Rd	Pennington – Rockerville Rd	Deuel – Hwy 311 rehab
Auora – E. 262nd St (Stickney)	Brown – Hwy 17	Codington – Old Hwy 81
Pennington – Bombing Range Rd	Aurora – 386th Ave (Plankinton)	
Brown – Hwy 14		
Clay – Saginaw Ave		

Figure 5.1 shows an example of Category 1 pavement condition on Saginaw Avenue in Clay County. This pavement has severe fatigue cracking with disintegrating pavement in and around these cracks. This disintegration has resulted in some potholes. The multiple patches contain similar fatigue cracking and disintegration as the original pavement. There is also detrimental raveling and significant rutting present.

Figure 5.1: Category 1 Pavement Condition – Clay County Saginaw Avenue

The original section of Deuel County Highway 311 as shown in Figure 5.2 is an example of Category 2 pavement condition. The asphalt surface exhibits moderate signs of oxidation, which is typical of a pavement that is 51 years old. There is also some age related cracking, as seen by the wide crack spacing. The cracks also show signs of low severity deterioration. Finally, there is moderate rutting in the wheel paths and some edge deterioration.

Figure 5.2: Category 2 Pavement Condition - Deuel County Highway 311-Original

Figure 5.3 shows Railroad Street in Canova, a town in Miner County. This road was classified as having Category 3 pavement condition. There is some partial weathering and oxidation. The visible cracking is minimal, and the cracks that exist are very narrow. There is essentially no rutting in the wheel paths.

Figure 5.3: Category 3 Pavement Condition–Miner County Railroad St. (Canova)

5.2 Base Course Quality

The gradations, LL, and PI for each base course sample determined during laboratory testing are shown Table 5.2, along with the requirements for the SDDOT base course specification. Charts of these results are presented in Appendix B. The gradation, LL, and PI results for the samples were compared to the specification to determine if the base course satisfied this specification. Base course samples that had any one of the gradations, LL, or PI outside of the range for the specification by more than 2% passing or 2% moisture content were considered to not meet the SDDOT base specification.

Table 5.2: Laboratory Test Results

Sieve Size	1"	3/4"	1/2"	No.4	No.8	No.40	No.200	LL	PI	Meets Spec
	Percent Passing									
SDDOT Base Spec	100	80-100	68-91	46-70	34-58	13-35	3-12	≤ 25	0-6	
Harding - Hwy 867	100	-	93	70	56	43	23	30	16	No
	100	100	97	77	62	47	21	24	8	
Bowman – 154th Ave	100	-	93	69	53	36	16	27	11	No
	100	96	89	65	50	33	15	27	8	
Miner - Railroad St	100	99	98	78	63	32	13	29	12	No
Beadle – Broadland Rd	100	92	79	62	51	31	14	21	NP	Yes
	99	92	83	66	51	24	8	22	NP	
	99	92	83	66	51	24	8	21	NP	
Deuel – Hwy 311 Rehab	96	92	85	64	51	27	9	N/A	NP	Yes
	100	97	92	73	60	30	9	N/A	NP	
Deuel – Hwy 311 Original	97	88	78	60	49	24	9	N/A	NP	Yes
Aurora – E. 262nd St (Stickney)	100	97	90	71	58	30	12	27	11	No
Aurora - W. 262nd St (Stickney)	100	95	86	69	57	29	13	25	10	No
Aurora - 386th Ave (Plankinton)	99	97	89	70	57	25	10	21	6	Yes
Codington – Old Hwy 81	100	94	83	54	38	16	6	N/A	NP	Yes
	100	99	91	67	51	20	7	20	NP	
	100	94	85	85	62	39	24	25	10	
Clay - Saginaw Ave	100	97	88	67	56	28	10	19	4	Yes
Lincoln - Hwy 135	98	92	86	71	56	19	8	N/A	NP	Yes
Pennington - Rockerville Rd	100	98	92	73	64	52	34	23	3	No
Pennington - Bombing Range Rd	100	96	91	73	62	34	20	37	22	No
Brown - Hwy 14	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Brown - Hwy 17	100	99	92	72	60	33	13	25	7	Yes

Within 2% passing / moisture content range (orange)

Over 2% passing / moisture content range (red)

5.3 Subgrade Classification

The results of the laboratory tests, as well as the resulting AASHTO classifications for the subgrade soil samples are shown in Table 5.3. For the roads that had more than one subgrade sample and the resulting classifications were different, the subgrade was considered to be the lowest classification. This was done to be conservative because the lower classified soils have lower strengths than the higher classified soils.

Table 5.3: Subgrade Gradation, LL, PI, and AASHTO Classification								
	Percent Passing				LL	PI	AASHTO Classification	
County - Road	**No.4**	**No.10**	**No.40**	**No.200**			Individual Sections	Road
Harding - Hwy 867	100	97	79	58	37	23	A-6	A-6
Bowman - 154th Ave	89	83	77	47	32	14	A-6	A-6
	97	96	93	68	37	22	A-6	
Miner - Railroad St	95	84	63	53	42	27	A-7-6	A-7-6
Beadle - Broadland Rd	99	97	90	59	42	24	A-7-6	A-7-6
	100	99	94	65	42	23	A-7-6	
	99	97	90	60	40	24	A-6	
Deuel - Hwy 311 Rehab	95	89	74	41	30	15	A-6	A-7-6
	98	94	81	53	41	21	A-7-6	
Deuel - Hwy 311 Original	98	96	87	67	38	21	A-6	A-6
Aurora - E. 262nd St (Stickney)	97	93	83	52	46	31	A-7-6	A-7-6
Aurora - W. 262nd St (Stickney)	100	100	96	79	40	25	A-6	A-6
Aurora - 386th Ave (Plankinton)	97	93	85	60	34	20	A-6	A-6
Codington - Old Hwy 81	98	95	81	61	41	23	A-6	A-6
	93	86	69	50	37	16	A-6	
	99	97	87	66	40	19	A-6	
Clay - Saginaw Ave	99	98	91	76	38	20	A-6	A-6
Lincoln - Hwy 135	99	99	94	80	54	32	A-7-5	A-7-5
Pennington - Rockerville Rd	100	93	86	66	24	2	A-4	A-4
Pennington - Bombing Range Rd	100	96	88	78	63	45	A-7-6	A-7-6
Brown - Hwy 14	100	100	94	74	64	35	A-7-6	A-7-6
Brown - Hwy 17	100	98	88	54	41	23	A-7-5	A-7-5

5.4 Subgrade DCP

The results of the DCP tests for each road are graphed in Appendix C. Table 5.4 has the average PR for the subgrade layer of each test section determined from the raw DCP data as presented in Section 2.4. The CBR for each section was then calculated with Equation 1. Then the CBR values for roads that had more than one section tested were averaged, as shown in Table 5.4. The resulting subgrade support to be used in the Rural Road Guide design method was then determined according to Table 2.3 from Section 2.2.2.

Table 5.4: Subgrade Support From DCP Test Results

	Average PR (mm/blow)	Average Section CBR	Average Road CBR	Support
Harding - Hwy 867	21	10	19	high
	8	28		
Bowman - 154 Ave	12	18	19	high
	11	20		
Miner - Railroad St	7	33	33	high
Deuel - Hwy 311 rehab	37	5	7.5	medium
	21	10		
Deuel - 311 org	33	6	6	medium
Aurora - E. Stickney	23	9	9	medium
Aurora - W. Stickney	27	7	7	medium
Aurora - Plankinton	28	7	7	medium
Codington - Old Hwy 81	39	5	7	medium
	18	12		
	44	4		
Clay - Saginaw Ave	31	6	6	medium
Lincoln - Hwy 135	37	5	5	medium
Pennington - Rockerville	11	20	20	high
Pennington - Scenic	31	6	6	medium
Brown - Hwy 14	28	7	7	medium
Brown - Hwy 17	24	8	8	medium

5.5 Results Summary

Figure 5.4 is a comparison of the layer thicknesses for each of the sections of all the roads tested. The poor performing roads are at the left of the chart, the average performers are in the middle, and the good performers are on the right side. Most of the good performing roads have significantly greater pavement and base thicknesses than the other roads.

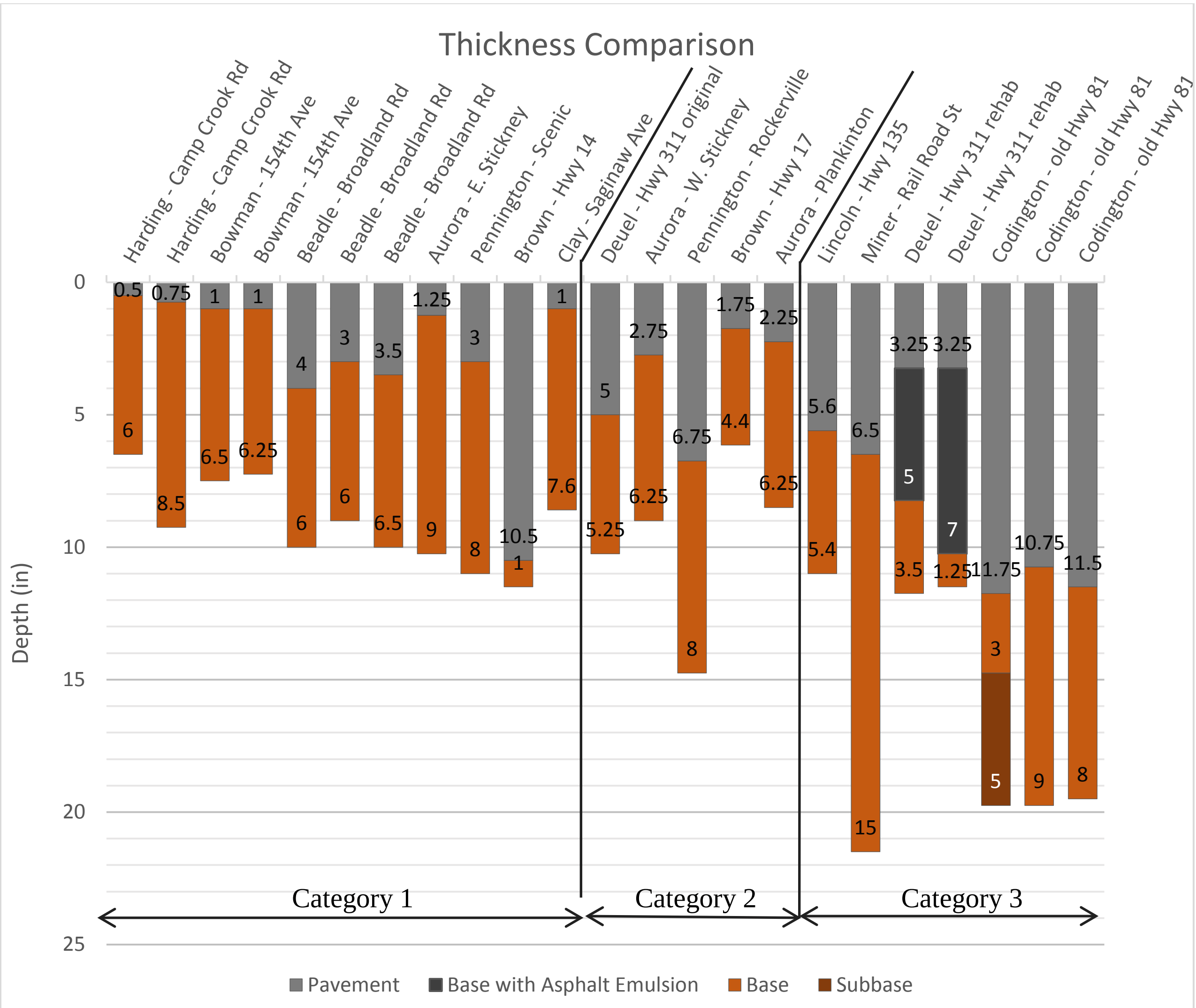


Figure 5.4: Actual Layer Thickness Comparison

Table 5.5 is a summary of the field and laboratory evaluations along with the average daily traffic for each road.

Table 5.5: Summary of Results								
Surface Condition	**County**	**Road**	**Average Pavement Thickness**	**Average Base Thickness**	**Pavement Type**	**ADT**	**Base Meets State Spec**	**Subgrade AASHTO Classification**
Category 1	Harding	867	0.625	7.25	Blotter	34	N	A-6
	Bowman	154 Ave	1	6.25	Blotter		N	A-6
	Beadle	Broadland Rd	3.5	6.25	Mat	97	Y	A-7-6, A-6
	Aurora	E. Stickney	1.25	9	Blotter	171	N	A-7-6, A-6
	Pennington	Bombing Range Rd	3	8	Mat	663	N	A-7-6
	Brown	Hwy 14	10.5	1	Mat	1400	N/A	A-7-6
	Clay	Saginaw Ave	1	7.625	Blotter	601	Y	A-6
Category 2	Deuel	311 - Original	5	5.25	Mat	35	Y	A-6
	Aurora	W. Stickney	2.75	6.25	Blotter	212	N	A-7-6
	Pennington	Rockerville Road	6.75	8	Mat	530	N	A-4
	Brown	Hwy 17	1.75	4.375	Blotter	325	Y	A-7-5
	Aurora	386th Ave	2.25	6.25	Blotter	113	Y	A-6
Category 3	Lincoln	135	5.625	5.375	Mat	506	Y	A-7-5
	Miner	Railroad St	6.5	15	Mat		N	A-7-6
	Deuel	311 - Rehab	3.25	8.25	Mat	370	Y	A-7-6, A-6
	Codington	Old Hwy 81	11.25	8.25	Mat	1929	Y	A-6

6. Analysis

The Rural Road Manual (Beckemeyer and McPeak, 1995) determines the subgrade support based on its CBR. The CBR may be estimated from the subgrade's liquid limit or from its DPI value from the DCP tests. The correlation between LL and CBR values was presented in Table 2.3. The DPI values were converted to CBR values using Equation 1, as described in Section 2.2.2. The ranges of CBR values that correlate to different subgrade supports are shown in Table 6.1 (Beckemeyer and McPeak, 1995).

Table 6.1: Subgrade Support Based on CBR

Subgrade Support	CBR
High	> 10
Medium	3 - 10
Low	< 3

The subgrade support may also be determined from its AASHTO soil classification. The AASHTO soil classification system was presented in Table 3.2. As previously shown in Table 5.3, all the subgrade soils were classified as A-6 or A-7 soils, except for the Pennington County Rockerville Road subgrade, which was classified as A-4. According to the AASHTO classification system these soils all are considered fair-poor rating as a subgrade. For this study, the AASHTO subgrade rating of fair-poor was considered to be equivalent to the Rural Road Manual subgrade support of low.

Therefore, there are three different ways the subgrade support was determined in this study. However, not all three methods resulted in the same support. The subgrade supports determined from each method for each road are summarized in Table 6.2. The AASHTO classification always resulted in low subgrade support. The support determined with the CBR from the DCP was always higher than the AASHTO support.

The subgrade support determined with the CBR from the LL varied: some agreeing with the AASHTO support, some agreeing with the DCP support, and others suggesting a subgrade support in between the AASHTO and DCP supports.

Table 6.2: Subgrade Comparison

Surface Condition	**County**	**Road**	**Subgrade Support**		
			AASHTO	**CBR from LL**	**CBR from DCP**
Category 1	Harding	867	low	med	high
	Bowman	154 Ave	low	med	high
	Beadle	Broadland Rd	low	med	N/A
	Aurora	E. Stickney	low	med	med
	Pennington	Bombing Range Rd	low	low	med
	Brown	Hwy 14	low	low	med
	Clay	Saginaw Ave	low	med	med
Category 2	Deuel	311	low	med	med
	Aurora	W. Stickney	low	med	med
	Pennington	Rockerville Road	low	high	high
	Brown	Hwy 17	low	med	med
	Aurora	386th Ave	low	med	med
Category 3	Lincoln	135	low	low	med
	Miner	Railroad St	low	med	high
	Deuel	311	low	med	med
	Codington	Old Hwy 81	low	med	med

The subgrade supports determined with the CBR calculated from the DCP test results are all higher than the AASHTO supports because these tests were performed throughout the summer when the conditions were drier than in the wet design conditions, and so they may not be a true representation of the soil type. Therefore, the subgrades would have been stronger when they were tested throughout the summer than they are in their weaker condition when it is wet. Flexible road design methods typically use subgrade strength parameters obtained when the subgrade is in its weakest state. Because of this the DCP results may not be accurate representations of the design conditions of the subgrade soils in their weakest state, this may overestimate subgrade strength conditions. Detailed review of the literature did not provide a method to correct DCP results based on changes in moisture content. Had all the roads been tested during the spring thaw, then the DCP results may have been more consistent with the other methods used to estimate subgrade support in the Rural Road Design Guide. Therefore, the subgrade support values estimated from the DCP test results were not used as part of the design analysis.

The actual thicknesses of the layers for the roads were compared to the thicknesses required by the Rural Road Design Guide and the SD Local Road Plan. This comparison, as well as the ADTT used in the design are shown in Table 6.3. The actual ADTT was only known for three of the roads: Brown County Highways 14 & 17 and Deuel County Highway 311 – Rehab. For the other roads with unknown ADTT, an ADTT range was estimated as 8-15% of the road ADT. If this estimated range fell into multiple ADTT levels in the Rural Road Design Guide, the higher ADTT level was used for the design comparison.

Table 6.3: Comparison of Actual Layer Thicknesses to Design Thicknesses								
			Actual Thickness		Rural Road Guide Thickness		SD Local Road Plan Thickness	
	County - Road	ADTT (8% - 15%)	Pavement	Base	Pavement	Base	Pavement	Base
Category 1	Harding – Hwy 867	3-6	0.625	7.25	N/A	6.5	N/A	8-10
	Bowman - 154 Ave	0-5	1	6.25	N/A	6.5	N/A	8-10
	Beadle - Broadland Rd	8-15	3.5	6.25	6.5	6	N/A	8-10
	Aurora- E. 262nd	14-26	1.25	9	N/A	11.5	N/A	8-10
	Pennington- Bombing Range Rd	53-100	3	8	9	10	3	10
	Brown – Hwy 14	280*	10.5	1	11.5	1	N/A (ADT>750)	
	Clay – Saginaw Ave	48-90	1	7.625	N/A	14.5	N/A	8-10
Category 2	Deuel – Hwy 311 Org	3-6	5	5.25	6.5	6	N/A	8-10
	Aurora – W. 262nd St	17-32	2.75	6.25	N/A	14.5	N/A	8-10
	Pennington - Rockerville Rd	42-80	6.75	8	9	10	3	10
	Brown – Hwy 17	0*	1.75	4.375	N/A	6.5	N/A	8-10
	Aurora – 386th Ave	9-17	2.25	6.25	N/A	11.5	N/A	8-10
Category 3	Lincoln - Hwy 135	40-76	5.625	5.375	9	10	3	10
	Miner – Railroad St	**	6.5	15	6.5	12	N/A	8-10
	Deuel – Hwy 311 Rehab	26*	3.25	8.25	7.5	8	N/A	8-10
	Codington – Old Hwy 81	154-290	11.25	8.25	9.5	8.25	N/A (ADT>750)	
	*actual ADTT	**estimated ADT < 50			Blotter	Mat		

Only three roads satisfied the Local Road Plan thickness requirement: Aurora County E. 262nd Avenue, Miner County Railroad Street, and Deuel County Highway 311 – Rehab. Also, the Local Road Plan design did not apply to Brown County Highway 14 and Codington County Old Highway 81 because they have ADTs greater than 750. The Local Road Plan design depends only on ADT and not the subgrade support. It is a more conservative design method than the Rural Road Guide. For these reasons, it is difficult to evaluate the effectiveness of the Local Road Plan design within this study. Therefore, the remainder of the analysis will evaluate only the Rural Road Guide design.

Table 6.4 summarizes the results of the comparison between the actual and design thicknesses, as well as whether the base course meets the SDDOT specification and whether the road received regular maintenance (regular chip seals). The design thicknesses were based on the subgrade support determined with the AASHTO soil classification only, not with the LL or DCP results. Only about a third of the Category 1 performing roads had adequate base course or received regular maintenance, and only two roads had adequate layer thicknesses. 50% of the Category 2 performing roads had base course that meets the specification. None of these roads had adequate layer thicknesses. There were also 60% of the Category 2 performing roads that received adequate maintenance. The maintenance records were not known for the two roads from Aurora County in this performance category, as indicated by the question marks in Table 6.4. However, since these roads were constructed as blotters, their current thicknesses suggest that they have received a few chips seals throughout their approximately 20 year lifetimes. If it is therefore assumed that this satisfied adequate maintenance schedules, then all of the average performing roads received regular maintenance. Three out of the four Category 3 performing roads had base course that met the specification. Half of these roads had layer thicknesses that satisfied the design criteria, and all of these roads received regular maintenance.

Table 6.4: Comparison to Design Guides						
Surface Condition	**County**	**Road**	**SD Local Road Plan Adequate Thickness**	**Rural Road Guide Adequate Thickness**	**Base Meets State Spec**	**Regular Maintenance**
Category 1	Harding	867	No	Yes	No	< 1 yr
	Bowman	154 Ave	No	Yes	No	< 1 yr
	Beadle	Broadland Rd	No	No	Yes	No
	Aurora	E. Stickney	Yes	No	No	No
	Pennington	Bombing Range Rd	No	No	No	Yes
	Brown	Hwy 14	N/A	No	N/A	Yes
	Clay	Saginaw Ave	No	No	Yes	No
Category 2	Deuel	Hwy 311 - org	No	No	Yes	Yes
	Aurora	W. Stickney	No	No	No	?
	Pennington	Rockerville Road	No	No	No	Yes
	Brown	Hwy 17	No	No	Yes	Yes
	Aurora	386th Ave	No	No	Yes	?
Category 3	Lincoln	Hwy 135	No	No	Yes	Yes
	Miner	Railroad St	Yes	Yes	No	Yes
	Deuel	Hwy 311 - rehab	Yes	No	Yes	Yes
	Codington	Old Hwy 81	N/A	Yes	Yes	Yes

Thickness appears to be one of the most important factors in pavement performance. Except for two roads, all those that had adequate thicknesses were categorized as Category 3 performers. Regular maintenance also seems to help a pavement perform as it meant to by preserving the pavement’s condition. All of the roads that received regular maintenance, except for two, had either Category 2 or Category 3 performance, and all of the roads in these two performance categories had regular maintenance. When a base course that met state specifications was combined with a pavement that receives regular maintenance, they worked together to keep a pavement at Category 2 performance condition. When a good quality base was combined with adequate layer thicknesses and regular maintenance, the roads had Category 3 performance.

The ages of the roads tested were compared to see if the ages correlated to the pavement performance. It might seem reasonable for the newer roads to perform better than the older roads. However, this is not the case for the roads tested, as shown in Table 6.5. Some of the newest roads are Category 1 performers, and a couple of the oldest roads were Category 3 performers. There appears to be little correlation between the age of the road since it was built and its performance.

Table 6.5: Age Comparison

County	Road	Age at Testing
Harding	Camp Crook Rd.	1
Bowman	154 Ave.	1
Beadle	Broadland Rd.	34
Aurora	281 St. - E.Stickney	23
Pennington	Bombing Range Rd. - Scenic	15
Brown	Hwy 14	37
Clay	Saginaw Ave	10
Deuel	Hwy 311 - original	51
Aurora	281 St. - W.Stickney	23
Pennington	Rockerville Rd.	21
Brown	Hwy 17	?
Aurora	386 Ave. - Plankinton	?
Lincoln	Hwy 135	53
Miner	S. Railroad St.	16
Deuel	Deuel - rehab	25
Codington	Old Hwy 81	78

LEGEND

Age (years)
0-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80

There are three main factors that can impact the performance of an asphalt surfaced road: subgrade support, thickness, and maintenance. Of these three factors, thickness had the greatest impact on the performance of the roads in this study. However, to build a good performing pavement, adequate thickness based on the Rural

Road Guide should be combined with good base quality and regular maintenance. On the other hand, the ages of the tested roads did not seem to have a significant correlation to their pavement performance.

7. Summary, Conclusions, and Recommendations

7.1 Summary

In this study, 16 different low volume, asphalt surfaced roads in the South Dakota area were tested in order to correlate design with performance. The age, maintenance, and traffic count information was obtained for the roads tested. For each road, the pavement was analyzed for its performance, the in-situ base and subgrade were tested with the DCP and measured for their thicknesses, and base and subgrade samples were obtained. The base and subgrade samples were tested for moisture, gradation and Atterberg Limits. Using the base gradation and Atterberg Limit test results, it was determined whether each base course satisfied the SDDOT base course specification. The subgrade gradation and Atterberg Limit test results were used to determine the support each subgrade provided. The subgrade support, ADTT, and layer thicknesses were then used to compare each road to the applicable design recommendation in the SDDOT Rural Road Design, Maintenance, and Rehabilitation Guide for each road. This comparison was then used with the result of the pavement performance evaluation to determine if the recommendations from this Rural Road Manual are adequate.

7.2 Conclusions

1. The three design requirements of material quality, layer thicknesses, and maintenance schedule all contribute to the pavement performance of low volume, asphalt surfaced roads. When these three aspects satisfy the recommendations of the Rural Road Design, Maintenance, and Rehabilitation Guide, they provide the support needed for the pavement to perform well. Therefore, this design guide

provides adequate design recommendations for low volume, asphalt surfaced roads in South Dakota.

a. If none of the design recommendations are satisfied, the road performance fall into Category 1.
b. If only one of the design recommendations is satisfied, the pavement may have either Category 1 or Category 2 performance.
c. If both the base course specification and regular maintenance are satisfied, the road performance will most likely be Category 2 but may also be Category 3.
d. If both the required layer thicknesses and regular maintenance are satisfied, the pavement will have a performance of Category 3.
e. If all three of the design recommendations are satisfied, the road have Category 3 pavement performance.

2. The AASHTO soil classification is the most suitable method, compared to using the liquid limit or DCP results, for determining the subgrade support used in the Rural Road Design Guide.
3. The age of the road does not strongly correlate to the pavement's performance. Therefore, the way the road is built and the quality with which the road is built and maintained have a greater impact on the performance than the age of the road.
4. The DCP may not be an adequate measure of the base course and subgrade soil design support when tested throughout the summer, at lower moisture contents than the wet, spring design condition.

7.3 Recommendations

1. Due to the overestimation of subgrade strength by the summer DCP tests, it is recommended that:
    a. DCP tests are run on these same roads in the spring during wet conditions and then the analysis repeated.
    b. A methodology be developed to adjust DCP data based on water content variations and then the analysis repeated.
2. In this study, roads with both blotter and HMA flexible pavements were tested and analyzed together. If the number of roads tested was increased, then the two types of pavements could be analyzed separately to determine the effectiveness of the design methods for each type instead of for flexible pavements as a whole.
3. It is recommended that the SDDOT Rural Road Design, Maintenance, and Rehabilitation Guide be used as recommendations for the design of low volume, asphalt surfaced roads in South Dakota coupled with a regular maintenance schedule in order to provide good performing pavements when resources are unavailable for an engineered pavement design.

APPENDIX A: TESTING LOCATIONS

Figures A.1 – A.15 present location maps for individual road testing sites. The red stars on the maps represent the approximate location of each field test.

1. Harding County, SD: Hwy 867 (Camp Crook Road).

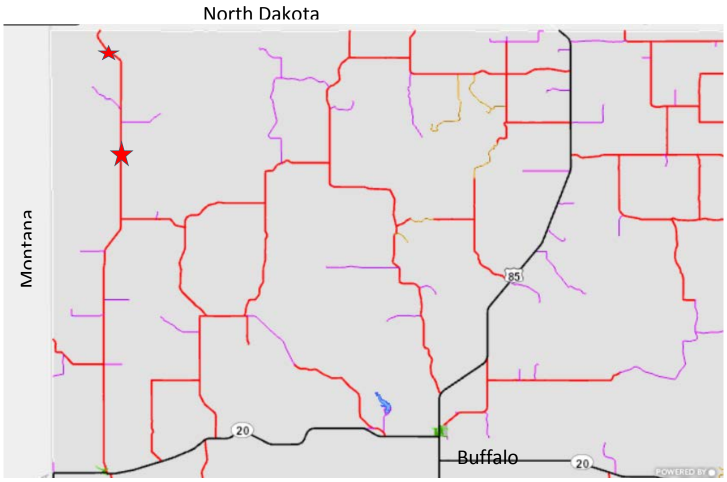


Figure A.1: Harding County Hwy 867 Testing Locations

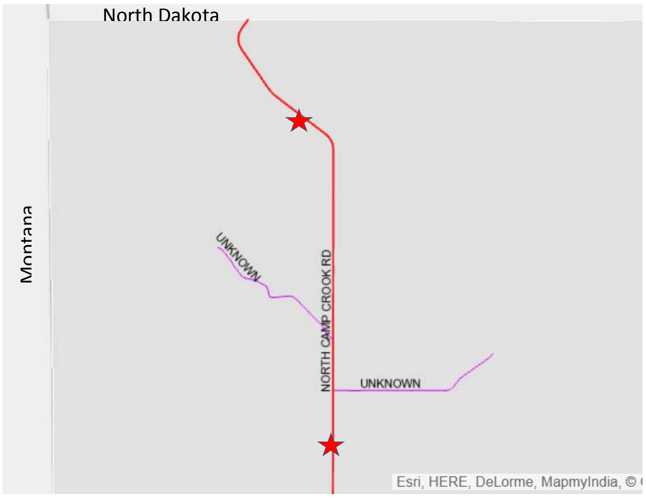


Figure A.2: Harding County Hwy 867 Testing Locations, Close Up

2. Miner County, SD: South Railroad Street (Canova)

Figure A.3: Miner County – Railroad St. Testing Location

3. Deuel County, SD: Hwy 311 (Astoria)

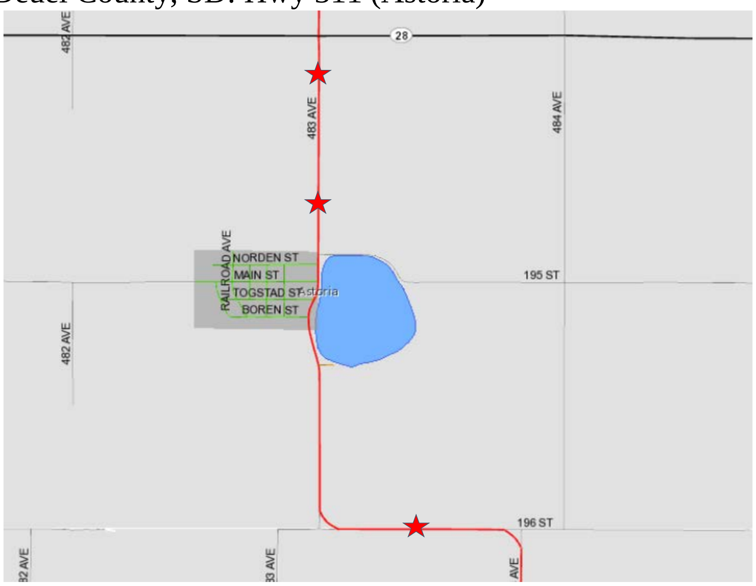


Figure A.4: Deuel County Hwy 311 – Original & Rehab Testing Locations

4. Aurora County: 262nd Street (Stickney)

Figure A.5: Aurora County – 262nd St. (East & West) Testing Locations

5. Aurora County: 386th Avenue (Plankinton)

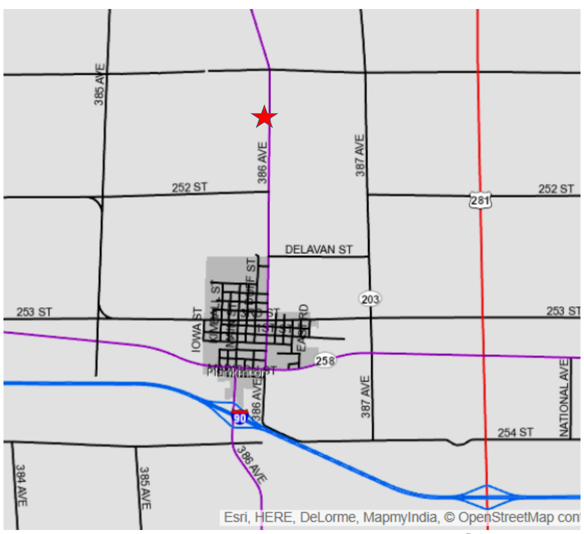


Figure A.6: Aurora County – 386th Ave. Testing Location

6. Codington County: Old Highway 81 (Watertown)

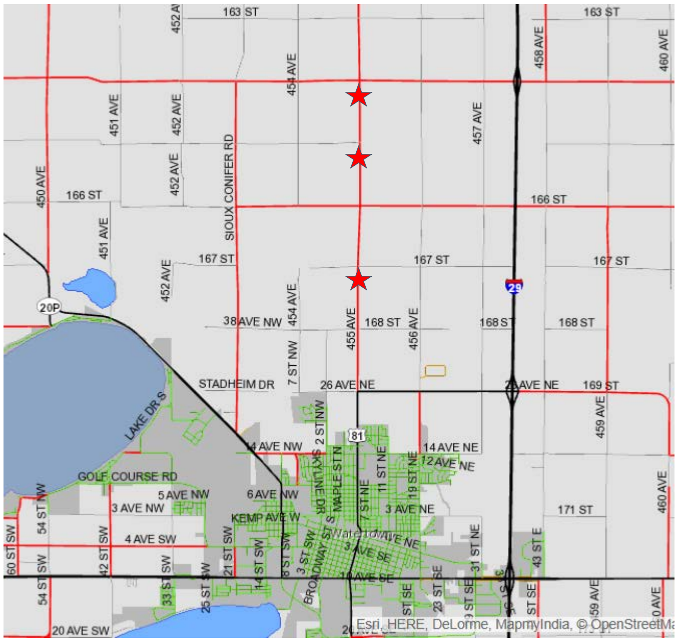


Figure A.7: Codington County Old Hwy 81 Testing Locations

7. Clay County: Saginaw Ave. (Vermillion)

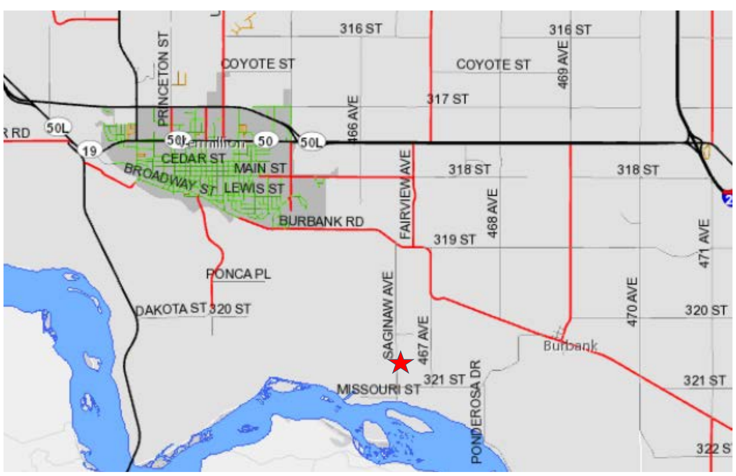


Figure A.8: Clay County – Saginaw Ave. Testing Location

8. Lincoln County: 135 - 481st Ave. (Canton)

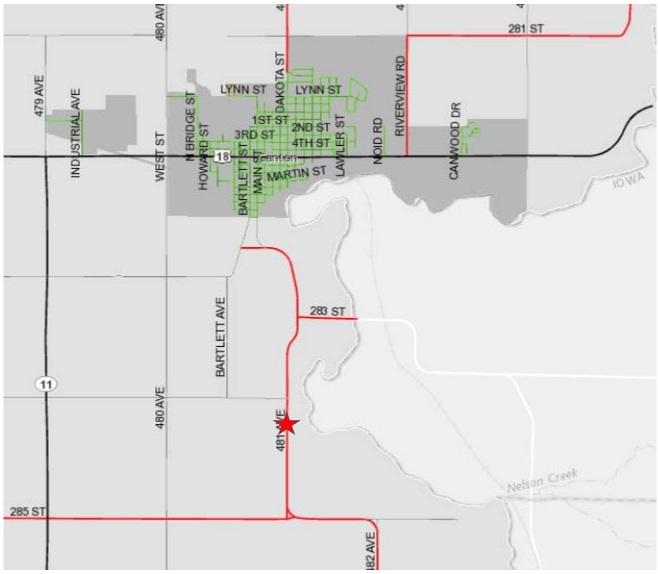


Figure A.9: Lincoln County Hwy 135 Testing Location

9. Pennington County: Rockerville Road (Rockerville)

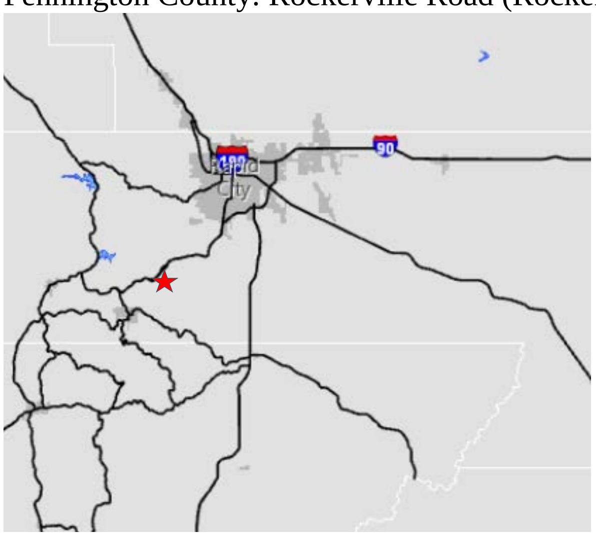


Figure A.10: Pennington County – Rockerville Rd. Testing Location

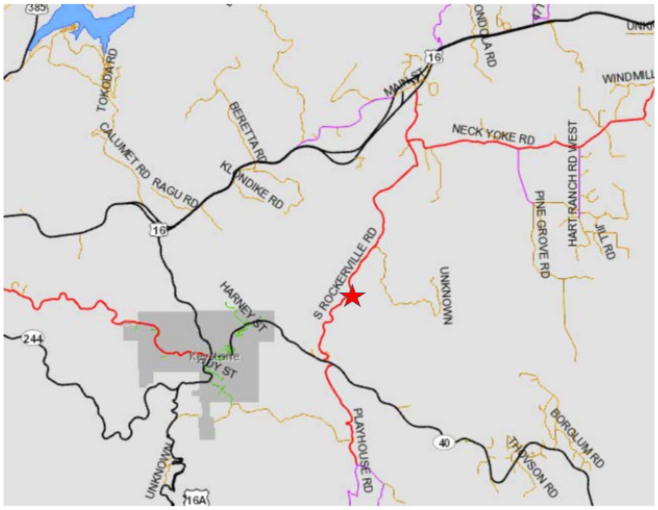


Figure A.11: Pennington County – Rockerville Rd. Testing Location, Close Up

10. Pennington County: Bombing Range Road (Scenic)

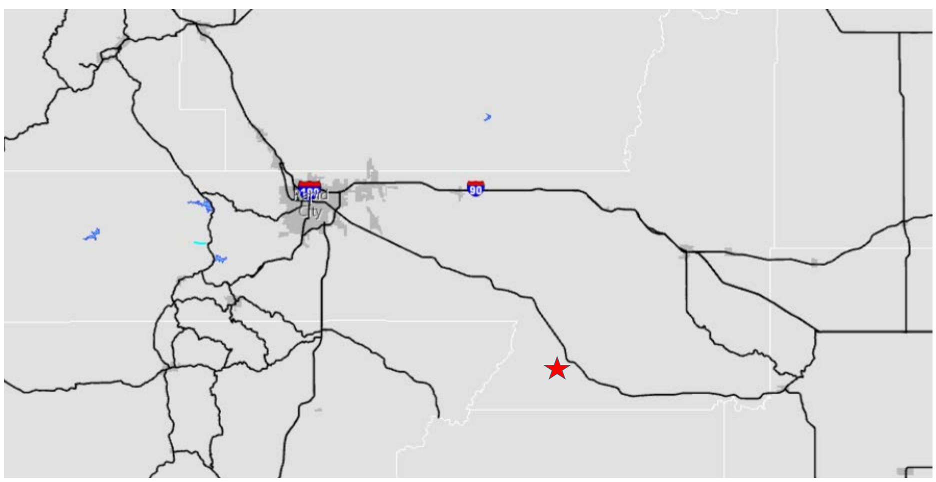


Figure A.12: Pennington County – Bombing Range Rd. Testing Location

Figure A.13: Pennington County – Bombing Range Rd. Testing Location, Close Up

11. Brown County: HWY 14 (Aberdeen)

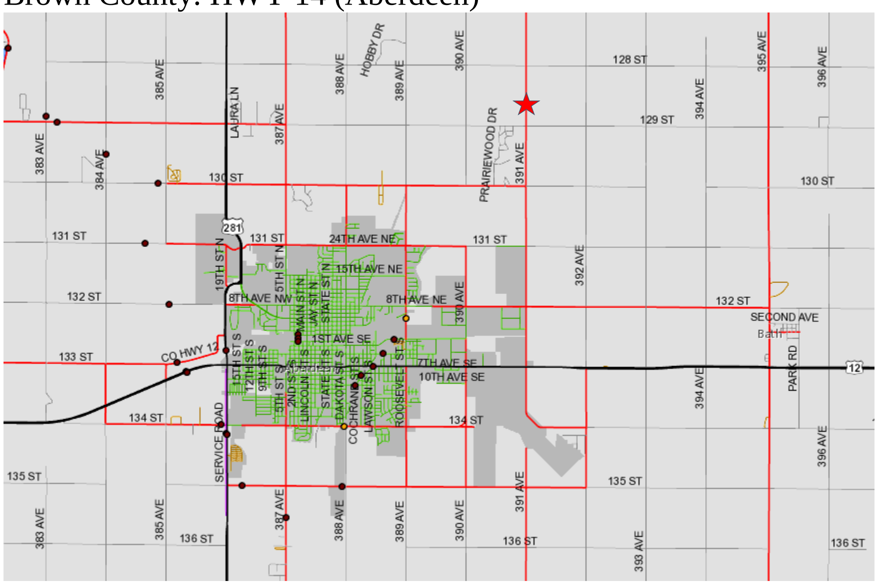


Figure A.14: Brown County Hwy 14 Testing Location

12. Brown County: HWY 17 (Aberdeen)

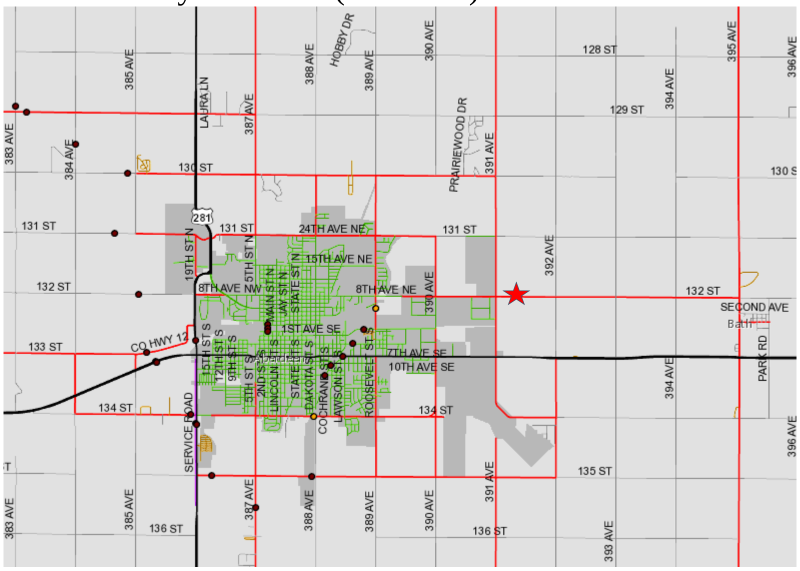


Figure A.15: Brown County Hwy 17 Testing Location

APPENDIX B: BASE COURSE GRADATIONS

Figures B.1 – B.3 show the gradations of the base course for each of the sections tested and compare those gradations to the SDDOT base specification limits (the dark black curves). The gradations are grouped according to the performance of the road.

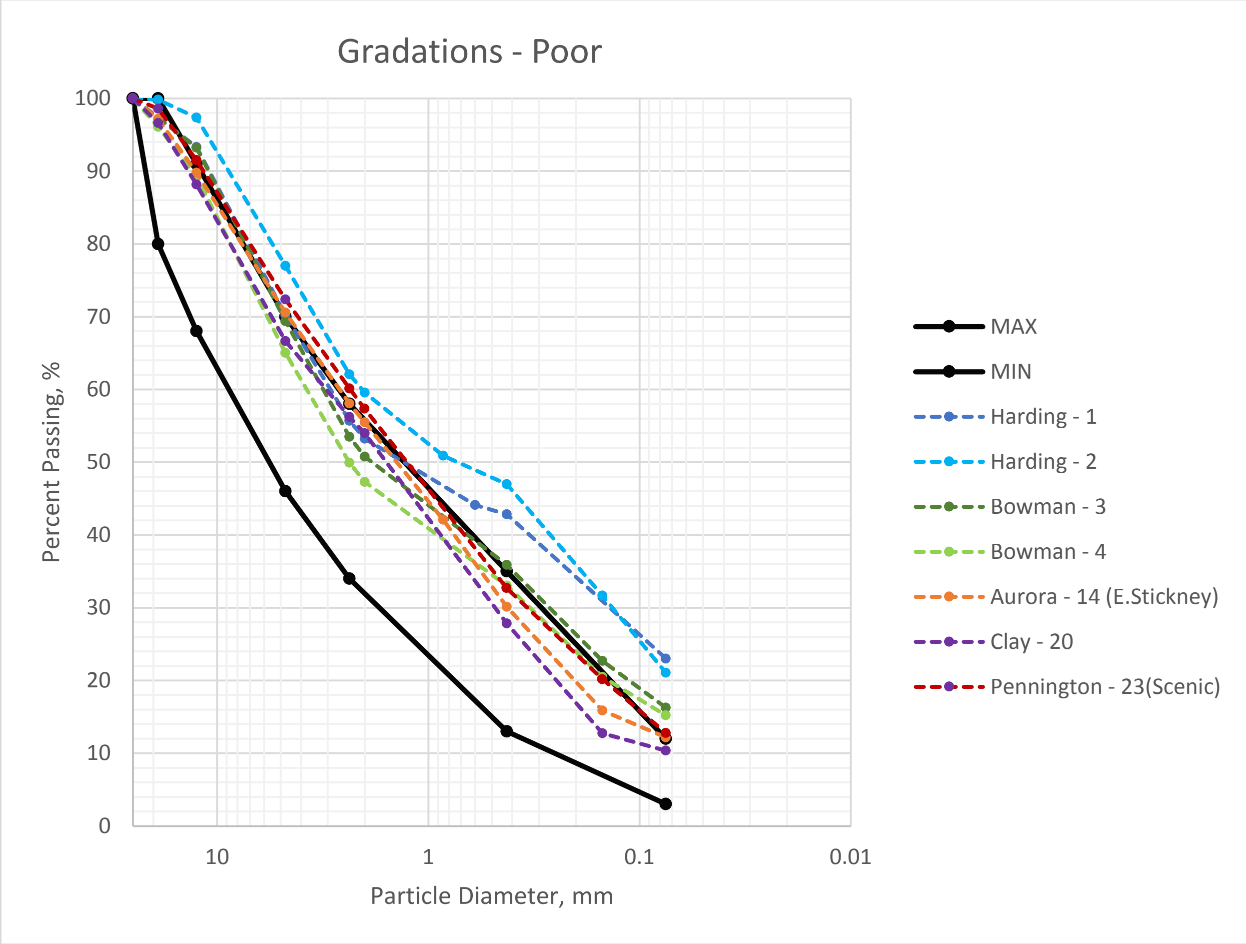


Figure B.1: Base Course Gradations for Poor Performing Roads

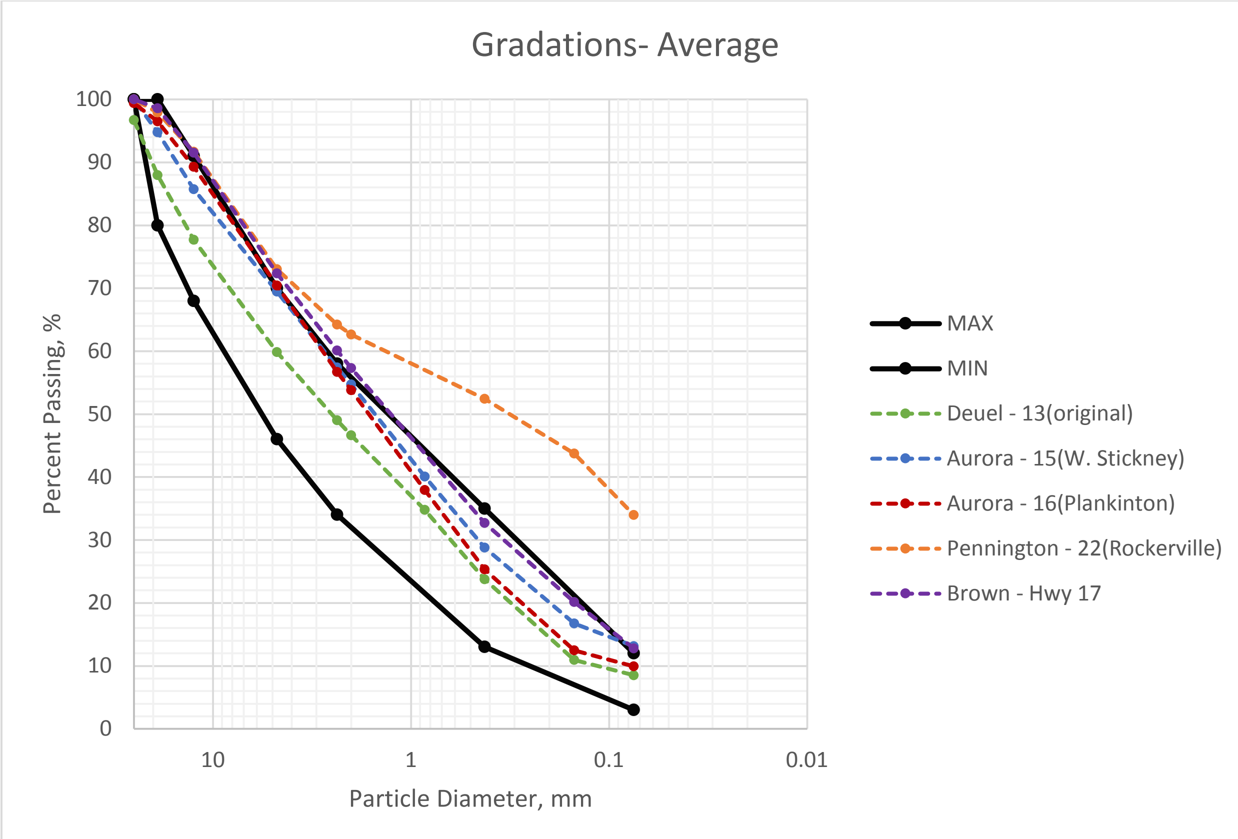


Figure B.2: Base Course Gradations for Average Performing Roads

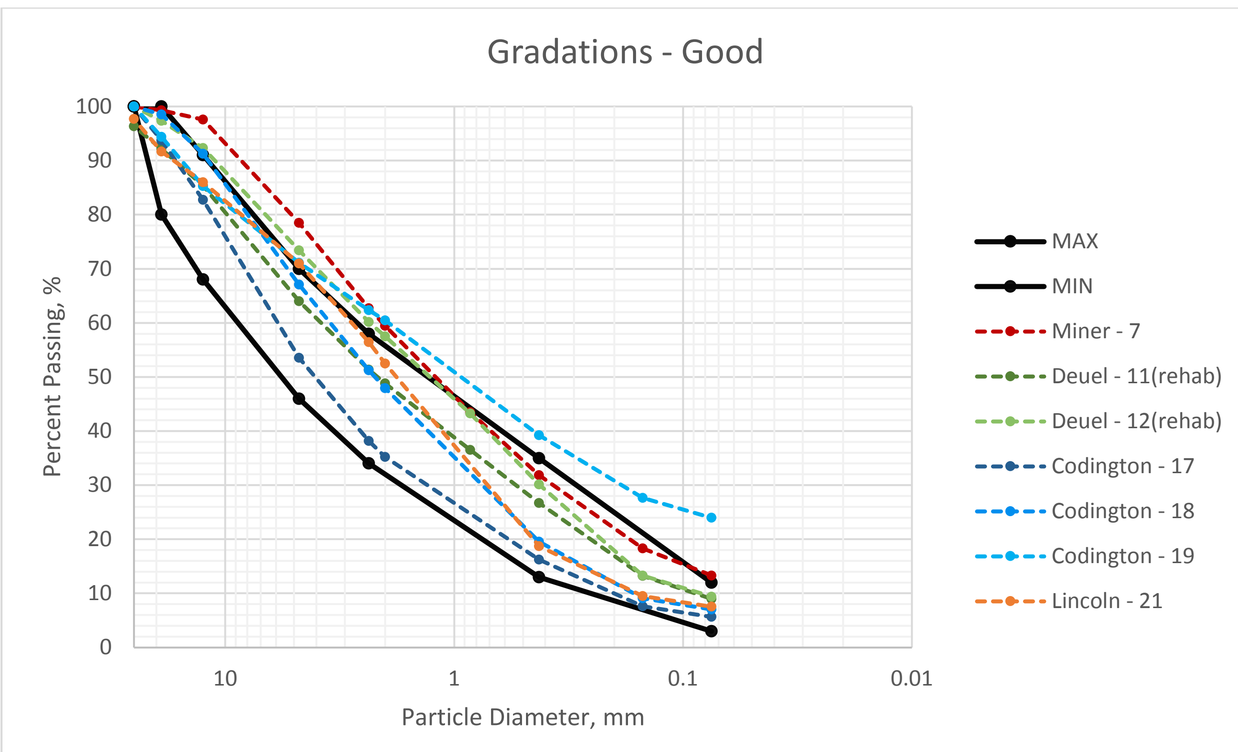


Figure B.3: Base Course Gradations for Good Performing Roads

APPENDIX C: DCP RESULTS

Figures C.1 – C.13 display the DCP results for each of the roads tested. The depth of the base course for each road is indicated by the solid brown horizontal line on the chart.

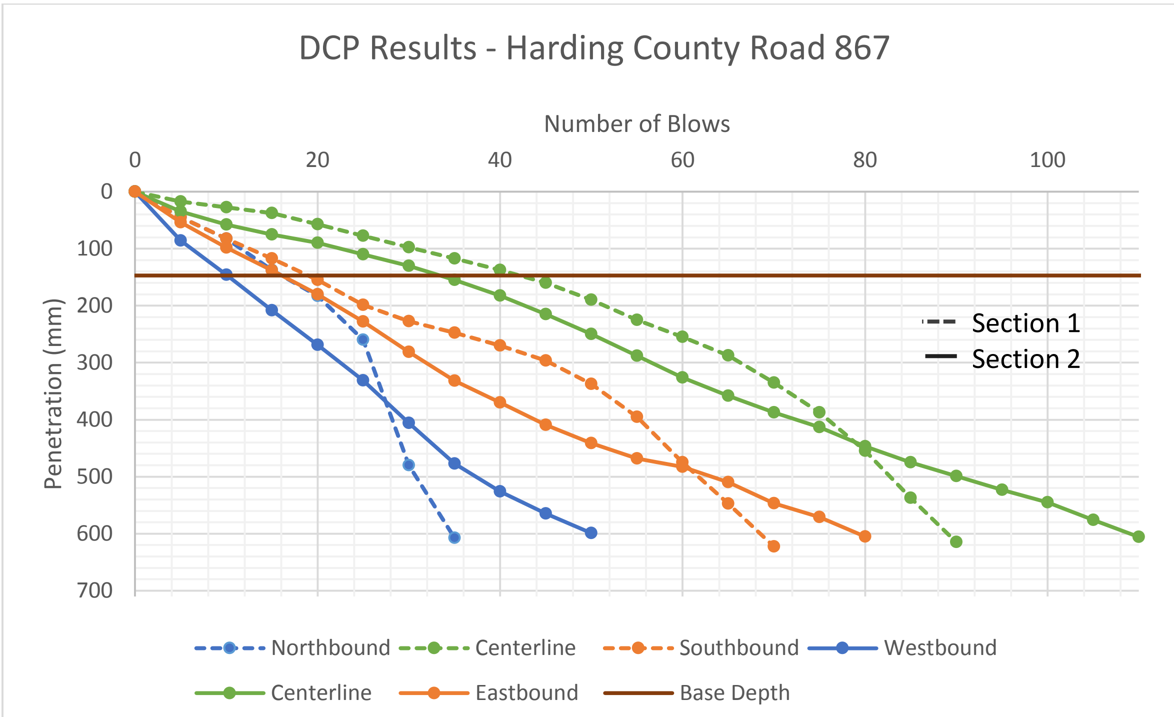


Figure C.1: DCP Results for Harding County Hwy 867

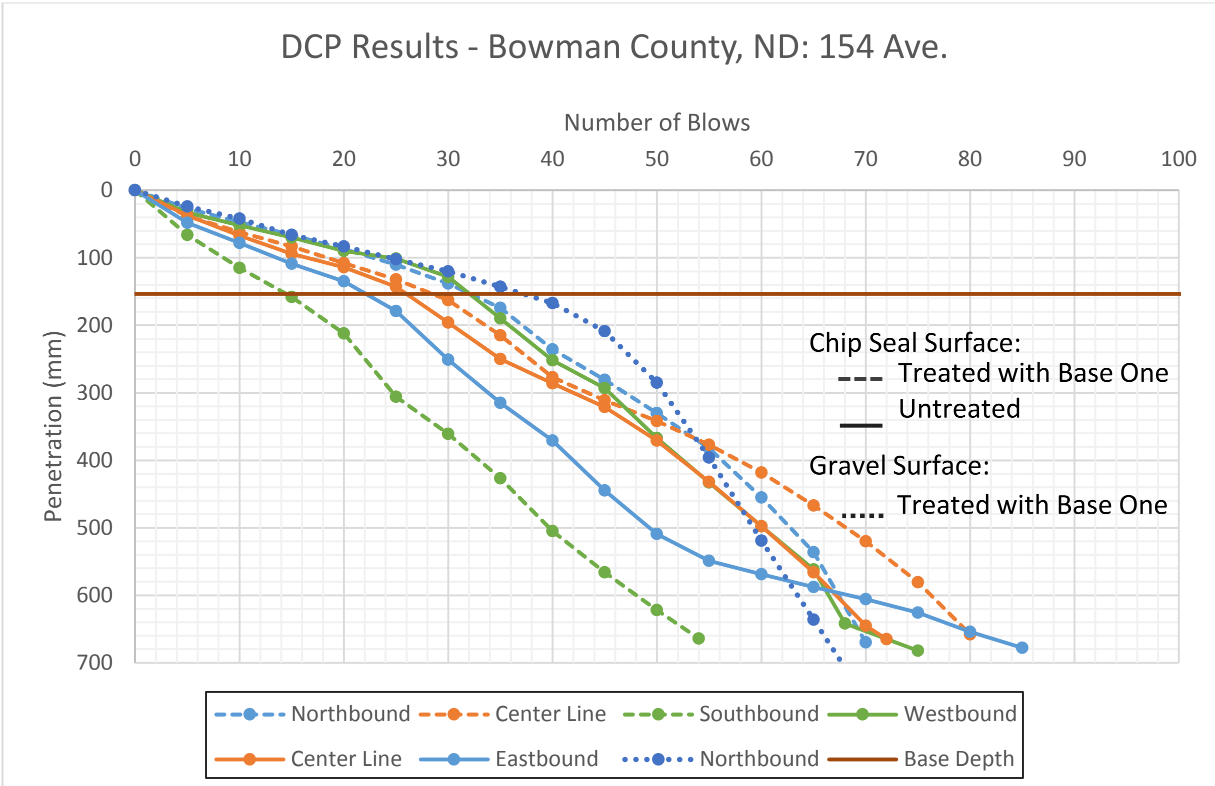


Figure C.2: DCP Results for Bowman County – 154th Ave.

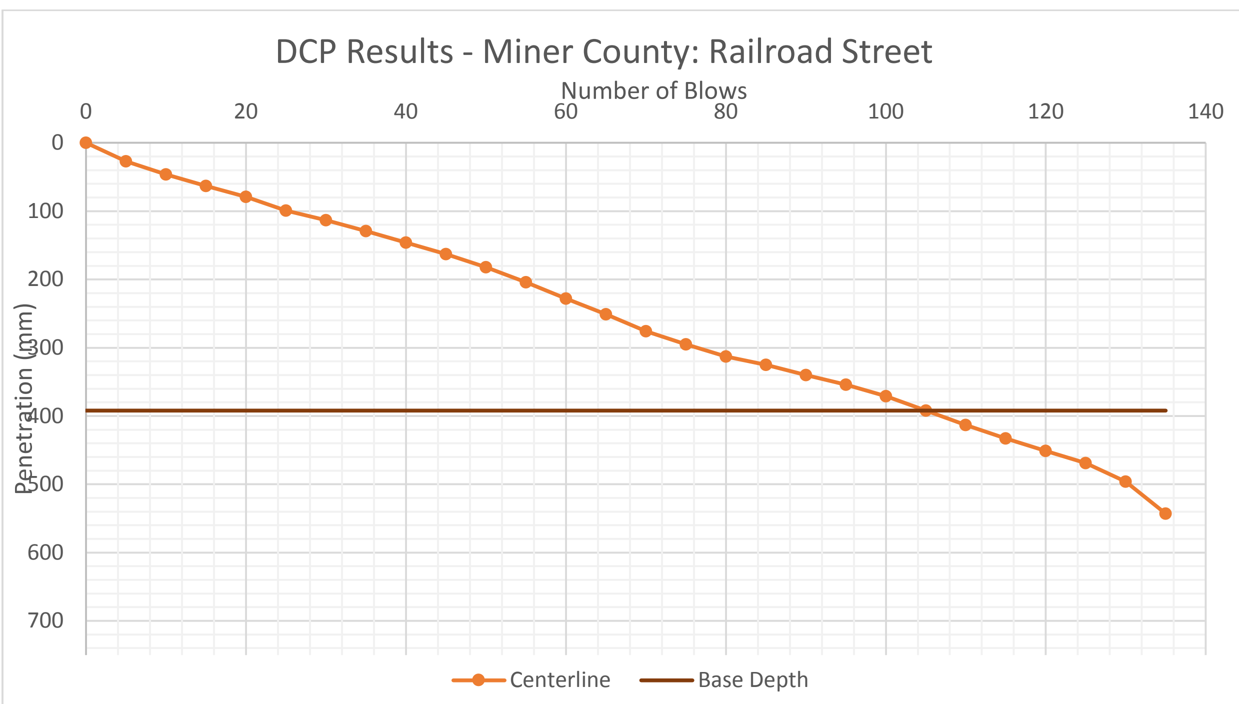
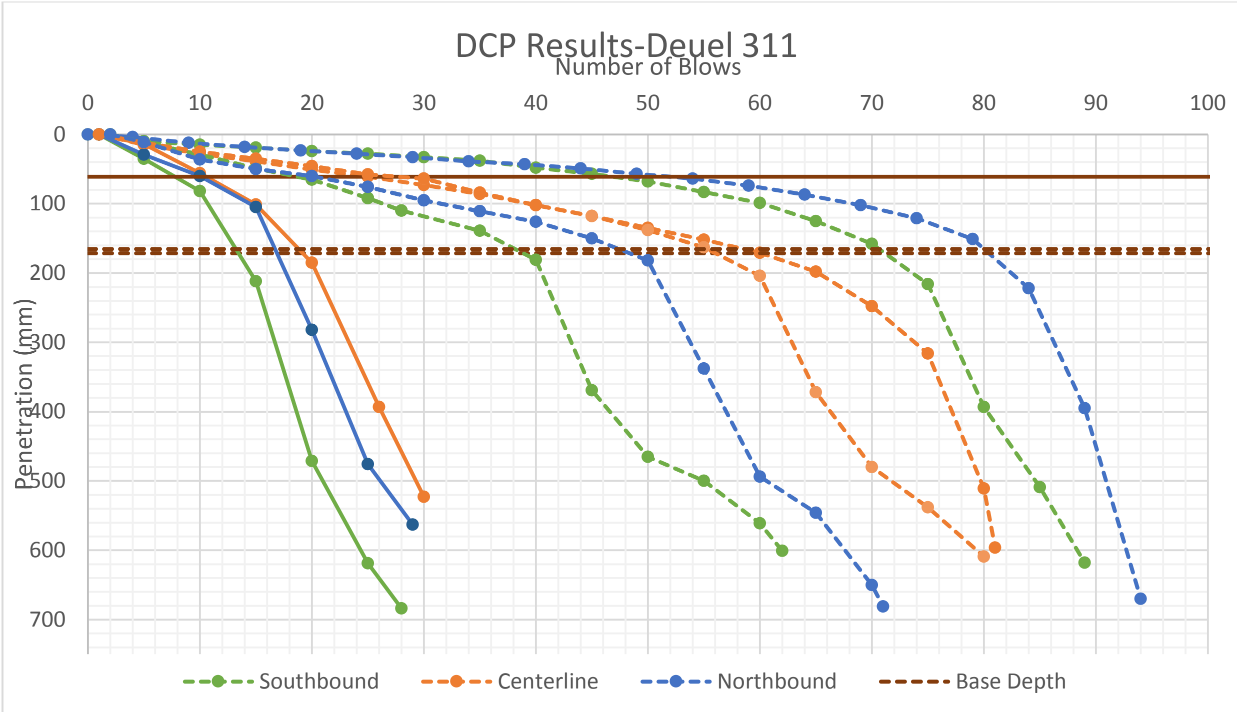


Figure C.3: DCP Results for Miner County – Railroad St. (Canova)



Solid line = original; dashed line = rehab

Figure C.4: DCP Results for Deuel County Hwy 311 – Original & Rehab (Astoria)

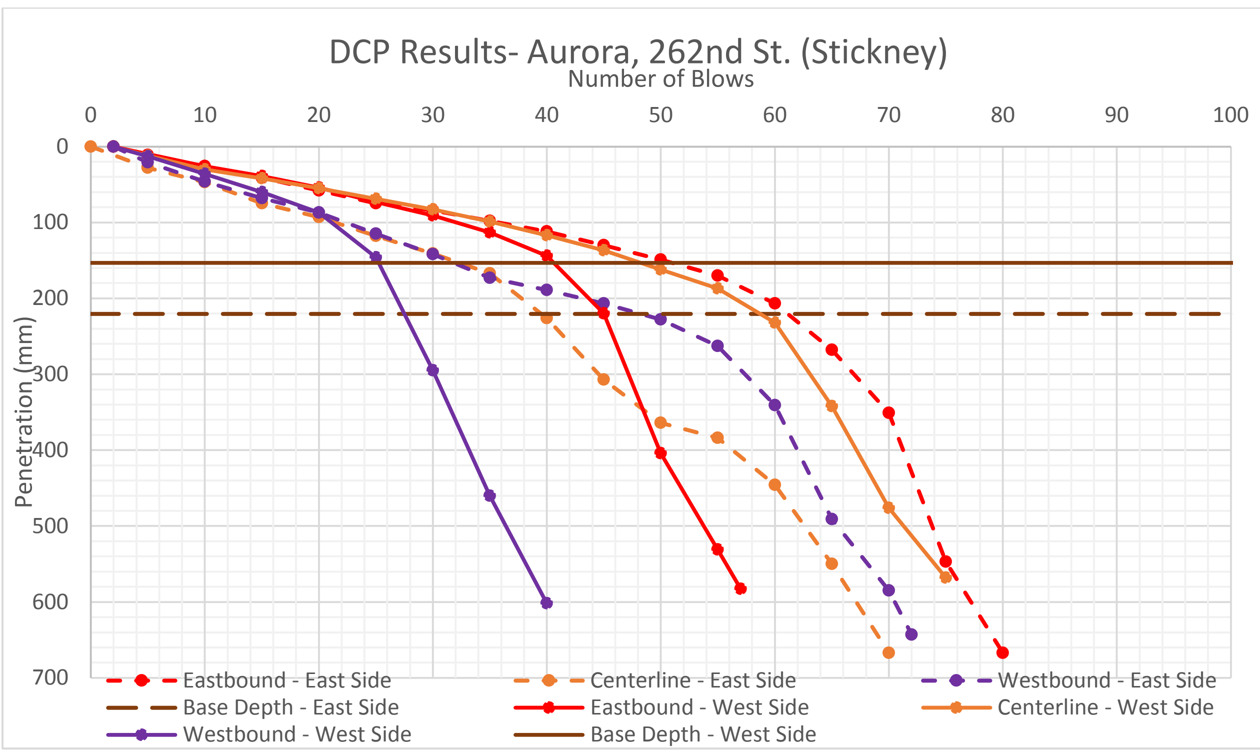


Figure C.5: DCP Results for Aurora County – 262nd St., East & West (Stickney)

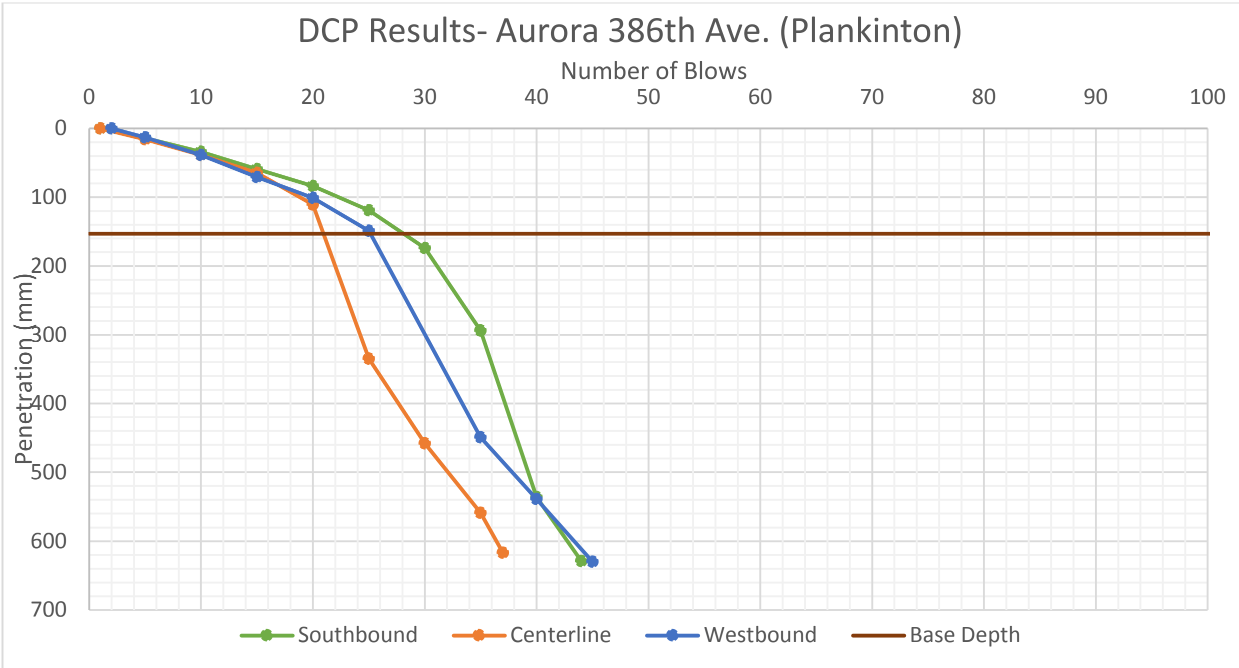


Figure C.6: DCP Results for Aurora County – 386th Ave. (Plankinton)

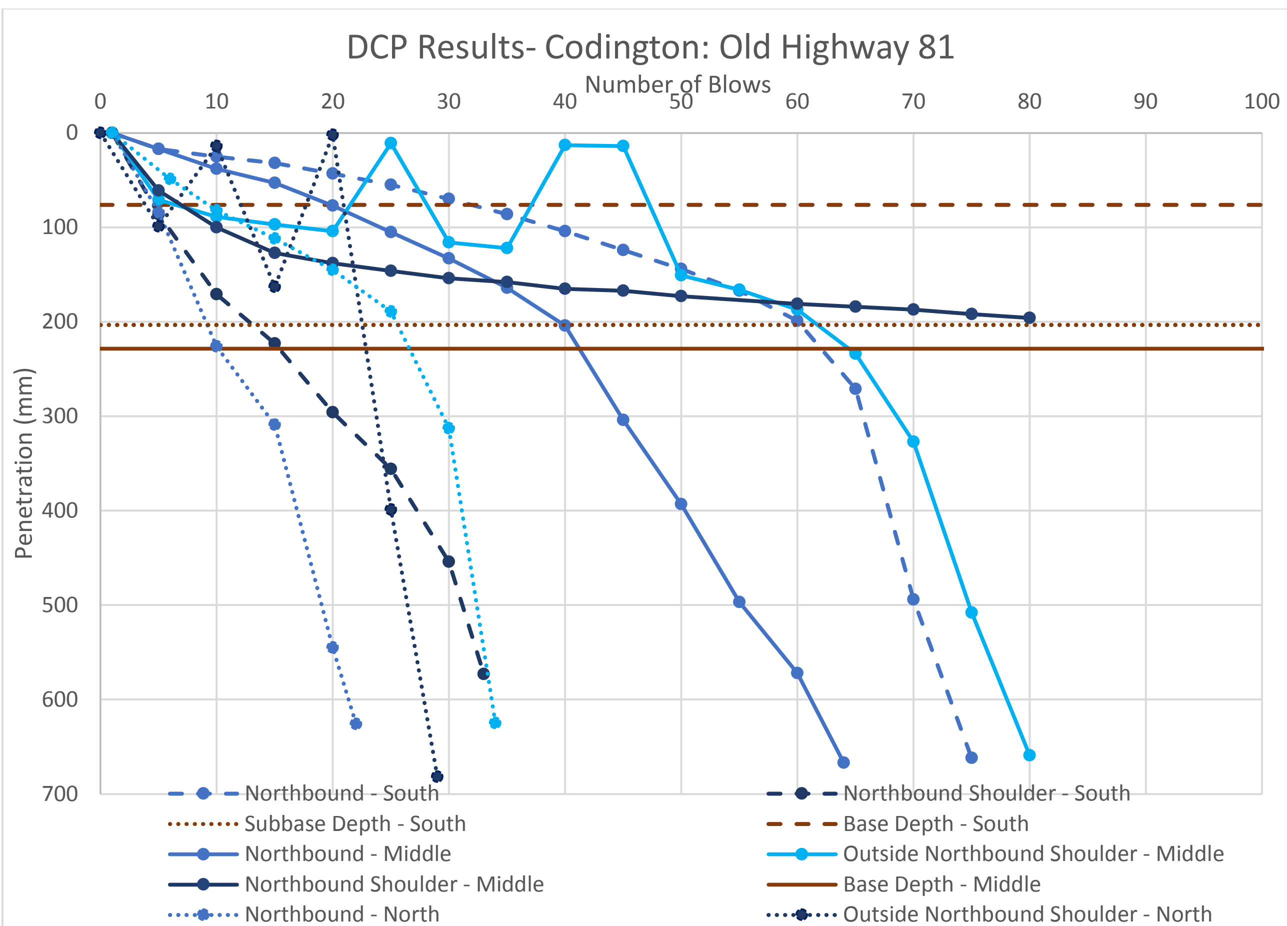


Figure C.7: DCP Results for Codington County Old Hwy 81

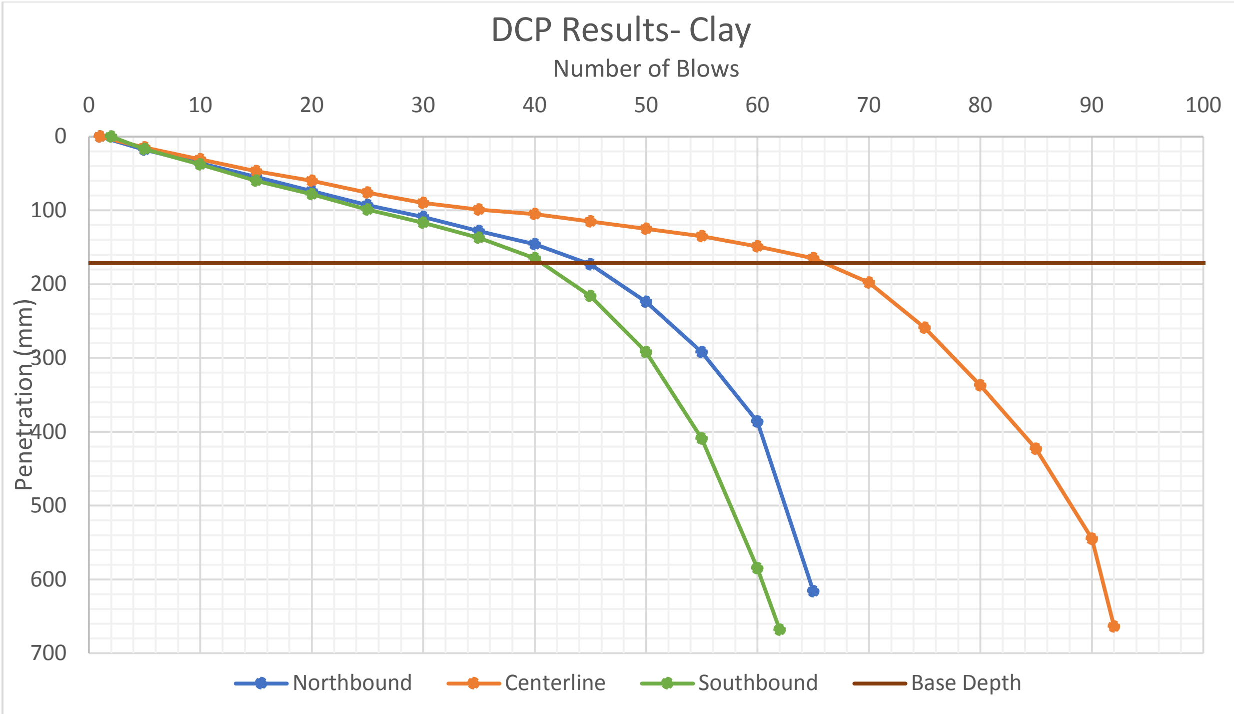


Figure C.8: DCP Results for Clay County – Saginaw Ave.

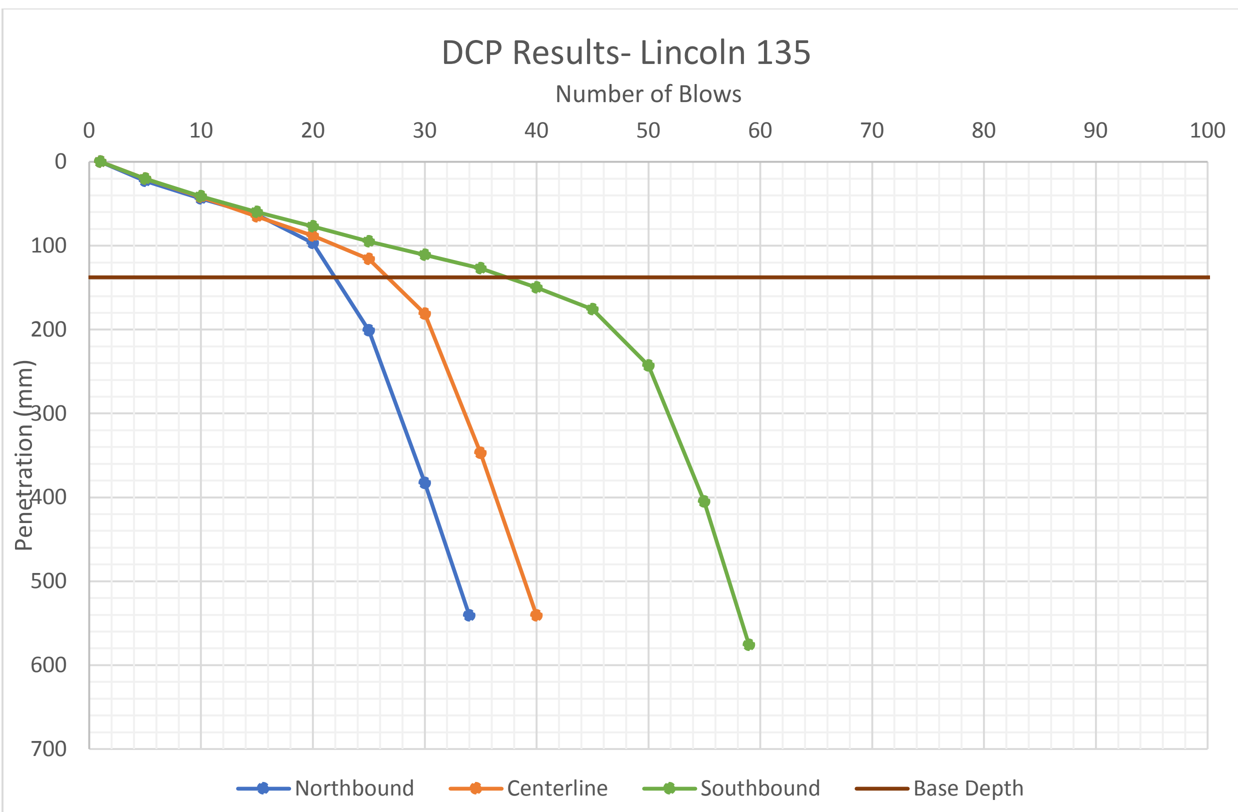


Figure C.9: DCP Results for Lincoln County Hwy 135

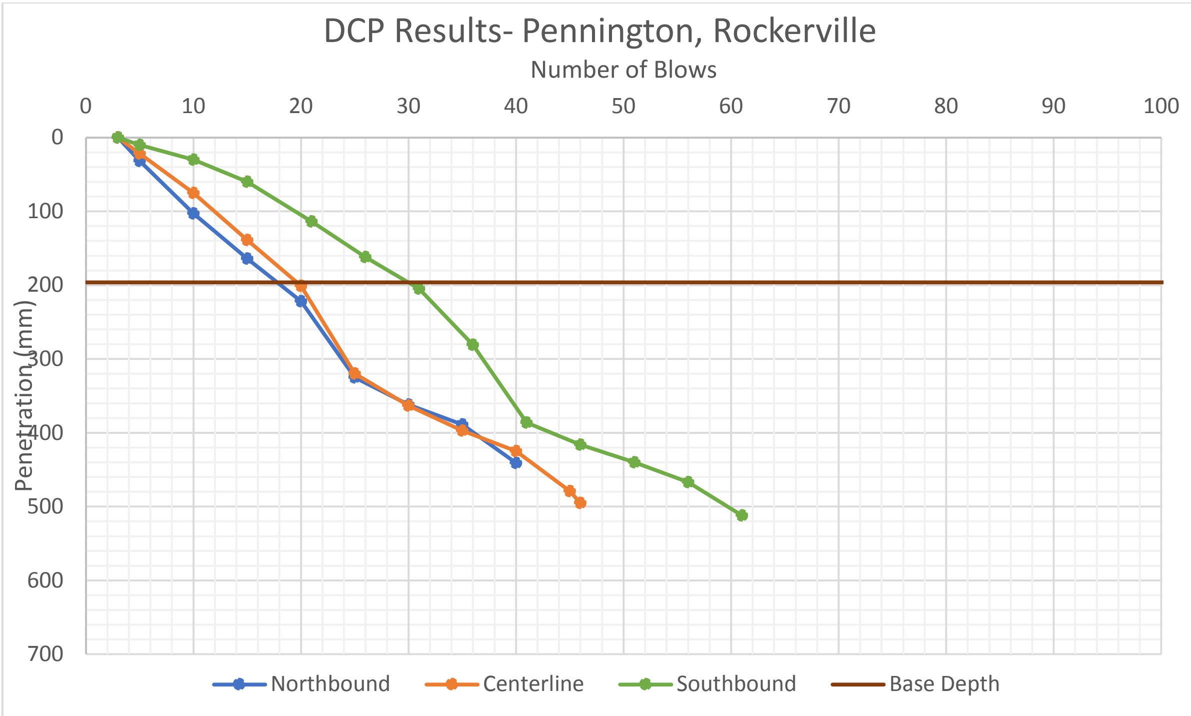


Figure C.10: DCP Results for Pennington County – Rockerville Rd.

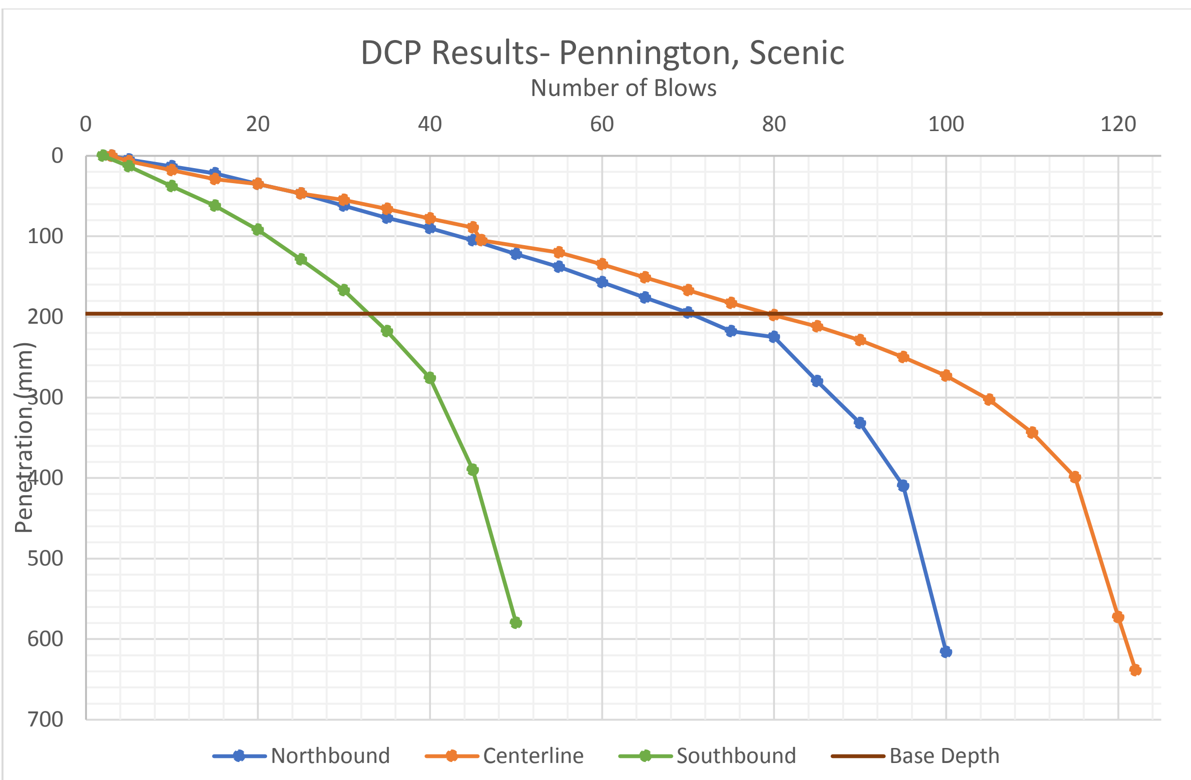


Figure C.11: DCP Results for Pennington County – Bombing Range Rd. (Scenic)

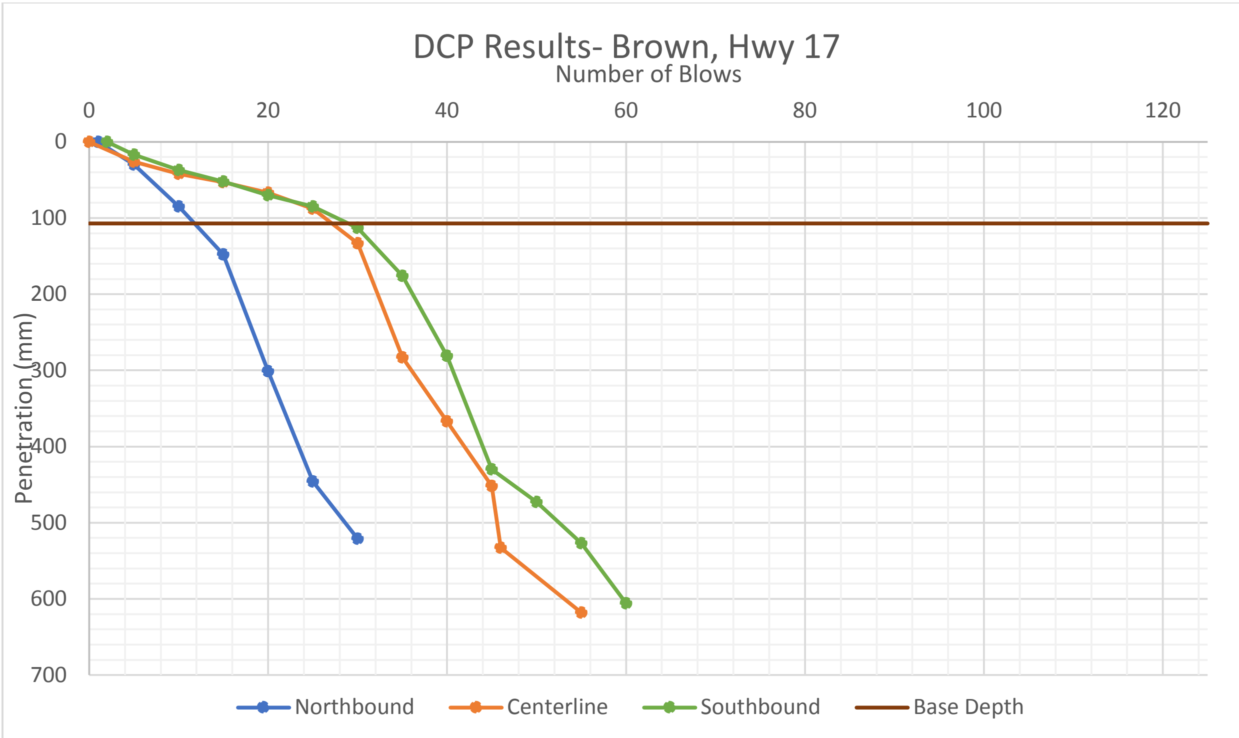


Figure C.12: DCP Results for Brown County Hwy 17

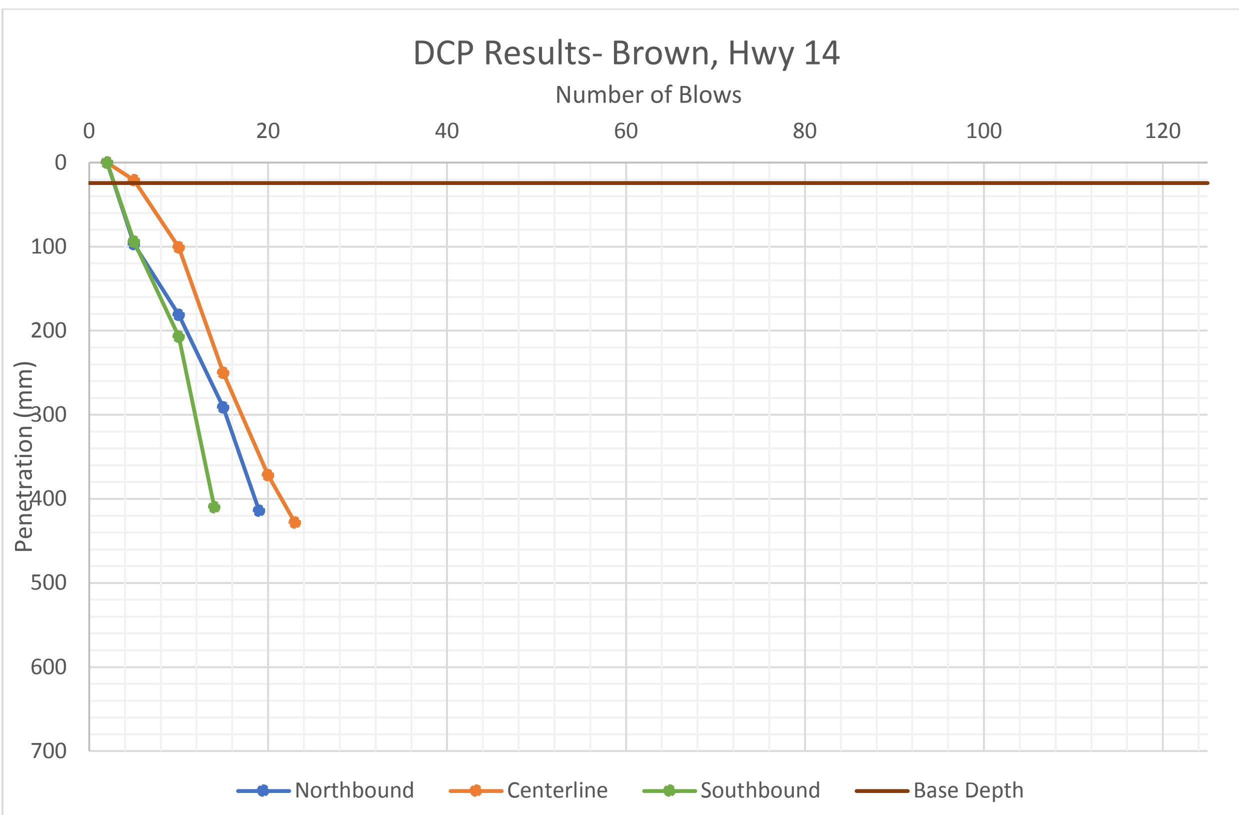


Figure C.13: DCP Results for Brown County Hwy 14

APPENDIX D: RAW DATA

Aurora County, East 262nd Street (Stickney)

Table D.1: Aurora Co. E. 262nd St. History & Field Observations	
Year Built	1991
Maintenance	Unknown
ADT / ADTT	171 / unknown
Surface Type	Blotter
Other Measurements & Observations	

Pavement Structure:

Table D.2: Aurora Co. E. 262nd St. Layer Thicknesses	
Surface Type	Blotter
Surface Thickness	1.25"
Base Thickness	9”
Subbase Thickness	N/A

DCP Tests:

Table D.3: Aurora Co. E. 262nd St. DCP: Eastbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	28.5	0	0	0
5	29.6	11	11	3.7
10	31.1	15	26	3
15	32.6	15	41	3
20	34.3	17	58	3.4
25	36	17	75	3.4
30	36.9	9	84	1.8
35	38.3	14	98	2.8
40	39.7	14	112	2.8
45	41.5	18	130	3.6
50	43.4	19	149	3.8
55	45.5	21	170	4.2
60	49.2	37	207	7.4
65	55.3	61	268	12.2
70	63.6	83	351	16.6
75	83.2	196	547	39.2
80	95.2	120	667	24

Table D.4: Aurora Co. E. 262nd St. DCP: Centerline				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	26.4	0	0	0
5	29.2	28	28	5.6
10	31.1	19	47	3.8
15	33.9	28	75	5.6
20	35.7	18	93	3.6
25	38.2	25	118	5
30	40.5	23	141	4.6
35	43.1	26	167	5.2
40	49	59	226	11.8
45	57.1	81	307	16.2
50	62.8	57	364	11.4
55	64.8	20	384	4
60	71	62	446	12.4
65	81.4	104	550	20.8
70	93.1	117	667	23.4

Table D.5: Aurora Co. E. 262nd St. DCP: Westbound Lane - Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	27.7	0	0	0
5	29.8	21	21	7
10	32.3	25	46	5
15	34.5	22	68	4.4
20	36.4	19	87	3.8
25	39.2	28	115	5.6
30	41.9	27	142	5.4
35	45	31	173	6.2
40	46.6	16	189	3.2
45	48.4	18	207	3.6
50	50.5	21	228	4.2
55	54	35	263	7
60	61.8	78	341	15.6
65	76.8	150	491	30
70	86.2	94	585	18.8
72	92	58	643	29

Moisture Content Tests:

Table D.6: Aurora Co. E. 262nd St. Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
22	3.56	93.52	87.78	5.74	84.22	6.8	**6.7**
A2	3.62	85.93	80.9	5.03	77.28	6.5	
SUBGRADE							
1	3.56	78.92	68.82	10.1	65.26	15.5	**15.2**
2	3.61	122.73	107.34	15.39	103.73	14.8	

Atterberg Limits Tests:

Table D.7: Aurora Co. E. 262nd St. Base - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	28	1B	3.52	11.26	9.65	1.61	6.13	26.3	**1.4**	1.40	**27**
N blows (20-30)	22	47	3.52	12.55	10.61	1.94	7.09	27.4	**1.3**		
N blows (15-25)	17	7	3.53	13.62	11.4	2.22	7.87	28.2	**1.2**		

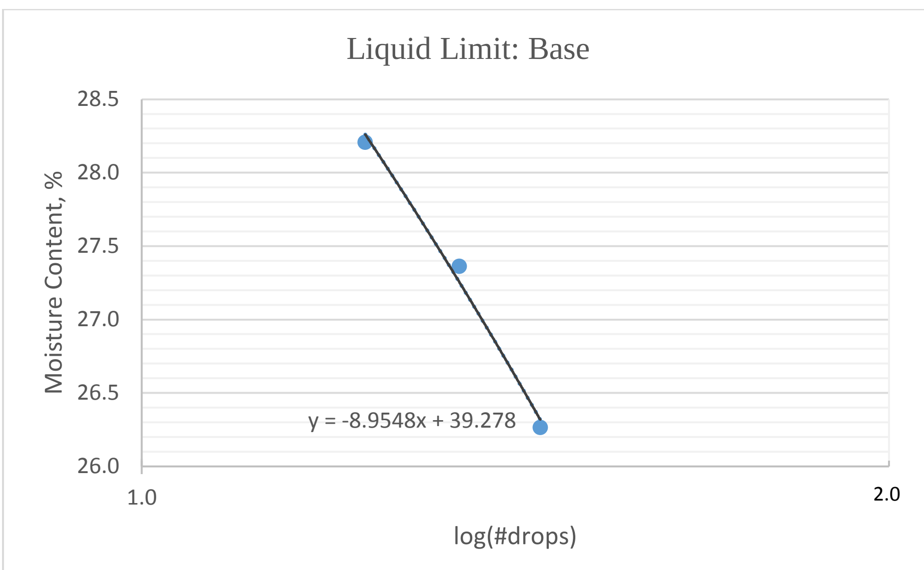


Figure D.1: Aurora Co. E. 262nd St. Liquid Limit - Base

Table D.8: Aurora Co. E. 262nd St. Base – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	3	3.56	11.09	10.08	1.01	6.52	15.5	**15.6**
Trial 2	1	3.56	11.48	10.41	1.07	6.85	15.6	

Base Plasticity Index = 11

Table D.9: Aurora Co. E. 262nd St. Subgrade - Liquid Limit												
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	37	3k2	3.56	9.78	7.88	1.9	4.32	44.0	**1.6**	1.40	**46**
N blows (20-30)	24	1	3.57	9.66	7.73	1.93	4.16	46.4	**1.4**		
N blows (15-25)	17	3	3.56	8.98	7.21	1.77	3.65	48.5	**1.2**		

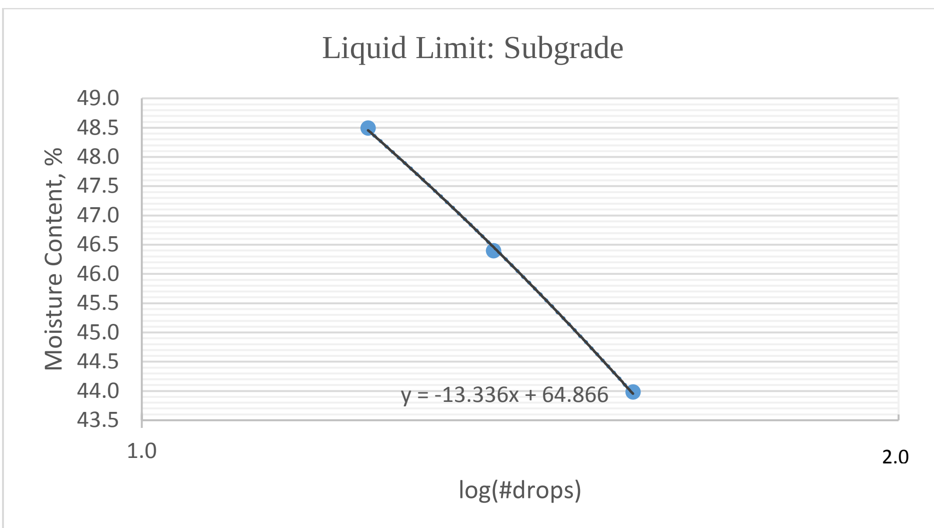


Figure D.2: Aurora Co. E. 262nd St. Liquid Limit - Subgrade

Table D.10: Aurora Co. E. 262nd St. Subgrade – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	G1	3.57	10.07	9.17	0.9	5.6	16.1	**15.6**
Trial 2	G2	3.58	8.82	8.13	0.69	4.55	15.2	

Subgrade Plasticity Index = 31

<u>Gradation Tests:</u>

Table D.11: Aurora Co. E. 262nd St. Base Gradation								
	Total Soil Mass (g) =		5322.1					
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	0	100
	1"	0	0	0	0	0	0	100
	3/4"	565.6	618.8	641	587.2	150.2	2.8	97
	1/2"	491.3	653.9	643.3	570.4	393.7	7.4	90
	3/8"	483.6	648.1	563.4	528.1	288.8	5.4	84
	No. 4	512.5	900.5	751.3	620.2	734.5	13.8	71
	No. 8	683.5	1027	880.7	807	664.2	12.5	58
	No. 10	471.4	542.5	512.8	498.1	139.2	2.6	55
	No.20	378.8	732.9	590.1	525.6	712.2	13.4	42
	No. 40	338.4	642.7	528	481.5	637	12.0	30
	No. 60	324.4	536.4	463.5	435.7	462.4	8.7	21
	No. 100	519.3	646.5	613.8	594.1	296.5	5.6	16
	No. 200	332.4	404.8	399.8	387.4	194.8	3.7	12
	Pan	284.4	301	303.9	299.8	51.5	11.6	1
	No.200-Wash					566		

Table D.12: Aurora Co. E. 262nd St. Base 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
5615	5049	566

Table D.13: Aurora Co. E. 262nd St. Subgrade Gradation						
	Total Soil Mass (g) =		758.2			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.5	538.6	26.1	3.4	97
	No. 10	471.4	498.2	26.8	3.5	93
	No. 40	338.3	417.4	79.1	10.4	83
	No. 200	332.5	566	233.5	30.8	52
	Pan	284.4	317.5	33.1	51.7	0
	No.200-Wash			358.7		

Table D.14: Aurora Co. E. 262nd St. Subgrade 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
1046.7	688	358.7

Aurora County, West 262nd Street (Stickney)

Table D.15: Aurora Co. W. 262nd St. History & Field Observations	
Year Built	1991
Maintenance	5 Chip seals
ADT / ADTT	212 / unknown
Surface Type	Blotter
Other Measurements & Observations	

Pavement Structure:

Table D.16: Aurora Co. W. 262nd St. Layer Thicknesses	
Surface Type	Blotter
Surface Thickness	2.75"
Base Thickness	6.25”
Subbase Thickness	N/A

DCP Tests:

Table D.17: Aurora Co. W. 262nd St. DCP: Eastbound - Outer Wheelpath

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
2	32	0	0	0
10	34.6	26	26	3.25
15	35.9	13	39	2.6
20	37.4	15	54	3
25	39.3	19	73	3.8
30	41.1	18	91	3.6
35	43.3	22	113	4.4
40	46.4	31	144	6.2
45	54	76	220	15.2
50	72.4	184	404	36.8
55	85.1	127	531	25.4
57	90.3	52	583	26

Table D.18: Aurora Co. W. 262nd St. DCP: Centerline				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	31.3	0	0	0
5	32.5	12	12	4
10	34.3	18	30	3.6
15	35.5	12	42	2.4
20	36.8	13	55	2.6
25	38.2	14	69	2.8
30	39.6	14	83	2.8
35	41.2	16	99	3.2
40	43	18	117	3.6
45	45	20	137	4
50	47.5	25	162	5
55	50	25	187	5
60	54.5	45	232	9
65	65.5	110	342	22
70	78.9	134	476	26.8
75	88.1	92	568	18.4

Table D.19: Aurora Co. W. 262nd St. DCP: Westbound - Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	33.9	0	0	0
5	35.2	13	13	4.3
10	37.5	23	36	4.6
15	39.9	24	60	4.8
20	42.6	27	87	5.4
25	48.5	59	146	11.8
30	63.4	149	295	29.8
35	79.9	165	460	33
40	94.1	142	602	28.4

Moisture Content Tests:

Table D.20: Aurora Co. W. 262nd St. Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
3B	3.61	105.83	99.03	6.8	95.42	7.1	**7.1**
4BA	3.58	95.58	89.19	6.39	85.61	7.5	
3	3.58	79.33	74.64	4.69	71.06	6.6	
SUBGRADE							
1	3.61	84.41	70.11	14.3	66.5	21.5	**21.5**
D33	3.55	62.19	51.87	10.32	48.32	21.4	
2A	3.6	53.62	44.69	8.93	41.09	21.7	

Atterberg Limits Tests:

Table D.21: Aurora Co. W. 262nd St. Base - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	33	4*	3.58	13.99	11.97	2.02	8.39	24.1	**1.5**	1.40	**25**
N blows (20-30)	24	4ba	3.58	17	14.35	2.65	10.77	24.6	**1.4**		
N blows (15-25)	20	3	3.55	13.11	11.19	1.92	7.64	25.1	**1.3**		

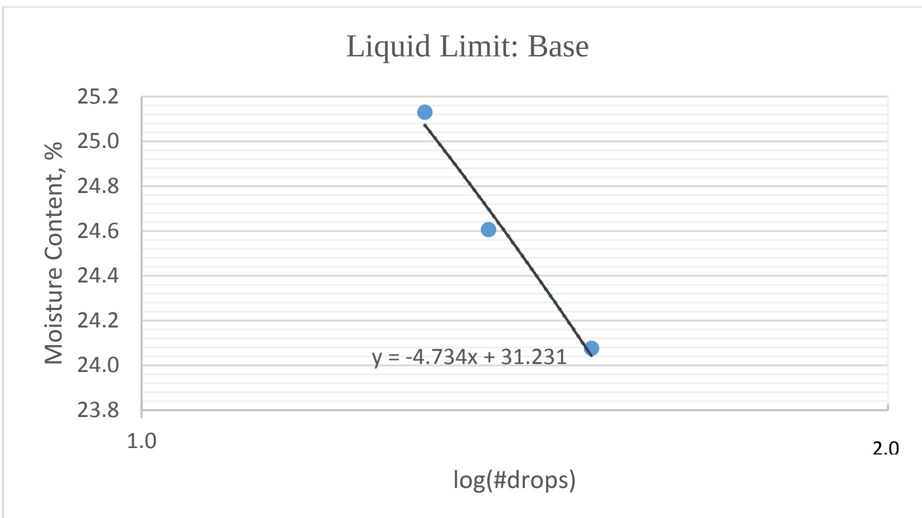


Figure D.3: Aurora Co. W. 262nd St. Liquid Limit - Base

Table D.22: Aurora Co. W. 262nd St. Base – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	2B	3.61	9.81	9.03	0.78	5.42	14.4	**14.5**
Trial 2	6	3.55	11.04	10.09	0.95	6.54	14.5	

Base Plasticity Index = 10

Table D.23: Aurora Co. W. 262nd St. Subgrade - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	LL
N blows (25-35)	36	g2	3.56	9.66	7.97	1.69	4.41	38.3	**1.6**	1.40	**40**
N blows (20-30)	24	g1	3.55	11.09	8.92	2.17	5.37	40.4	**1.4**		
N blows (15-25)	20	f5	3.6	10.97	8.82	2.15	5.22	41.2	**1.3**		

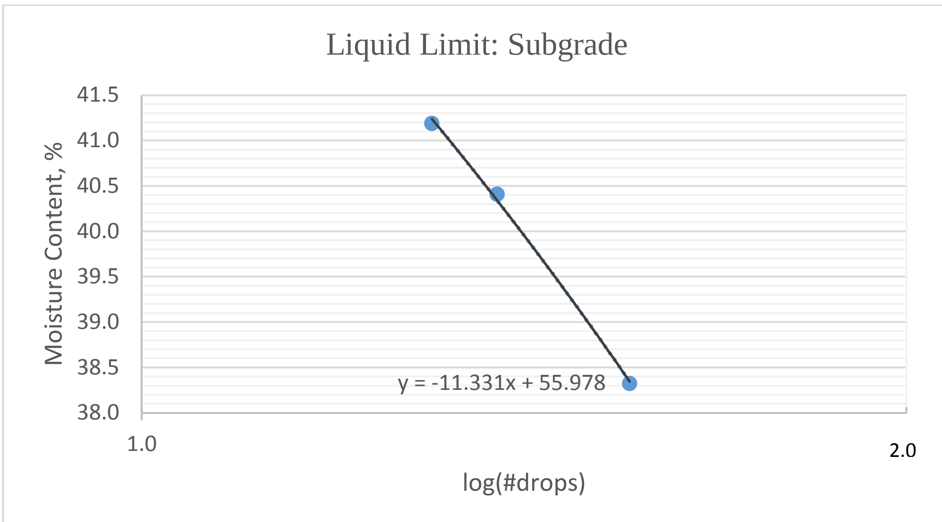


Figure D.4: Aurora Co. W. 262nd St. Liquid Limit - Subgrade

Table D.24: Aurora Co. W. 262nd St. Subgrade –Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	G3	3.52	9.6	8.78	0.82	5.26	15.6	**15.0**
Trial 2	G4	3.57	11.31	10.34	0.97	6.77	14.3	

Subgrade Plasticity Index = 25

Gradation Tests:

Table D.25: Aurora Co. W. 262nd St. Base Gradation

Base Aggregate	Total Soil Mass (g) =		3411.2				
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	0	100
	1"	0	0	0	0	0.00	100
	3/4"	565.6	704.4	605.7	178.9	5.24	95
	1/2"	491.4	674.8	615.9	307.9	9.03	86
	3/8"	483.7	561.8	547	141.4	4.15	82
	No. 4	512.5	773.3	665.5	413.8	12.13	69
	No. 8	683.4	906.2	871.7	411.1	12.05	57
	No. 10	471.3	519.1	516	92.5	2.71	55
	No.20	378.7	627.3	628.8	498.7	14.62	40
	No. 40	338.4	523.1	539.4	385.7	11.31	29
	No. 60	324.4	445.5	457.5	254.2	7.45	21
	No. 100	519.3	593	601.3	155.7	4.56	17
	No. 200	332.5	397.8	390	122.8	3.60	13
	Pan	284.4	307.1	306.4	44.7	13.1	0
	No.200-Wash				402		

Table D.26: Aurora Co. W. 262nd St. Base 200 Wash

Mass Before (g)	Mass After (g)	Mass Pass No.200
3762	3360	402

Table D.27: Aurora Co. W. 262nd St. Subgrade Gradation

	Total Soil Mass (g) =		523.3			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.5	512.9	0.4	0.1	100
	No. 10	471.4	472.2	0.8	0.2	100
	No. 40	338.3	356.6	18.3	3.5	96
	No. 200	332.5	421.8	89.3	17.1	79
	Pan	284.4	314.6	30.2	78.7	0
	No.200-Wash			381.7		

Table D.28: Aurora Co. W. 262nd St. Subgrade 200 Wash

Mass Before (g)	Mass After (g)	Mass Pass No.200
801.8	420.1	381.7

Aurora County, 386th Avenue (Plankinton)

Table D.29: Aurora Co. 386th Ave. History & Field Observations	
Year Built	Unknown
Maintenance	Unknown
ADT / ADTT	113 / unknown
Surface Type	Blotter
Other Measurements & Observations	

Pavement Structure:

Table D.30: Aurora Co. 386th Ave. Layer Thicknesses	
Surface Type	Blotter
Surface Thickness	2.25"
Base Thickness	6.25”
Subbase Thickness	N/A

DCP Tests:

Table D.31: Aurora Co. 386th Ave. DCP: Southbound Lane – Outer Wheelpath

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
1	29.1	0	0	0
5	30.5	14	14	3.5
10	32.5	20	34	4
15	35	25	59	5
20	37.5	25	84	5
25	41	35	119	7
30	46.5	55	174	11
35	58.5	120	294	24
40	82.7	242	536	48.4
44	92	93	629	23.25

Table D.32: Aurora Co. 386th Ave. DCP: Centerline

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
1	29.5	0	0	0
5	31.1	16	16	4
10	33.4	23	39	4.6
15	36	26	65	5.2
20	40.6	46	111	9.2
25	63	224	335	44.8
30	75.3	123	458	24.6
35	85.4	101	559	20.2
37	91.2	58	617	29

Table D.33: Aurora Co. 386th Ave. DCP: Northbound Lane - Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	29	0	0	0
5	30.3	13	13	4.3
10	32.9	26	39	5.2
15	36.1	32	71	6.4
20	39.1	30	101	6
25	43.9	48	149	9.6
35	73.9	300	449	30
40	82.9	90	539	18
45	92	91	630	18.2

Moisture Content Tests:

Table D.34: Aurora Co. 386th Ave. Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
1B	3.52	109.07	102.3	6.77	98.78	6.9	**6.8**
47	3.53	82.23	77.35	4.88	73.82	6.6	
7	3.55	76.33	71.58	4.75	68.03	7.0	
SUBGRADE							
MM	3.54	61.96	47.05	14.91	43.51	34.3	**15.4**
C5	3.58	54.83	52.31	2.52	48.73	5.2	
4*	3.57	49.52	42.06	7.46	38.49	19.4	

Atterberg Limits Tests:

Table D.35: Aurora Co. 386th Ave. Base - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	33	51b	3.56	11.33	9.72	1.61	6.16	26.1	**1.5**	1.40	**21**
N blows (20-30)	28	2	3.55	12.34	10.52	1.82	6.97	26.1	**1.4**		
N blows (15-25)	21	1b	3.61	13.39	11.31	2.08	7.7	27.0	**1.3**		

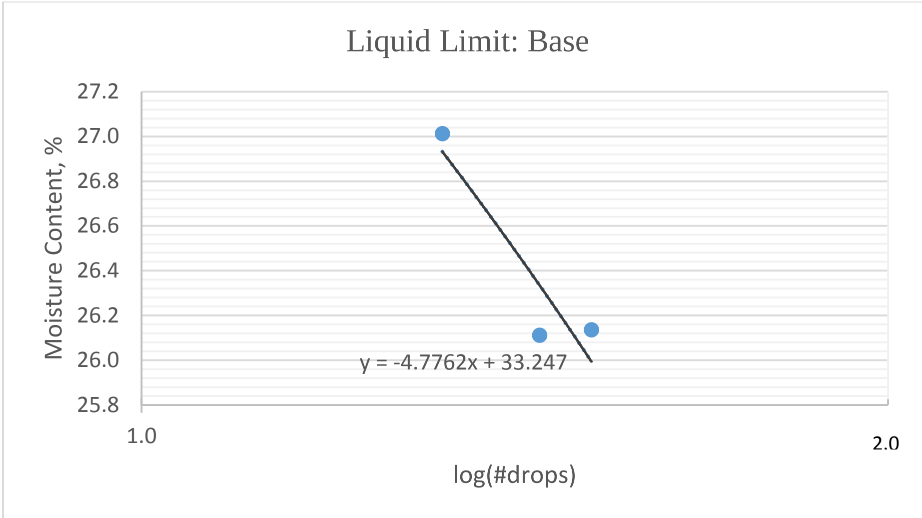


Figure D.5: Aurora Co. 386th Ave. Liquid Limit - Base

Table D.36: Aurora Co. 386th Ave. Base - Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	3k2	3.56	10.77	9.79	0.98	6.23	15.7	**15.4**
Trial 2	2ab	3.6	10.45	9.55	0.9	5.95	15.1	

Base Plasticity Index = 6

Table D.37: Aurora Co. 386th Ave. Subgrade - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	31	y2	3.56	10.07	8.45	1.62	4.89	33.1	**1.5**	1.40	**34**
N blows (20-30)	25	5	3.56	10.14	8.48	1.66	4.92	33.7	**1.4**		
N blows (15-25)	18	774b	3.6	10.16	8.45	1.71	4.85	35.3	**1.3**		

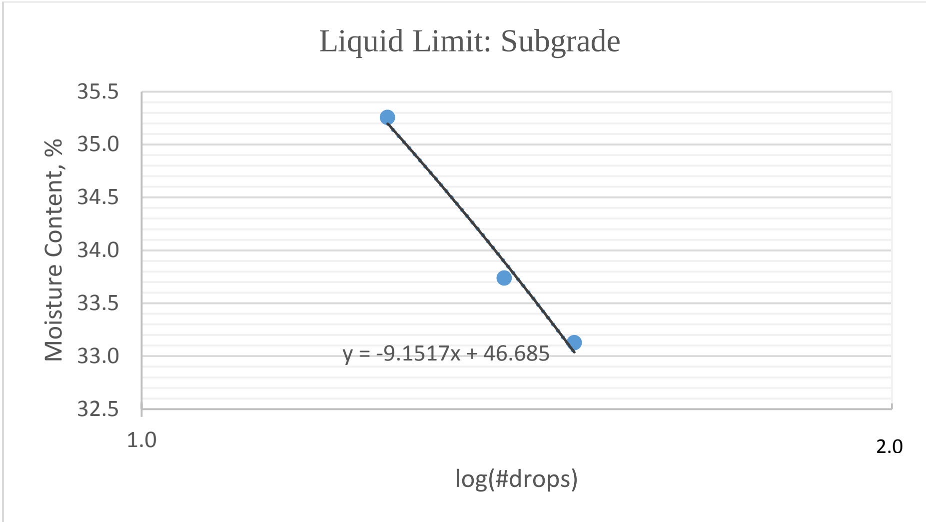


Figure D.6: Aurora Co. 386th Ave. Liquid Limit - Subgrade

Table D.38: Aurora Co. 386th Ave. Subgrade – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	F4	3.54	10.63	9.75	0.88	6.21	14.2	**14.0**
Trial 2	G4	3.56	11.06	10.15	0.91	6.59	13.8	

Subgrade Plasticity Index = 20

Gradation Tests:

Table D.39: Aurora Co. 386th Ave. Base Gradation								
	Total Soil Mass (g) =		6347.1					
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	0	100
	1"	489	525.9	0	0	36.9	0.6	99
	3/4"	565.6	658.2	637.9	585.3	184.6	2.9	97
	1/2"	491.3	718.7	625.5	590.1	460.4	7.3	89
	3/8"	483.6	632.9	596.6	542.9	321.6	5.1	84
	No. 4	512.5	896.4	783.2	730.9	873	13.8	70
	No. 8	683.5	1109.8	906.5	907.4	873.2	13.8	57
	No. 10	471.4	566.5	514.2	517.6	184.1	2.9	54
	No.20	378.8	921.9	592.2	629.3	1007	15.9	38
	No. 40	338.4	775.5	496.2	541.7	798.2	12.6	25
	No. 60	324.3	621.8	425.7	462.8	537.4	8.5	17
	No. 100	519.2	669.1	574.3	592.8	278.6	4.4	12
	No. 200	332.4	445.3	354.4	359.4	161.9	2.6	10
	Pan	284.4	317.3	289.4	288.5	42	9.9	0
	No.200-Wash					587		

Table D.40: Aurora Co. 386th Ave. Base 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
6635	6048	587

Table D.41: Aurora Co. 386th Ave. Subgrade Gradation						
	Total Soil Mass (g) =		364.5			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Subgrade Soil	No. 4	512.5	523.9	11.4	3.1	97
	No. 10	471.3	484.6	13.3	3.6	93
	No. 40	338.4	368.1	29.7	8.1	85
	No. 200	332.4	422.6	90.2	24.7	60
	Pan	284.4	308.6	24.2	60.3	0
	No.200-Wash			195.6		

Table D.42: Aurora Co. 386th Ave. Subgrade 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
647.7	452.1	195.6

Beadle County, Broadland Road

Table D.43: Beadle Co. Broadland Rd. History & Field Observations	
Year Built	~1980, exact year unknown; originally built as a blotter
Maintenance	unknown
ADT / ADTT	98 / unkown
Surface Type	Mat
Other Measurements & Observations	

No DCP tests were performed on Broadland Road in Beadle County.

Testing Location 1

Pavement Structure:

Table D.44: Beadle Co. Broadland Rd. Layer Thicknesses -1	
Surface Type	Mat
Surface Thickness	3.5"
Base Thickness	6.5”
Subbase Thickness	N/A

Moisture Content Tests:

Table D.45: Beadle Co. Broadland Rd. Moisture Content -1

Cup	Cup Mass (g)	Mass Cup + Moist Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average (%)
BASE							
ZQ	3.55	92.65	86.76	5.89	83.21	7.1	**6.8**
3	3.56	97.61	91.77	5.84	88.21	6.6	
SUBGRADE							
K	3.57	66.63	54.41	12.22	50.84	24.0	**23.4**
3K2	3.56	79.88	65.71	14.17	62.15	22.8	

Atterberg Limits Tests:

Table D.46: Beadle Co. Broadland Rd. Base - Liquid Limit -1

	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	LL
N blows (25-35)	27	zq	3.55	15.6	13.52	2.08	9.97	20.9	**1.4**	1.40	**21**
N blows (20-30)	24	y2	3.57	13.39	11.69	1.7	8.12	20.9	**1.4**		
N blows (15-25)	17	j	3.59	12.81	11.17	1.64	7.58	21.6	**1.2**		

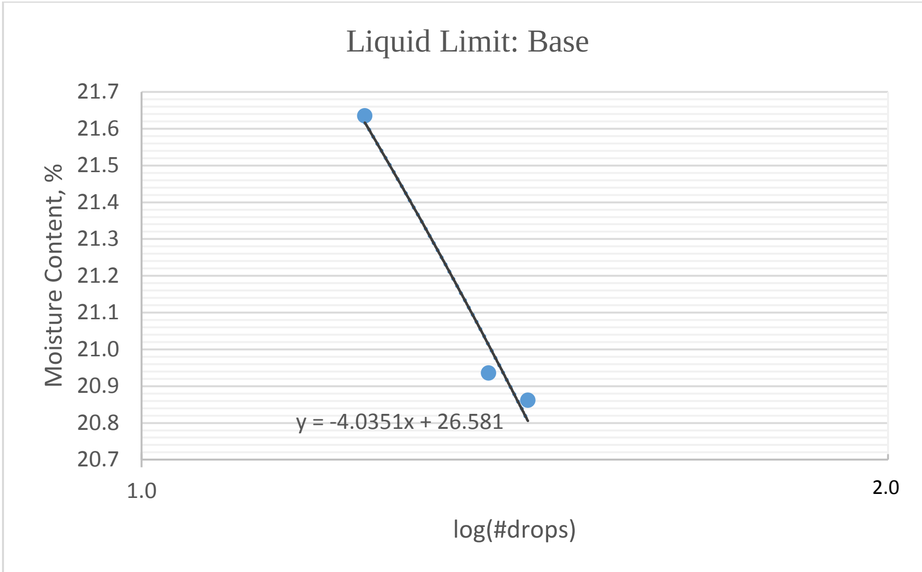


Figure D.7: Beadle Co. Broadland Rd. Liquid Limit – Base -1

Table D.47: Beadle Co. Broadland Rd. Base - Plastic Limit -1								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	N/A – Nonplastic (NP)							**NP**
Trial 2	N/A - NP							

Base Plasticity Index = NP

Table D.48: Beadle Co. Broadland Rd. Subgrade - Liquid Limit -1											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	31	28	5	3.57	12	9.54	2.46	5.97	41.2	1.40	**42**
N blows (20-30)	25	23	2	3.54	10.74	8.6	2.14	5.06	42.3		
N blows (15-25)	18	19	3	3.61	9.34	7.62	1.72	4.01	42.9		

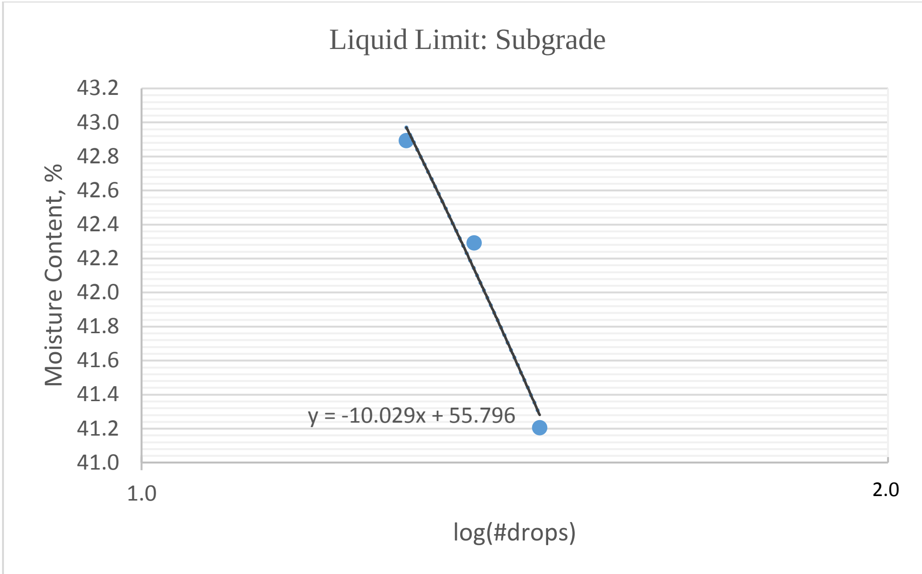


Figure D.8: Beadle Co. Broadland Rd. Liquid Limit – Subgrade -1

Table D.49: Beadle Co. Broadland Rd. Subgrade – Plastic Limit -1

	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	2	3.54	9.07	8.25	0.82	4.71	17.4	**17.4**
Trial 2	1	3.54	10.2	9.21	0.99	5.67	17.5	

Subgrade Plasticity Index = 24

Gradation Tests:

Table D.50: Beadle Co. Broadland Rd. Base Gradation -1						
	Total Soil Mass (g) =		1804.3			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	100
	1"	562.4	711.8	0	0	100
	3/4"	491.4	716.4	149.4	8.3	92
	1/2"	536.9	651.2	225	12.5	79
	3/8"	512.5	710.4	114.3	6.3	73
	No. 4	683.4	873.3	197.9	11.0	62
	No. 8	471.4	505.8	189.9	10.5	51
	No. 10	378.9	545.5	34.4	1.9	50
	No.20	338.5	507.8	166.6	9.2	40
	No. 40	324.4	477.4	169.3	9.4	31
	No. 60	519.2	609	153	8.5	22
	No. 100	332.3	390.7	89.8	5.0	17
	No. 200	284.4	292	58.4	3.2	14
	Pan	562.4	711.8	7.6	14.3	0
	No.200-Wash			251		

Table D.51: Beadle Co. Broadland Rd. Base 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
2127	1876	251

Table D.52: Beadle Co. Broadland Rd. Subgrade Gradation -1						
	Total Soil Mass (g) =		611.5			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Subgrade Soil	No. 4	512.6	518.6	6	1.0	99
	No. 10	471.4	483.1	11.7	1.9	97
	No. 40	338.5	384.3	45.8	7.5	90
	No. 200	332.4	517.6	185.2	30.3	59
	Pan	284.4	303.6	19.2	57.7	2
	No.200-Wash			333.4		

Table D.53: Beadle Co. Broadland Rd. Subgrade 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
899.4	566	333.4

Testing Location 2

Pavement Structure:

Table D.54: Beadle Co. Broadland Rd. Layer Thicknesses -2	
Surface Type	Mat
Surface Thickness	3"
Base Thickness	6”
Subbase Thickness	N/A

Moisture Content Tests:

Table D.55: Beadle Co. Broadland Rd. Moisture Content -2

Cup	Cup Mass (g)	Mass Cup + Moist Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average (%)
BASE							
AB1	3.51	65.88	62.79	3.09	59.28	5.2	**5.3**
3B	3.52	80.04	76.29	3.75	72.77	5.2	
Y2	3.55	78.12	74.11	4.01	70.56	5.7	
SUBGRADE							
4A	3.55	71.08	57.48	13.6	53.93	25.2	**25.2**
3B	3.58	76.62	61.93	14.69	58.35	25.2	

Atterberg Limits Tests:

Table D.56: Beadle Co. Broadland Rd. Base - Liquid Limit -2

	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	35	4a	3.57	9.4	8.35	1.05	4.78	22.0	**1.5**	1.40	**22**
N blows (20-30)	30	3b	3.6	11.63	10.2	1.43	6.6	21.7	**1.5**		
N blows (15-25)	16	8b	3.55	11.17	9.79	1.38	6.24	22.1	**1.2**		

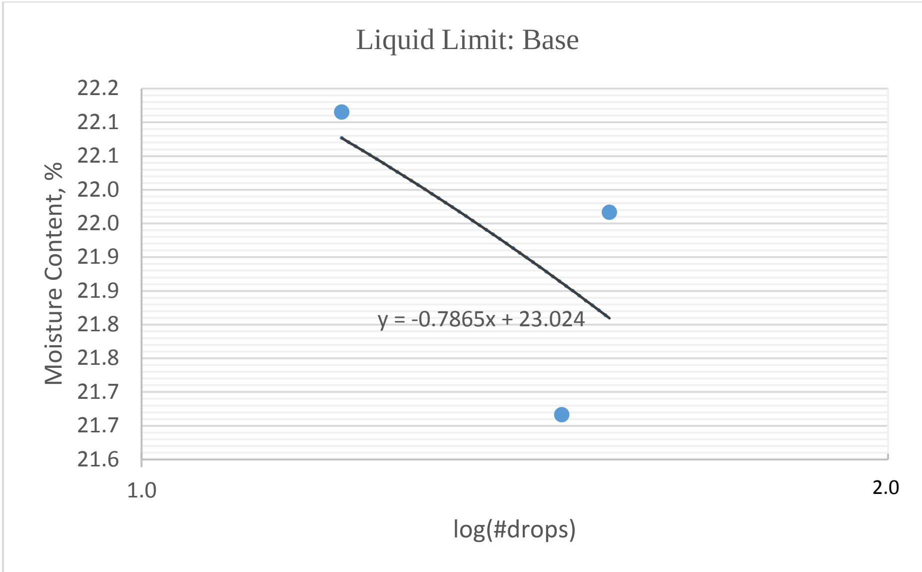


Figure D.9: Beadle Co. Broadland Rd. Liquid Limit – Base -2

Table D.57: Beadle Co. Broadland Rd. Base - Plastic Limit -2								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	N/A - NP							**NP**
Trial 2	N/A - NP							

Base Plasticity Index = NP

Table D.58: Beadle Co. Broadland Rd. Subgrade - Liquid Limit -2											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	29	1	3.57	13.28	10.41	2.87	6.84	42.0	**1.5**	1.40	**42**
N blows (20-30)	24	2	3.57	11.43	9.08	2.35	5.51	42.6	**1.4**		
N blows (15-25)	15	3	3.55	10.43	8.32	2.11	4.77	44.2	**1.2**		

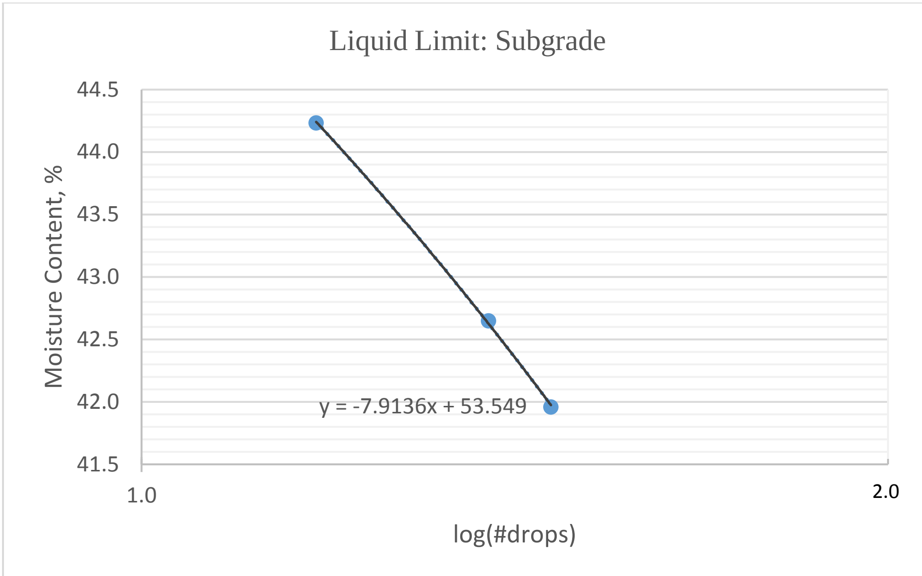


Figure D.10: Beadle Co. Broadland Rd. Liquid Limit – Subgrade -2

Table D.59: Beadle Co. Broadland Rd. Subgrade – Plastic Limit -2

	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	g	3.53	9.45	8.51	0.94	4.98	18.9	**19.0**
Trial 2	4	3.57	10.03	8.99	1.04	5.42	19.2	

Subgrade Plasticity Index = 23

Gradation Tests:

Table D.60: Beadle Co. Broadland Rd. Base Gradation -2						
Base Aggregate	Total Soil Mass (g) =		3107.4			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	100
	1"	490.8	520.7	29.9	1.0	99
	3/4"	562.4	780.5	218.1	7.0	92
	1/2"	491.4	777.6	286.2	9.2	83
	3/8"	536.9	666.8	129.9	4.2	79
	No. 4	512.5	919.7	407.2	13.1	66
	No. 8	683.4	1130.4	447	14.4	51
	No. 10	471.4	569.3	97.9	3.2	48
	No.20	378.9	838.8	459.9	14.8	33
	No. 40	338.5	632.4	293.9	9.5	24
	No. 60	324.4	526.7	202.3	6.5	17
	No. 100	519.2	715.2	196	6.3	11
	No. 200	332.3	427	94.7	3.0	8
	Pan	284.4	295.6	11.2	7.9	0
	No.200-Wash			233		

Table D.61: Beadle Co. Broadland Rd. Base 200 Wash -2		
Mass Before (g)	Mass After (g)	Mass Pass No.200
3477	3244	233

Table D.62: Beadle Co. Broadland Rd. Subgrade Gradation -2						
	Total Soil Mass (g) =		496.3			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.5	514.7	2.2	0.4	100
	No. 10	471.4	475.5	4.1	0.8	99
	No. 40	338.4	363.1	24.7	5.0	94
	No. 200	332.6	476.6	144	29.0	65
	Pan	284.4	298.8	14.4	64.7	0
	No.200-Wash			306.9		

Table D.63: Beadle Co. Broadland Rd. Subgrade 200 Wash: -2		
Mass Before (g)	Mass After (g)	Mass Pass No.200
785	478.1	306.9

Testing Location 3

Pavement Structure:

Table D.64: Beadle Co. Broadland Rd. Layer Thicknesses -3	
Surface Type	Mat
Surface Thickness	4"
Base Thickness	6”
Subbase Thickness	N/A

Moisture Content Tests:

Table D.65: Beadle Co. Broadland Rd. Moisture Content -3

Cup	Cup Mass (g)	Mass Cup + Moist Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average (%)
BASE							
2A	3.61	70.82	67.3	3.52	63.69	5.5	**5.3**
35N	3.56	92.79	88.46	4.33	84.9	5.1	
SUBGRADE							
5	3.55	46.87	40.76	6.11	37.21	16.4	**16.4**
6	3.57	73.73	64.11	9.62	60.54	15.9	
1A	3.54	93.74	80.68	13.06	77.14	16.9	

Atterberg Limits Tests:

Table D.66: Beadle Co. Broadland Rd. Base - Liquid Limit -3

	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	30	53c	3.57	10.73	9.5	1.23	5.93	20.7	**1.5**	1.40	**21**
N blows (20-30)	24	2a	3.61	12.23	10.71	1.52	7.1	21.4	**1.4**		
N blows (15-25)	19	4ba	3.56	13.47	11.69	1.78	8.13	21.9	**1.3**		

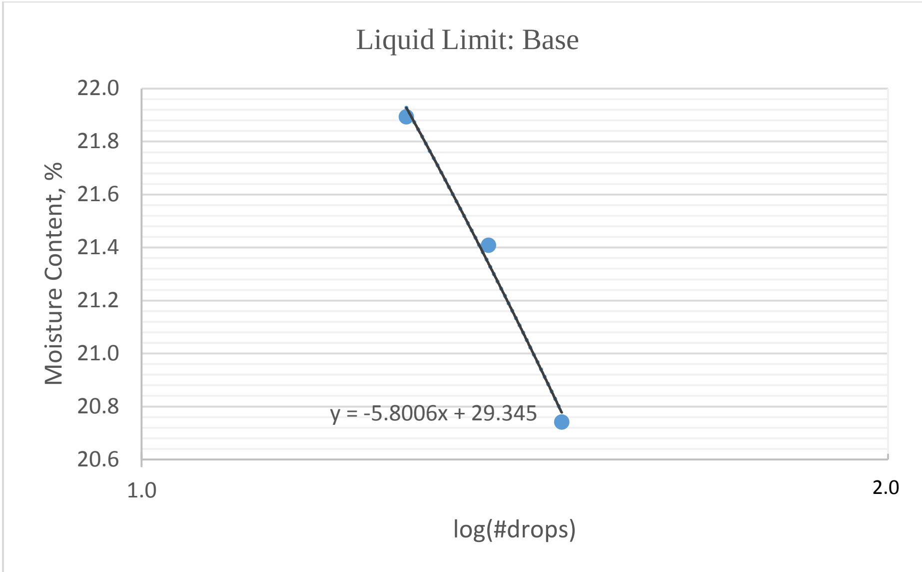


Figure D.11: Beadle Co. Broadland Rd. Liquid Limit – Base -3

Table D.67: Beadle Co. Broadland Rd. Base - Plastic Limit -3

	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	N/A - NP							**NP**
Trial 2	N/A - NP							

Base Plasticity Index = NP

Table D.68: Beadle Co. Broadland Rd. Subgrade - Liquid Limit -3

	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	28	1	3.59	11.54	9.31	2.23	5.72	39.0	**1.4**	1.40	**40**
N blows (20-30)	23	2	3.55	11.15	8.97	2.18	5.42	40.2	**1.4**		
N blows (15-25)	15	3	3.57	11.69	9.31	2.38	5.74	41.5	**1.2**		

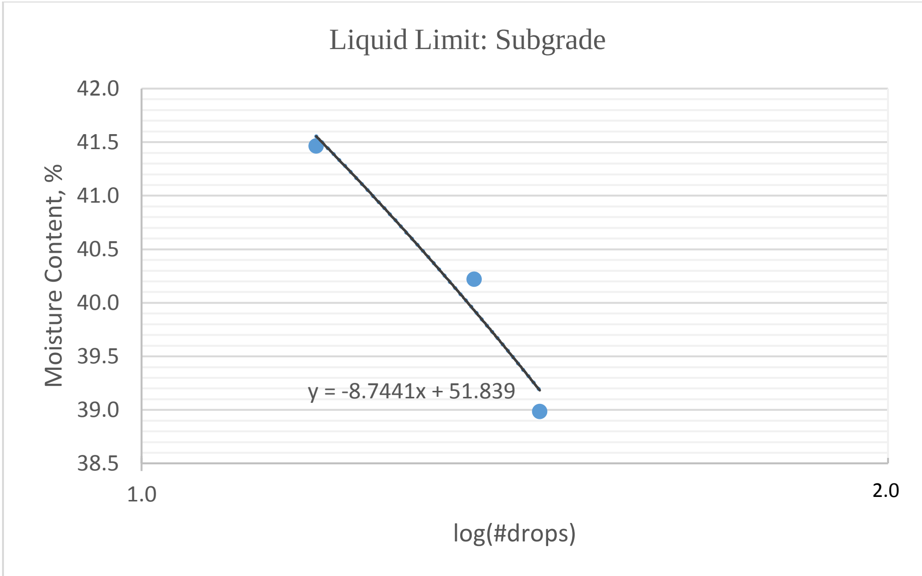


Figure D.12: Beadle Co. Broadland Rd. Liquid Limit – Base -3

Table D.69: Beadle Co. Broadland Rd. Subgrade – Plastic Limit -3

	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	e2	3.61	10.28	9.37	0.91	5.76	15.8	**15.5**
Trial 2	c5	3.57	9.33	8.57	0.76	5	15.2	

Subgrade Plasticity Index = 24

Gradation Tests:

Table D.70: Beadle Co. Broadland Rd. Base Gradation -3							
	Total Soil Mass (g) =		3107.4				
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	100
	1"	489.1	611.9	554.5	188.2	3.4	97
	3/4"	562.3	770.4	741.4	387.2	6.9	90
	1/2"	491.4	723.4	697.4	438	7.8	82
	3/8"	537	695.4	676.7	298.2	5.3	77
	No. 4	512.5	935.7	845.8	756.5	13.5	63
	No. 8	683.4	1102.4	1024	759.6	13.6	49
	No.20	378.8	900.9	782.1	925.3	16.6	33
	No. 40	338.5	625.4	540.3	488.6	8.7	24
	No. 60	324.3	521.8	461.1	334.2	6.0	18
	No. 100	519.5	717.6	655.1	333.8	6.0	12
	No. 200	332.4	417.1	403.2	155.5	2.8	9
	Pan	284.4	300.2	298.6	30	9.3	0
	No.200-Wash				490		

Table D.71: Beadle Co. Broadland Rd. Base 200 Wash -3		
Mass Before (g)	Mass After (g)	Mass Pass No.200
5868	5378	490

Table D.72: Beadle Co. Broadland Rd. Subgrade Gradation -3						
	Total Soil Mass (g) =		605.2			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Subgrade Soil	No. 4	512.5	519.9	7.4	1.2	99
	No. 10	471.3	479.1	7.8	1.3	97
	No. 40	338.4	383.6	45.2	7.5	90
	No. 200	332.4	514.1	181.7	30.0	60
	Pan	284.4	298.5	14.1	60.7	0
	No.200-Wash			353.2		

Table D.73: Beadle Co. Broadland Rd. Subgrade 200 Wash -3		
Mass Before (g)	Mass After (g)	Mass Pass No.200
956.1	602.9	353.2

Bowman County, ND, 154th Avenue

Table D.74: Bowman Co. 154th Ave. History & Field Observations	
Year Built	2013; design was 9” of ND CL 13 base with a layer of scoria on bottom, above subgrade; density tests were performed during construction; base at testing location 1 was treated with Base One
Maintenance	None
ADT / ADTT	Unkown - minimal / unkown
Surface Type	Blotter
Other Measurements & Observations	Edges broken and soft; surface is 2 layers of chip seal

Testing Location 1:

Pavement Structure:

Table D.75: Bowman Co. 154th Ave. Layer Thicknesses -1	
Surface Type	Blotter
Surface Thickness	1"
Base Thickness	6.5”
Subbase Thickness	N/A

DCP Tests:

Table D.76: Bowman Co. 154th Ave. DCP: Northbound Lane – Outer Wheelpath -1

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
0	24	0	0	0
5	26.7	27	27	5.4
10	28.7	20	47	4
15	30.6	19	66	3.8
20	32.7	21	87	4.2
25	35	23	110	4.6
30	37.8	28	138	5.6
35	41.4	36	174	7.2
40	47.6	62	236	12.4
45	52.1	45	281	9
50	57	49	330	9.8
55	62.2	52	382	10.4
60	69.5	73	455	14.6
65	77.6	81	536	16.2
70	91	134	670	26.8

Table D.77: Bowman Co. 154th Ave. DCP: Centerline -1				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	25.2	0	0	0
5	29	38	38	7.6
10	31.4	24	62	4.8
15	33.5	21	83	4.2
20	36	25	108	5
25	38.4	24	132	4.8
30	41.5	31	163	6.2
35	46.7	52	215	10.4
40	52.9	62	277	12.4
45	56.3	34	311	6.8
50	59.4	31	342	6.2
55	62.9	35	377	7
60	67	41	418	8.2
65	71.9	49	467	9.8
70	77.2	53	520	10.6
75	83.3	61	581	12.2
80	91	77	658	15.4

Table D.78: Bowman Co. 154th Ave. DCP: Southbound Lane – Outer Wheelpath -1				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	25	0	0	0
5	31.6	66	66	13.2
10	36.5	49	115	9.8
15	40.8	43	158	8.6
20	46.2	54	212	10.8
25	55.6	94	306	18.8
30	61.1	55	361	11
35	67.7	66	427	13.2
40	75.5	78	505	15.6
45	81.6	61	566	12.2
50	87.2	56	622	11.2
54	91.4	42	664	10.5

Moisture Content Tests:

Table D.79: Bowman Co. 154th Ave. Moisture Content -1

Cup	Cup Mass (g)	Mass Cup + Moist Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average (%)
BASE							
3-C	3.56	79.16	74.03	5.13	70.47	7.3	**7.5**
54 A	3.6	80.5	75.04	5.46	71.44	7.6	
SUBGRADE							
1b	3.6	63.05	56.03	7.02	52.43	13.4	**13.2**
2A	3.59	57.13	50.95	6.18	47.36	13.0	

Atterberg Limits Tests:

Table D.80: Bowman Co. 154th Ave. Base - Liquid Limit -1

	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	LL
N blows (25-35)	34	C	3.54	13.31	11.29	2.02	7.75	26.1	**1.5**	1.40	**27**
N blows (20-30)	26	CM#6	3.52	18.76	15.55	3.21	12.03	26.7	**1.4**		
N blows (15-25)	16	T	3.6	18.71	15.36	3.35	11.76	28.5	**1.2**		

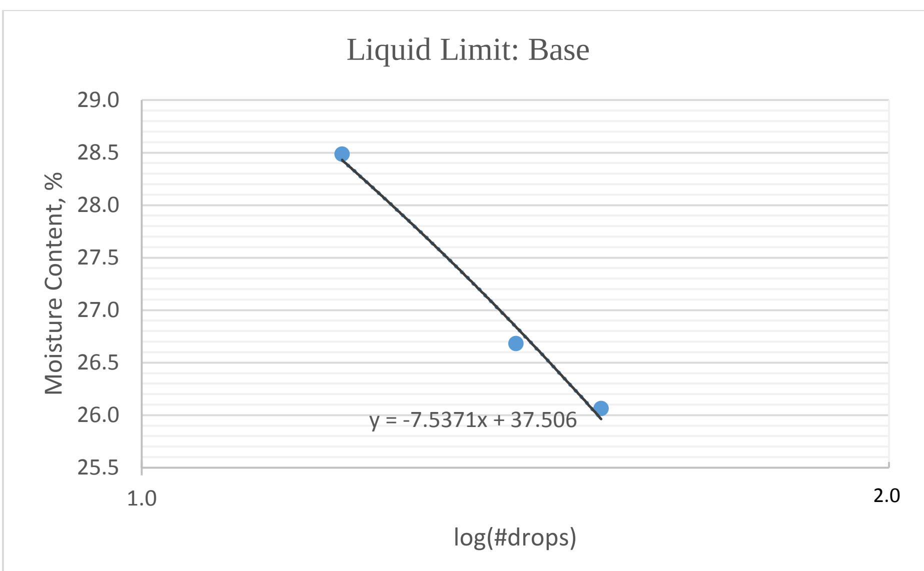


Figure D.13: Bowman Co. 154th Ave. Liquid Limit – Base -1

Table D.81: Bowman Co. 154th Ave. Base - Plastic Limit -1								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	Y2	3.58	10.45	9.47	0.98	5.89	16.6	**16.3**
Trial 2	3K2	3.57	9.88	9.01	0.87	5.44	16.0	

Base Plasticity Index = 11

Table D.82: Bowman Co. 154th Ave. Subgrade - Liquid Limit -1												
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	35	1-A	3.54	12.49	10.42	2.07	6.88	30.1	**1.5**	1.40	**32**
N blows (20-30)	27	4B	3.56	15.57	12.7	2.87	9.14	31.4	**1.4**		
N blows (15-25)	22	3B	3.52	14.47	11.79	2.68	8.27	32.4	**1.3**		

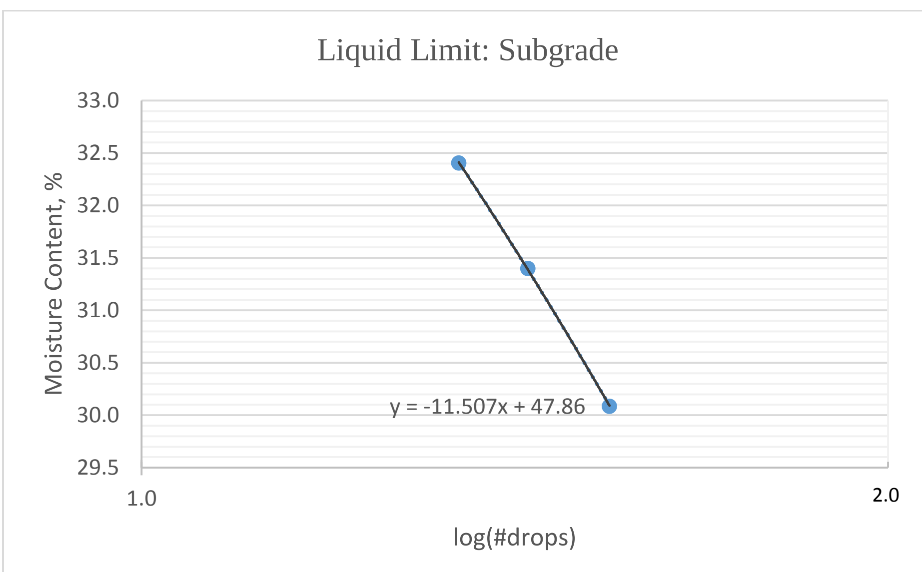


Figure D.14: Bowman Co. 154th Ave. Liquid Limit – Subgrade -1

Table D.83: Bowman Co. 154th Ave. Subgrade – Plastic Limit -1								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	4BA	3.58	9.73	8.81	0.92	5.23	17.6	**18.0**
Trial 2	53C	3.58	9.74	8.78	0.96	5.2	18.5	

Subgrade Plasticity Index = 14

Gradation Tests:

Table D.84: Bowman Co. 154th Ave. Base Gradation -1						
	Total Soil Mass (g) =		3690			
Base Aggregate	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	100
	1"	0	0	0	0	100
	1/2"	491.4	741.5	250.1	6.8	93
	No. 4	512.5	1393.2	880.7	23.9	69
	No. 8	683.5	1268.9	585.4	15.9	53
	No. 10	471.5	572.1	100.6	2.7	51
	No.20	378.6	758.4	379.8	10.3	40
	No. 30	602.8	690.4	87.6	2.4	38
	No. 40	338.2	419.5	81.3	2.2	36
	No. 100	519.1	1006	486.9	13.2	23
	No. 200	332.5	570.1	237.6	6.4	16
	Pan	284.4	331.5	47.1	16.3	0
	No.200-Wash			553		

Table D.85: Bowman Co. 154th Ave. Base 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
3978	3425	553

Table D.86: Bowman Co. 154th Ave. Subgrade Gradation -1						
	Total Soil Mass (g) =		422.0			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.6	557.7	45.1	10.7	512.6
	No. 10	471.6	497.7	26.1	6.2	471.6
	No. 40	338.4	365	26.6	6.3	338.4
	No. 200	332.4	458.4	126	29.9	332.4
	Pan	284.5	296.9	12.4	46.9	284.5
	No.200-Wash			185.7		

Table D.87: Bowman Co. 154th Ave. Subgrade 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
791.5	602.8	185.7

Testing Location 2:

Pavement Structure:

Table D.88: Bowman Co. 154th Ave. Layer Thicknesses -2	
Surface Type	Blotter
Surface Thickness	1"
Base Thickness	6.25”
Subbase Thickness	N/A

DCP Tests:

Table D.89: Bowman Co. 154th Ave. DCP: Westbound Lane – Outer Wheelpath -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	23	0	0	0
5	26.3	33	33	6.6
10	28.2	19	52	3.8
15	30	18	70	3.6
20	32	20	90	4
25	33.1	11	101	2.2
30	35.8	27	128	5.4
35	42	62	190	12.4
40	48.2	62	252	12.4
45	52.3	41	293	8.2
50	59.7	74	367	14.8
55	66.3	66	433	13.2
60	72.8	65	498	13
65	79.2	64	562	12.8
68	87.2	80	642	26.7
75	91.2	40	682	5.7

Table D.90: Bowman Co. 154th Ave. DCP: Centerline -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	24.5	0	0	0
5	28.2	37	37	7.4
10	31.2	30	67	6
15	33.9	27	94	5.4
20	35.9	20	114	4
25	38.8	29	143	5.8
30	44.1	53	196	10.6
35	49.5	54	250	10.8
40	53.1	36	286	7.2
45	56.6	35	321	7
50	61.6	50	371	10
55	67.7	61	432	12.2
60	74.3	66	498	13.2
65	81.1	68	566	13.6
70	89	79	645	15.8
72	91	20	665	10

Table D.91: Bowman Co. 154th Ave. DCP: Eastbound Lane – Outer Wheelpath -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	23.7	0	0	0
5	28.5	48	48	9.6
10	31.5	30	78	6
15	34.6	31	109	6.2
20	37.2	26	135	5.2
25	41.6	44	179	8.8
30	48.8	72	251	14.4
35	55.2	64	315	12.8
40	60.8	56	371	11.2
45	68.2	74	445	14.8
50	74.6	64	509	12.8
55	78.6	40	549	8
60	80.6	20	569	4
65	82.5	19	588	3.8
70	84.3	18	606	3.6
75	86.3	20	626	4
80	89.1	28	654	5.6
85	91.5	24	678	4.8

Moisture Content Tests:

Table D.92: Bowman Co. 154th Ave. Moisture Content -2							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
#80	3.61	70.91	64.64	6.27	61.03	10.3	**10.3**
LL 1-2	3.56	69.51	63.31	6.2	59.75	10.4	
SUBGRADE							
3K2	3.54	72.2	63.85	8.35	60.31	13.8	**14.1**
LL 1-3	3.56	88.9	78.21	10.69	74.65	14.3	

Atterberg Limits Tests:

Table D.93: Bowman Co. 154th Ave. Base - Liquid Limit -2												
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	33	2	3.59	12.34	10.5	1.84	6.91	26.6	**1.5**	1.40	**27**
N blows (20-30)	24	774B	3.6	11.59	9.89	1.7	6.29	27.0	**1.4**		
N blows (15-25)	19	1	3.59	11.56	9.81	1.75	6.22	28.1	**1.3**		

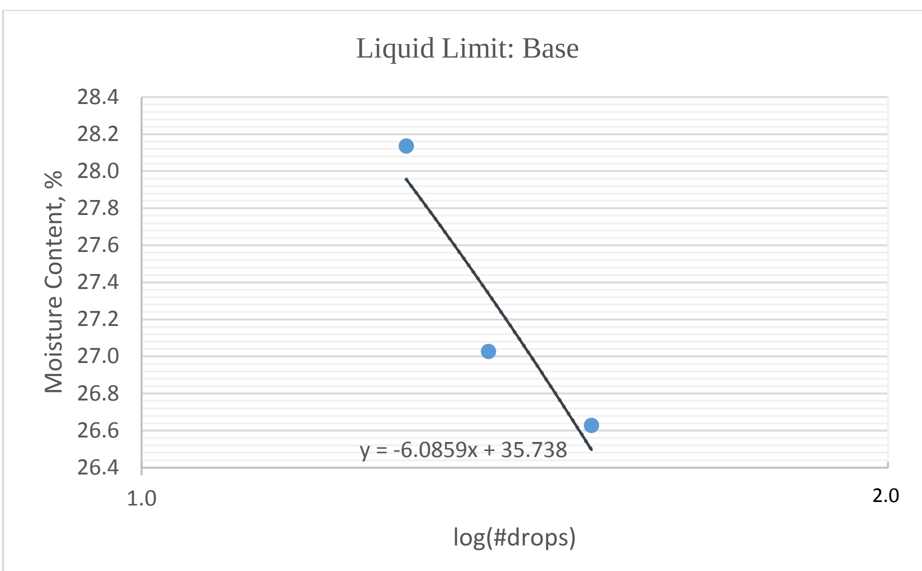


Figure D.15: Bowman Co. 154th Ave. Liquid Limit – Base -2

Table D.94: Bowman Co. 154th Ave. Base - Plastic Limit -2								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	6	3.56	11.38	10.13	1.25	6.57	19.0	**19.0**
Trial 2	LL2-1	3.55	9.96	8.94	1.02	5.39	18.9	

Base Plasticity Index = 8

Table D.95: Bowman Co. 154th Ave. Subgrade - Liquid Limit -2											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	33	5	3.59	13.57	10.94	2.63	7.35	35.8	**1.5**	1.40	**37**
N blows (20-30)	23	80	3.6	14.16	11.28	2.88	7.68	37.5	**1.4**		
N blows (15-25)	18	3B	3.61	12.31	9.88	2.43	6.27	38.8	**1.3**		

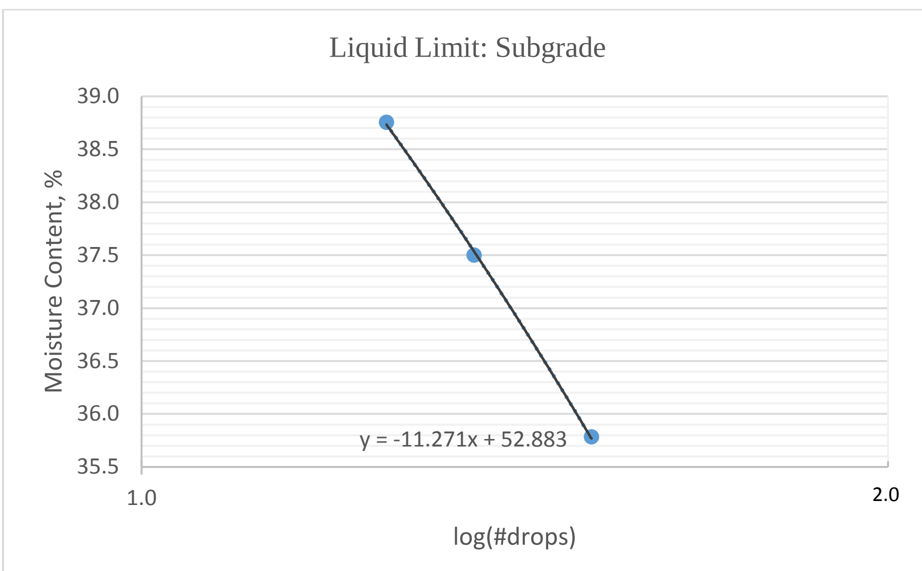


Figure D.16: Bowman Co. 154th Ave. Liquid Limit – Subgrade -2

Table D.96: Bowman Co. 154th Ave. Subgrade – Plastic Limit -2								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	3	3.57	10.8	9.86	0.94	6.29	14.9	**15.2**
Trial 2	6	3.54	10.44	9.52	0.92	5.98	15.4	

Subgrade Plasticity Index = 22

<u>Gradation Tests:</u>

Table D.97: Bowman Co. 154th Ave. Base Gradation -2						
Base Aggregate	Total Soil Mass (g) =		2198			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	100
	1"	0	0	0	0	100
	3/4”	562.4	648.8	86.4	3.9	96
	1/2"	491.5	640.8	149.3	6.8	89
	No. 4	512.5	1045.4	532.9	24.2	65
	No. 8	683.5	1015.9	332.4	15.1	50
	No. 10	471.5	529.2	57.7	2.6	47
	No.40	338.3	651.8	313.5	14.3	33
	No. 60	363.7	480.6	116.9	5.3	28
	No. 100	519.6	678.2	158.6	7.2	20
	No. 200	332.5	448.5	116	5.3	15
	Pan	284.4	311.3	26.9	15.2	0
	No.200-Wash			307		

Table D.98: Bowman Co. 154th Ave. Base 200 Wash -2		
Mass Before (g)	Mass After (g)	Mass Pass No.200
2491	2184	307

Table D.99: Bowman Co. 154th Ave. Subgrade Gradation -2						
	Total Soil Mass (g) =		268.7			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.5	519.9	7.4	2.8	97
	No. 10	471.5	476	4.5	1.7	96
	No. 40	338.2	345.9	7.7	2.9	93
	No. 200	332.4	399.3	66.9	24.9	68
	Pan	284.4	303	18.6	80.2	0
	No.200-Wash			196.8		

Table D.100: Bowman Co. 154th Ave. Subgrade 200 Wash -2		
Mass Before (g)	Mass After (g)	Mass Pass No.200
591	394.2	196.8

Brown County, Highway 14

Table D.101: Brown Co. Hwy 14 History & Field Observations	
Year Built	1978
Maintenance	Regular chip seals; Milled 2” & HMA overlay 2” in 2005; ditch trenched out in 2005
ADT / ADTT	1400 / 280
Surface Type	Mat
Other Measurements & Observations	Significant shoving – may be result of drainage problems in the ditch

<u>Pavement Structure:</u>

Table D.102: Brown Co. Hwy 14 Layer Thicknesses	
Surface Type	Mat
Surface Thickness	10.5"
Base Thickness	1”
Subbase Thickness	N/A

There was not enough base course to collect a sample, so the laboratory tests are only for the subgrade soil.

<u>DCP Tests:</u>

Table D.103: Brown Co. Hwy 14 DCP: Northbound Lane – Outer Wheelpath

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
2	52.4	0	0	0
5	62.1	97	97	32.3
10	70.5	84	181	16.8
15	81.5	110	291	22
19	93.8	123	414	30.8

Table D.104: Brown Co. Hwy 14 DCP: Centerline

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
2	49.5	0	0	0
5	51.6	21	21	7
10	59.6	80	101	16
15	74.5	149	250	29.8
20	86.7	122	372	24.4
23	92.3	56	428	18.7

Table D.105: Brown Co. Hwy 14 DCP: Southbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	52.1	0	0	0
5	61.5	94	94	31.3
10	72.8	113	207	22.6
14	93.1	203	410	50.8

Moisture Content Tests:

Table D.106: Brown Co. Hwy 14 Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
N/A – Not enough base for a sample.							
SUBGRADE							
LS #40	4.15	156.19	114.77	41.42	110.62	37.4	**38.1**
21 B	4.29	138.23	101.3	36.93	97.01	38.1	

Atterberg Limits Tests:

Table D.107: Brown Co. Hwy 14 Subgrade - Liquid Limit												
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	35	d2	3.58	9	6.92	2.08	3.34	62.3	**1.5**	1.40	**64**
N blows (20-30)	29	c4	3.58	8.65	6.67	1.98	3.09	64.1	**1.5**		
N blows (15-25)	22	15	3.58	8.67	6.67	2	3.09	64.7	**1.3**		
N blows (15-25)	17	16	3.6	8.46	6.51	1.95	2.91	67.0	**1.2**		

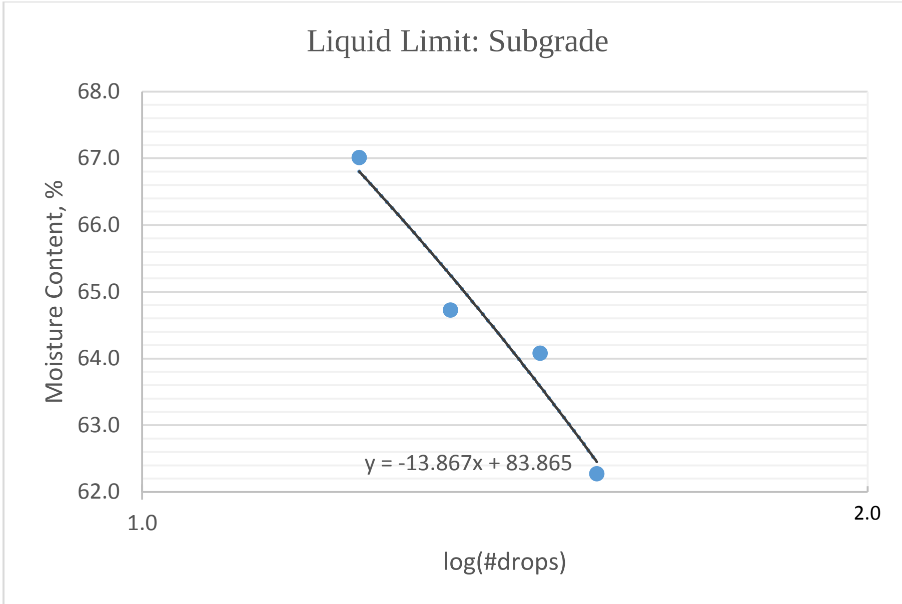


Figure D.17: Brown Co. Hwy 14 Liquid Limit – Subgrade

Table D.108: Brown Co. Hwy 14 Subgrade – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	16	3.6	10.59	9	1.59	5.4	29.4	**29.6**
Trial 2	13	3.58	9.94	8.51	1.43	4.93	29.0	
Trial 3	15	3.59	10.91	9.21	1.7	5.62	30.2	

Subgrade Plasticity Index = 35

Gradation Tests:

Table D.109: Brown Co. Hwy 14 Subgrade Gradation						
	Total Soil Mass (g) =		294.1			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	778	779.6	1.6	0.5	100
	No. 8	683.5	684	0.5	0.2	100
	No. 40	338.2	355.4	17.2	5.8	94
	No. 200	332.4	390.5	58.1	19.8	74
	Pan	284.4	298.3	13.9	73.5	1
	No.200-Wash			202.2		

Table D.110: Brown Co. Hwy 14 Subgrade 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
577.2	375	202.2

Brown County, Highway 17

Table D.111: Brown Co. Hwy 17 History & Field Observations	
Year Built	~late 1970's, exact year unknown
Maintenance	Regular chip seals; milled ¼" overlay in 2004
ADT / ADTT	325 / 0 (truck ban)
Surface Type	Blotter
Other Measurements & Observations	

Pavement Structure:

Table D.112: Brown Co. Hwy 17 Layer Thicknesses	
Surface Type	Blotter
Surface Thickness	1.75"
Base Thickness	4.4"
Subbase Thickness	N/A

DCP Tests:

Table D.113: Brown Co. Hwy 17 DCP: Eastbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	35.8	0	0	0
5	38.8	30	30	7.5
10	44.3	55	85	11
15	50.6	63	148	12.6
20	65.9	153	301	30.6
25	80.4	145	446	29
30	87.9	75	521	15

Table D.114: Brown Co. Hwy 17 DCP: Centerline				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	30.1	0	0	0
5	32.7	26	26	5.2
10	34.3	16	42	3.2
15	35.4	11	53	2.2
20	36.8	14	67	2.8
25	38.9	21	88	4.2
30	43.4	45	133	9
35	58.4	150	283	30
40	66.8	84	367	16.8
45	75.3	85	452	17
46	83.4	81	533	81
55	91.9	85	618	9.4

Table D.115: Brown Co. Hwy 17 DCP: Westbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	30	0	0	0
5	31.7	17	17	5.7
10	33.7	20	37	4
15	35.2	15	52	3
20	37	18	70	3.6
25	38.5	15	85	3
30	41.3	28	113	5.6
35	47.6	63	176	12.6
40	58.1	105	281	21
45	73	149	430	29.8
50	77.3	43	473	8.6
55	82.7	54	527	10.8
60	90.6	79	606	15.8

Moisture Content Tests:

Table D.116: Brown Co. Hwy 17 Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
2	4.09	137.29	129.4	7.89	125.31	6.3	**6.3**
3	4.08	130.01	122.44	7.57	118.36	6.4	
SUBGRADE							
10	4.21	166.05	139.76	26.29	135.55	19.4	**18.5**
1	4.04	179.63	153.4	26.23	149.36	17.6	

Atterberg Limits Tests:

Table D.117: Brown Co. Hwy 17 Base - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	34	A2	3.56	11.44	9.95	1.49	6.39	23.3	**1.5**	1.40	**25**
N blows (20-30)	26	A3	3.58	13.51	11.61	1.9	8.03	23.7	**1.4**		
N blows (20-30)	24	6	3.58	9.33	8.17	1.16	4.59	25.3	**1.4**		
N blows (15-25)	19	16	3.59	11.25	9.68	1.57	6.09	25.8	**1.3**		

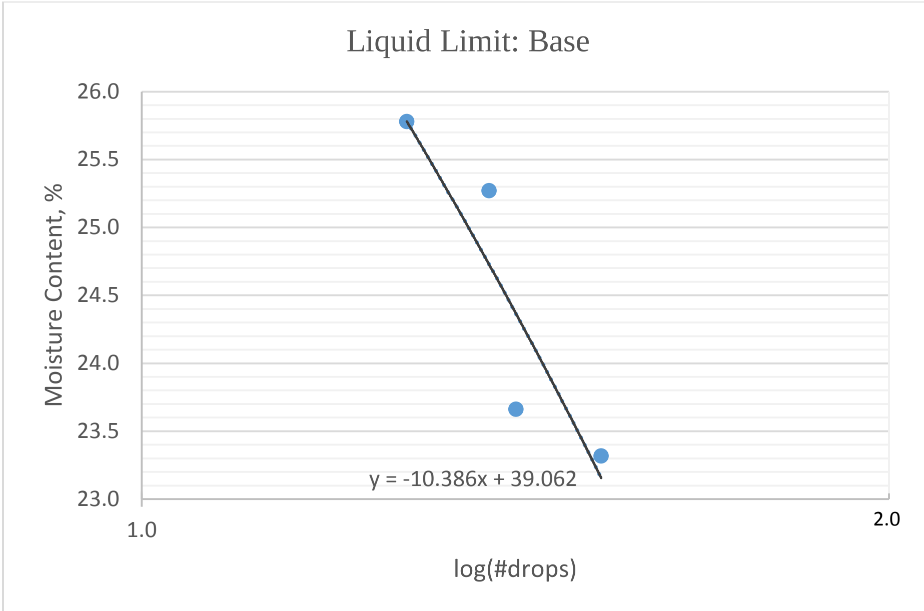


Figure D.18: Brown Co. Hwy 17 Liquid Limit – Base

Table D.118: Brown Co. Hwy 17 Base - Plastic Limit

	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	5	3.59	10.58	9.58	1	5.99	16.7	**17.4**
Trial 2	15	3.6	10	9.02	0.98	5.42	18.1	

Base Plasticity Index = 7

Table D.119: Brown Co. Hwy 17 Subgrade - Liquid Limit

	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	31	7	3.58	8.43	7.06	1.37	3.48	39.4	**1.5**	1.40	**41**
N blows (20-30)	29	2	3.56	7.96	6.71	1.25	3.15	39.7	**1.5**		
N blows (15-25)	25	4	3.53	8.52	7.07	1.45	3.54	41.0	**1.4**		
N blows (15-25)	21	11	3.53	8.81	7.24	1.57	3.71	42.3	**1.3**		

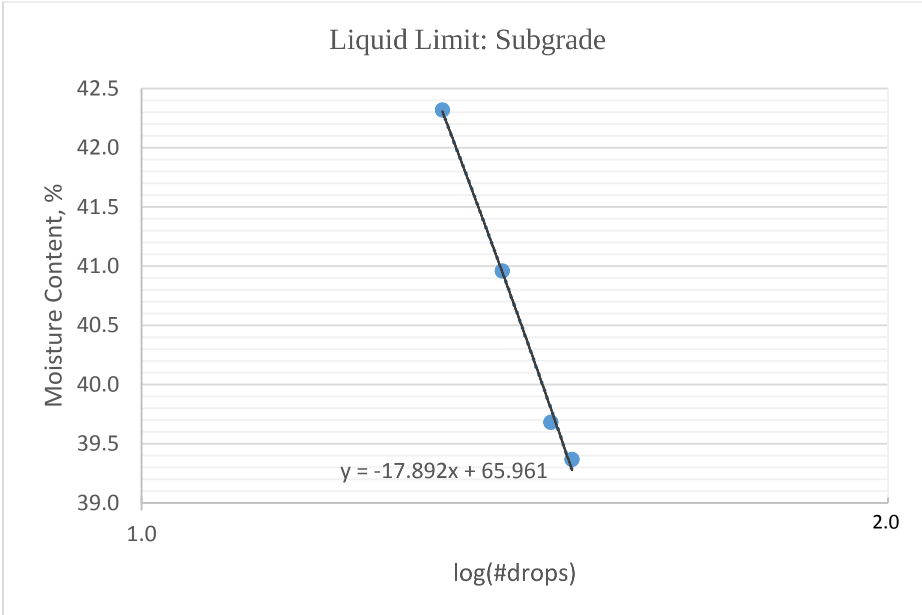


Figure D.19: Brown Co. Hwy 17 Liquid Limit – Subgrade

Table D.120: Brown Co. Hwy 17 Subgrade – Plastic Limit

	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	11	3.62	9.95	8.99	0.96	5.37	17.9	**18.0**
Trial 2	6	3.58	11.1	9.94	1.16	6.36	18.2	
Trial 3	7	3.57	11.21	10.05	1.16	6.48	17.9	

Subgrade Plasticity Index = 23

Gradation Tests:

Table D.121: Brown Co. Hwy 17 Base Gradation

	Total Soil Mass (g) =		4919.5					
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	0	100
	1"	0	0	0	0	0	0	100
	3/4"	511.3	560.9	530.7	0	69	1.4	99
	1/2"	491.3	695.6	602.1	525.1	348.9	7.1	92
	No. 4	777.9	1261.4	1131.1	882.7	941.5	19.1	72
	No. 8	683.4	954.7	901.5	796.9	602.9	12.3	60
	No. 10	477.3	536.9	526.6	505.8	137.4	2.8	57
	No.20	379.1	659.2	603.2	529.7	654.8	13.3	44
	No. 40	338.2	565.3	528.6	477.2	556.5	11.3	33
	No. 60	324.2	444.2	427.9	406.2	305.7	6.2	26
	No. 100	519.3	641	623.2	604.7	311	6.3	20
	No. 200	332.4	524.8	415.1	420.5	363.2	7.4	13
	Pan	284.4	334.3	298.8	302	81.9	15.2	0
	No.200-Wash					667.1		

Table D.122: Brown Co. Hwy 17 Base 200 Wash

Mass Before (g)	Mass After (g)	Mass Pass No.200
4919.5	4252.4	667.1

Table D.123: Brown Co. Hwy 17 Subgrade Gradation

	Total Soil Mass (g) =		402.8			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Subgrade Soil	No. 4	778	792.4	14.4	3.6	100
	No. 8	683.5	693.1	9.6	2.4	98
	No. 40	338.2	376.2	38	9.4	88
	No. 200	332.4	471.8	139.4	34.6	54
	Pan	284.3	310.6	26.3	49.6	4
	No.200-Wash			173.6		

Table D.124: Brown Co. Hwy 17 Subgrade 200 Wash

Mass Before (g)	Mass After (g)	Mass Pass No.200
698	524.4	173.6

Clay County, Saginaw Road

Table D.125: Clay Co. Saginaw Ave. History & Field Observations	
Year Built	~2002, exact year unknown
Maintenance	unknown
ADT / ADTT	601 / unknown
Surface Type	Blotter
Other Measurements & Observations	Numerous patches

Pavement Structure:

Table D.126: Clay Co. Saginaw Ave. Layer Thicknesses	
Surface Type	Blotter
Surface Thickness	1"
Base Thickness	7.6”
Subbase Thickness	N/A

DCP Tests:

Table D.127: Clay Co. Saginaw Ave. DCP: Northbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	26.5	0	0	0
5	28.3	18	18	4.5
10	30.1	18	36	3.6
15	32	19	55	3.8
20	33.9	19	74	3.8
25	35.8	19	93	3.8
30	37.4	16	109	3.2
35	39.3	19	128	3.8
40	41.1	18	146	3.6
45	43.8	27	173	5.4
50	48.9	51	224	10.2
55	55.7	68	292	13.6
60	65.1	94	386	18.8
65	88.1	230	616	46

Table D.128: Clay Co. Saginaw Ave. DCP: Centerline				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	26.5	0	0	0
5	28	15	15	3.75
10	29.6	16	31	3.2
15	31.2	16	47	3.2
20	32.5	13	60	2.6
25	34.1	16	76	3.2
30	35.5	14	90	2.8
35	36.4	9	99	1.8
40	37	6	105	1.2
45	38	10	115	2
50	39	10	125	2
55	40	10	135	2
60	41.4	14	149	2.8
65	43	16	165	3.2
70	46.3	33	198	6.6
75	52.4	61	259	12.2
80	60.2	78	337	15.6
85	68.8	86	423	17.2
90	81	122	545	24.4
92	92.9	119	664	59.5

Table D.129: Clay Co. Saginaw Ave. DCP: Southbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	26.8	0	0	0
5	28.5	17	17	5.7
10	30.6	21	38	4.2
15	32.8	22	60	4.4
20	34.6	18	78	3.6
25	36.7	21	99	4.2
30	38.5	18	117	3.6
35	40.5	20	137	4
40	43.3	28	165	5.6
45	48.4	51	216	10.2
50	56	76	292	15.2
55	67.7	117	409	23.4
60	85.3	176	585	35.2
62	93.6	83	668	41.5

Moisture Content Tests:

Table D.130: Clay Co. Saginaw Ave. Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
16	3.57	100.3	94.15	6.15	90.58	6.8	**6.4**
6	3.62	101.81	96.01	5.8	92.39	6.3	
3	3.55	78.82	74.44	4.38	70.89	6.2	
SUBGRADE							
g4	3.57	65.29	56.76	8.53	53.19	16.0	**16.0**
g3	3.52	58.91	51.32	7.59	47.8	15.9	

Atterberg Limits Tests:

Table D.131: Clay Co. Saginaw Ave. Base - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	26	2	3.56	13.89	12.22	1.67	8.66	19.3	**1.4**	1.40	**19**
N blows (20-30)	21	5	3.55	15.8	13.81	1.99	10.26	19.4	**1.3**		
N blows (15-25)	17	#4	3.53	11.9	10.49	1.41	6.96	20.3	**1.2**		

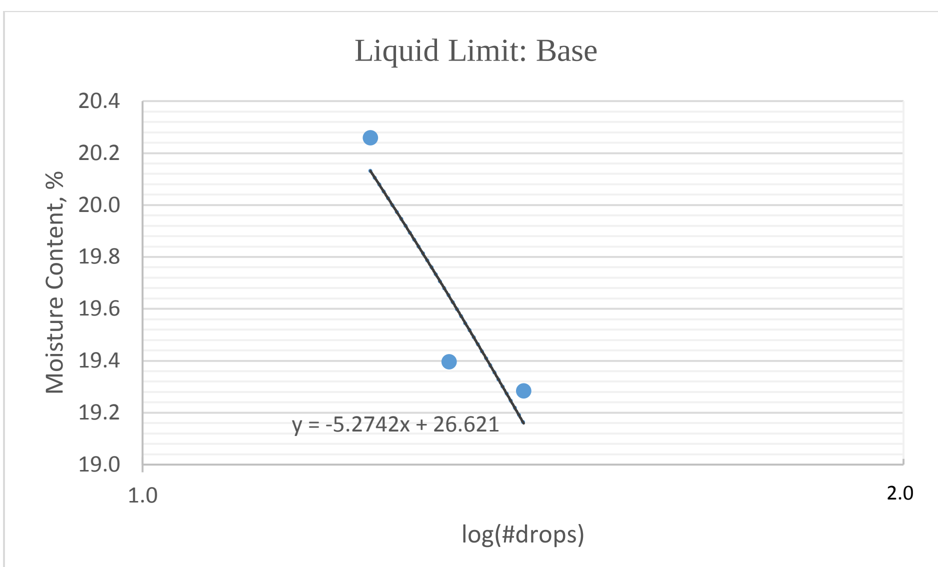


Figure D.20: Clay Co. Saginaw Ave. Liquid Limit – Base

Table D.132: Clay Co. Saginaw Ave. Base - Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	4	3.61	11.27	10.28	0.99	6.67	14.8	**15.0**
Trial 2	a2	3.6	9.65	8.85	0.8	5.25	15.2	

Base Plasticity Index = 4

Table D.133: Clay Co. Saginaw Ave. Subgrade - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	28	20	3.55	9.87	8.16	1.71	4.61	37.1	**1.4**	1.40	**38**
N blows (20-30)	22	774b	3.6	10.41	8.51	1.9	4.91	38.7	**1.3**		
N blows (15-25)	17	g4	3.56	10.24	8.36	1.88	4.8	39.2	**1.2**		
N blows (15-25)	28	20	3.55	9.87	8.16	1.71	4.61	37.1	**1.4**		

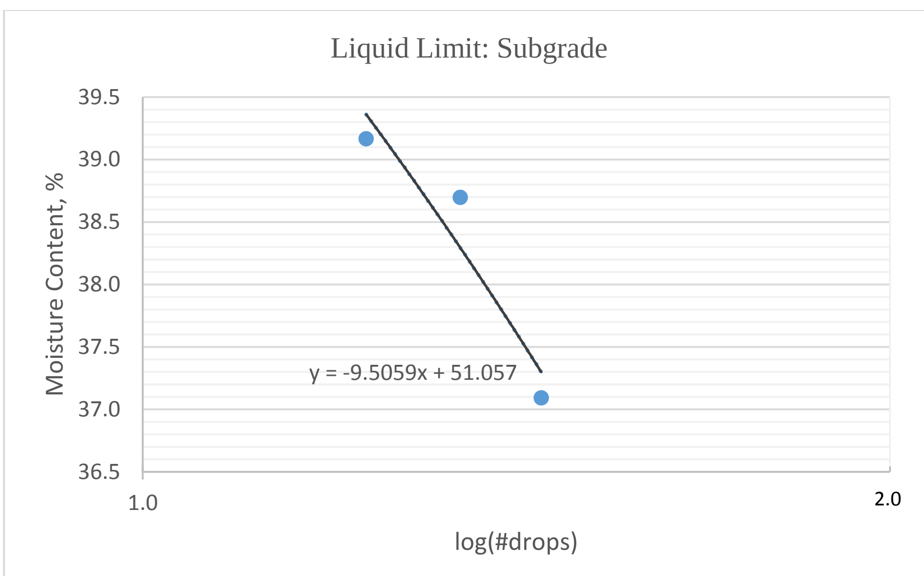


Figure D.21: Clay Co. Saginaw Ave. Liquid Limit – Subgrade

Table D.134: Clay Co. Saginaw Ave. Subgrade – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	21	3.57	10.99	9.85	1.14	6.28	18.2	**18.0**
Trial 2	19	3.59	10.23	9.22	1.01	5.63	17.9	

Subgrade Plasticity Index = 20

<u>Gradation Tests:</u>

Table D.135: Clay Co. Saginaw Ave. Base Gradation								
Base Aggregate	Total Soil Mass (g) =	6149.6						
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	0	0	100
	1"	0	0	0	0	0	0	100
	3/4"	512.7	594.5	607.9	542.8	207.1	3.4	97
	1/2"	567.3	822.4	756.2	645	521.7	8.5	88
	3/8”	491.3	664.5	612.4	579.6	382.6	6.2	82
	No. 4	486.8	930.1	777.8	692.6	940.1	15.3	67
	No. 8	686.3	986	887.6	826.8	641.5	10.4	56
	No. 10	464.5	526.3	508.7	495.6	137.1	2.2	54
	No. 30	508.4	1041.6	892.1	766.7	1175.2	19.1	35
	No. 40	363.3	556.7	509.4	455.6	431.8	7.0	28
	No. 50	548.1	730.6	703.9	637.4	427.6	7.0	21
	No. 100	333.1	551.3	511.7	437.6	501.3	8.2	13
	No. 200	513.3	583.7	557.4	545.8	147	2.4	10
	Pan	492.1	501.6	497	497.1	19.4	15.1	0
	No.200-Wash					910.3		

Table D.136: Clay Co. Saginaw Ave. Base 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
6643	5532.7	910.3

Table D.137: Clay Co. Saginaw Ave. Subgrade Gradation						
	Total Soil Mass (g) =		816.4			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	1/2"	567.2	572.1	4.9	0.6	100
	No. 4	486.7	494.4	7.7	0.9	99
	No. 10	464.4	476.7	12.3	1.5	98
	No. 40	363.3	417.5	54.2	6.6	91
	No. 200	513.3	640	126.7	15.5	76
	Pan	492.1	529.5	37.4	74.7	1
	No.200-Wash			572.6		

Table D.138: Clay Co. Saginaw Ave. Subgrade 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
1845.2	1272.6	572.6

Codington County, Old Highway 81

Table D.139: Codington Co. Old Hwy 81 History & Field Observations	
Year Built	~1937, exact year unknown
Maintenance	2" HMA Overlays in 1994 and 2007
ADT / ADTT	1929 / unknown
Surface Type	Blotter
Other Measurements & Observations	Base at testing location 1 appeared to be a "black base"; subbase at testing location 1 and base at testing locations 2 & 3 appeared to be mixed with river sand and kerosene; largest rut measured = 3mm

Testing Location 1

Pavement Structure:

Table D.140: Codington Co. Old Hwy 81 Layer Thicknesses -1	
Surface Type	Mat
Surface Thickness	11.75"
Base Thickness	3"
Subbase Thickness	5"

DCP Tests:

Table D.141: Codington Co. Old Hwy 81 DCP: Northbound Lane – Outer Wheelpath -1				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	26	0	0	0
5	27.7	17	17	4.3
10	28.5	8	25	1.6
15	29.2	7	32	1.4
20	30.3	11	43	2.2
25	31.5	12	55	2.4
30	33	15	70	3
35	34.6	16	86	3.2
40	36.4	18	104	3.6
45	38.4	20	124	4
50	40.4	20	144	4
55	42.7	23	167	4.6
60	45.9	32	199	6.4
65	53.1	72	271	14.4
70	75.4	223	494	44.6
75	92.2	168	662	33.6

Table D.142: Codington Co. Old Hwy 81 DCP: Northbound Lane – Outside of Shoulder -1				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	33.3	0	0	0
5	41.9	86	86	21.5
10	50.4	85	171	17
15	55.6	52	223	10.4
20	62.9	73	296	14.6
25	68.9	60	356	12
30	78.7	98	454	19.6
33	90.6	119	573	39.7

Moisture Content Tests:

Table D.143: Codington Co. Old Hwy 81 Moisture Content -1							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
7	3.56	82.76	79.89	2.87	76.33	3.8	
8	3.56	80.71	77.97	2.74	74.41	3.7	**3.8**
9	3.6	93.45	90.07	3.38	86.47	3.9	
SUBBASE							
4	3.56	57.15	54.76	2.39	51.2	4.7	
5	3.56	77.98	74.9	3.08	71.34	4.3	**4.6**
6	3.62	82.26	78.56	3.7	74.94	4.9	
SUBGRADE							
1	3.54	54.53	46.08	8.45	42.54	19.9	
2	3.57	62.22	52.09	10.13	48.52	20.9	**20.5**
3	3.56	65.24	54.59	10.65	51.03	20.9	

Atterberg Limits Tests:

Table D.144: Codington Co. Old Hwy 81 Base - Liquid Limit -1											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	29	5	3.55	12.49	11.04	1.45	7.49	19.4	**1.5**		
N blows (20-30)	20	4b	3.56	11.89	10.49	1.4	6.93	20.2	**1.3**	1.40	**27**
N blows (15-25)	15	y2	3.56	13.91	12.25	1.66	8.69	19.1	**1.2**		

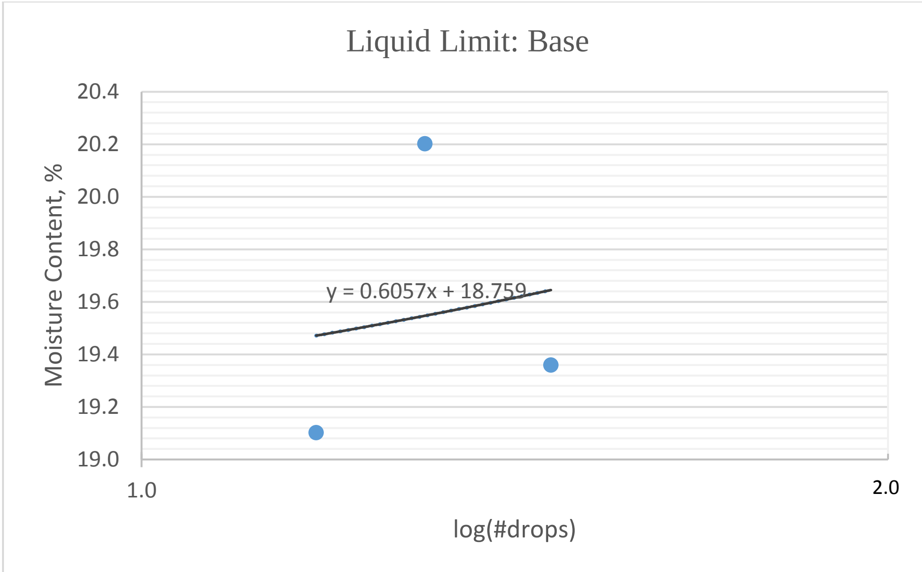


Figure D.22: Codington Co. Old Hwy 81 Liquid Limit – Base -1

The results of liquid limit test for the base course are not acceptable, but it was not rerun since it was found to be non-plastic from the plasticity test.

Table D.145: Codington Co. Old Hwy 81 Base - Plastic Limit -1

	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	N/A – NP							**NP**

Base Plasticity Index = NP

Table D.146: Codington Co. Old Hwy 81 Subbase - Liquid Limit -1

	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	LL
N blows (25-35)	33	7	3.56	13.21	11.5	1.71	7.94	21.5	**1.5**	1.40	**23**
N blows (20-30)	28	f3	3.58	11.28	9.86	1.42	6.28	22.6	**1.4**		
N blows (15-25)	20	c5	3.58	12.45	10.75	1.7	7.17	23.7	**1.3**		
N blows (15-25)	33	7	3.56	13.21	11.5	1.71	7.94	21.5	**1.5**		

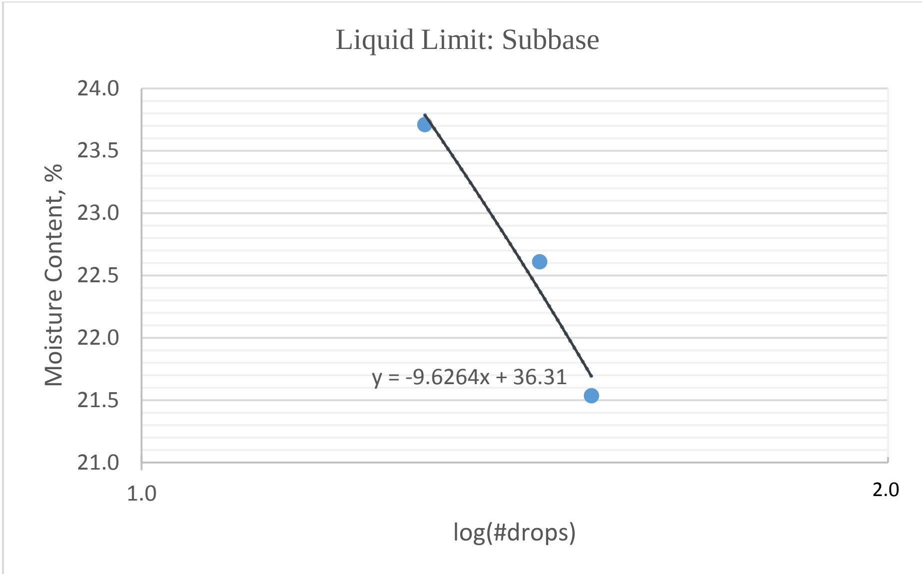


Figure D.23: Codington Co. Old Hwy 81 Liquid Limit – Subbase -1

Table D.147: Codington Co. Old Hwy 81 Subbase – Plastic Limit -1								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	1	3.54	11.43	10.43	1	6.89	14.5	**14.3**
Trial 2	8	3.55	11.53	10.55	0.98	7	14.0	

Subbase Plasticity Index = 9

Table D.148: Codington Co. Old Hwy 81 Subgrade - Liquid Limit -1											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	29	10	3.56	10.1	8.22	1.88	4.66	40.3	**1.5**	1.40	**41**
N blows (20-30)	23	18	3.55	12.43	9.81	2.62	6.26	41.9	**1.4**		
N blows (15-25)	17	12	3.62	11.51	9.15	2.36	5.53	42.7	**1.2**		

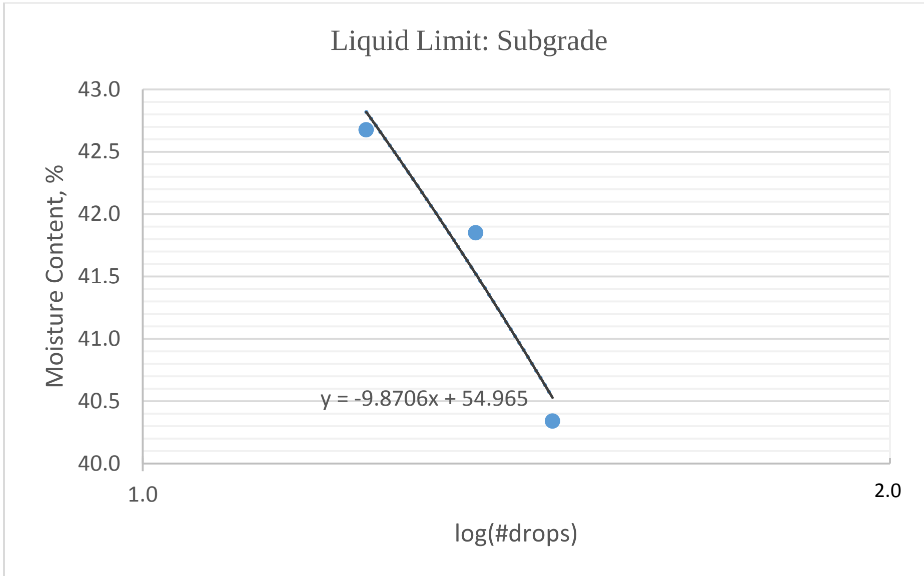


Figure D.24: Codington Co. Old Hwy 81 Liquid Limit – Subgrade -1

Table D.149: Codington Co. Old Hwy 81 Subgrade – Plastic Limit -1

	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	G1	3.57	11.04	9.88	1.16	6.31	18.4	**18.4**
Trial 2	G2	3.57	10.89	9.75	1.14	6.18	18.4	

Subgrade Plasticity Index = 23

Gradation Tests:

Table D.150: Codington Co. Old Hwy 81 Base Gradation -1								
	Total Soil Mass (g) =	5143						
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	0	100
	1"	0	0	0	0	0	0	100
	3/4"	512.7	683	570.9	607.2	323	6.28	94
	1/2"	567.3	858.3	761.4	647.7	565.5	11.00	83
	3/8”	491.4	667.1	659.7	605.7	458.3	8.91	74
	No. 4	486.9	998.3	820.3	683.3	1041.2	20.24	54
	No. 8	686.5	1078.7	946.7	827.4	793.3	15.42	38
	No. 10	464.6	539.1	514.4	490.6	150.3	2.92	35
	No. 30	508.3	860.1	796.2	649.9	781.3	15.19	20
	No. 40	363.3	444.5	438.4	403.8	196.8	3.83	16
	No. 50	548.2	626.7	628.6	592.8	203.5	3.96	12
	No. 100	333	421.8	427.8	388.1	238.7	4.64	8
	No. 200	513.3	556.3	550.5	534.4	101.3	1.97	6
	Pan	492.2	496.3	495.7	494.3	9.7	5.6	0
	No.200-Wash					277		

Table D.151: Codington Co. Old Hwy 81 Base 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
5494	5217	277

Table D.152: Codington Co. Old Hwy 81 Subbase Gradation -1							
	Total Soil Mass (g) =	4671.6					
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	100
	1"	0	0	0	0	0.00	100
	3/4"	512.6	584.2	540.6	99.6	2.13	98
	1/2"	567.2	670.2	710.6	246.4	5.27	93
	3/8”	491.3	598.9	592.6	208.9	4.47	88
	No. 4	486.7	807.2	787.3	621.1	13.30	75
	No. 8	686.4	998.8	998.5	624.5	13.37	61
	No. 10	464.5	531.9	535.3	138.2	2.96	59
	No. 30	508.3	922.8	976.2	882.4	18.89	40
	No. 40	363.3	494.9	521.3	289.6	6.20	33
	No. 50	548.1	693.7	718.2	315.7	6.76	27
	No. 100	333.1	534.8	573.6	442.2	9.47	17
	No. 200	513.4	601.2	612.9	187.3	4.01	13
	Pan	492.2	502.2	504.5	22.3	13.2	0
	No.200-Wash				596		

Table D.153: Codington Co. Old Hwy 81 Subbase 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
4960	4364	596

Table D.154: Codington Co. Old Hwy 81 Subgrade Gradation -1						
	Total Soil Mass (g) =		738.8			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.4	524	11.6	1.6	98
	No. 10	471.4	496.9	25.5	3.5	95
	No. 40	338.4	440.4	102	13.8	81
	No. 200	332.5	483.5	151	20.4	61
	Pan	284.4	299.1	14.7	60.8	0
	No.200-Wash			434.4		

Table D.155: Codington Co. Old Hwy 81 Subgrade 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
1022.1	587.7	434.4

Testing Location 2

Pavement Structure:

Table D.156: Codington Co. Old Hwy 81 Layer Thicknesses -2	
Surface Type	Mat
Surface Thickness	10.75"
Base Thickness	9”
Subbase Thickness	N/A

DCP Tests:

Table D.157: Codington Co. Old Hwy 81 DCP: Northbound Lane – Outer Wheelpath -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	23.4	0	0	0
5	25.1	17	17	4.25
10	27.2	21	38	4.2
15	28.7	15	53	3
20	31.1	24	77	4.8
25	33.9	28	105	5.6
30	36.7	28	133	5.6
35	39.8	31	164	6.2
40	43.8	40	204	8
45	53.8	100	304	20
50	62.7	89	393	17.8
55	73.1	104	497	20.8
60	80.6	75	572	15
64	90.1	95	667	23.75

Table D.158: Codington Co. Old Hwy 81 DCP: Northbound Lane – Shoulder -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	29.3	0	0	0
5	35.4	61	61	15.3
10	39.3	39	100	7.8
15	42	27	127	5.4
20	43.1	11	138	2.2
25	43.9	8	146	1.6
30	44.7	8	154	1.6
35	45.1	4	158	0.8
40	45.8	7	165	1.4
45	46	2	167	0.4
50	46.6	6	173	1.2
60	47.4	8	181	0.8
65	47.7	3	184	0.6
70	48	3	187	0.6
75	48.5	5	192	1
80	48.9	4	196	0.8

Table D.159: Codington Co. Old Hwy 81 DCP: Northbound Lane – Outside of Shoulder -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	27.3	0	0	0
5	34.4	71	71	17.75
10	36.2	18	89	3.6
15	37	8	97	1.6
20	37.7	7	104	1.4
25	38.3	6	110	1.2
30	38.9	6	116	1.2
35	39.5	6	122	1.2
40	40.3	8	130	1.6
45	41.3	10	140	2
50	42.4	11	151	2.2
55	43.9	15	166	3
60	46	21	187	4.2
65	50.7	47	234	9.4
70	60	93	327	18.6
75	78.1	181	508	36.2
80	93.2	151	659	30.2

Moisture Content Tests:

Table D.160: Codington Co. Old Hwy 81 Moisture Content -2							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
13	3.58	70.93	68.91	2.02	65.33	3.1	
14	3.57	89.64	87.12	2.52	83.55	3.0	**3.1**
15	3.57	91.47	88.86	2.61	85.29	3.1	
SUBGRADE							
10	3.56	67.11	57.17	9.94	53.61	18.5	
11	3.57	64.11	55.07	9.04	51.5	17.6	**17.5**
12	3.62	82.15	71.01	11.14	67.39	16.5	

Atterberg Limits Tests:

Table D.161: Codington Co. Old Hwy 81 Base - Liquid Limit -2											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	33	3	3.56	15.16	13.35	1.81	9.79	18.5	**1.5**	1.40	**20**
N blows (20-30)	27	1	3.57	12.46	10.98	1.48	7.41	20.0	**1.4**		
N blows (15-25)	13	6	3.55	13.87	12.09	1.78	8.54	20.8	**1.1**		

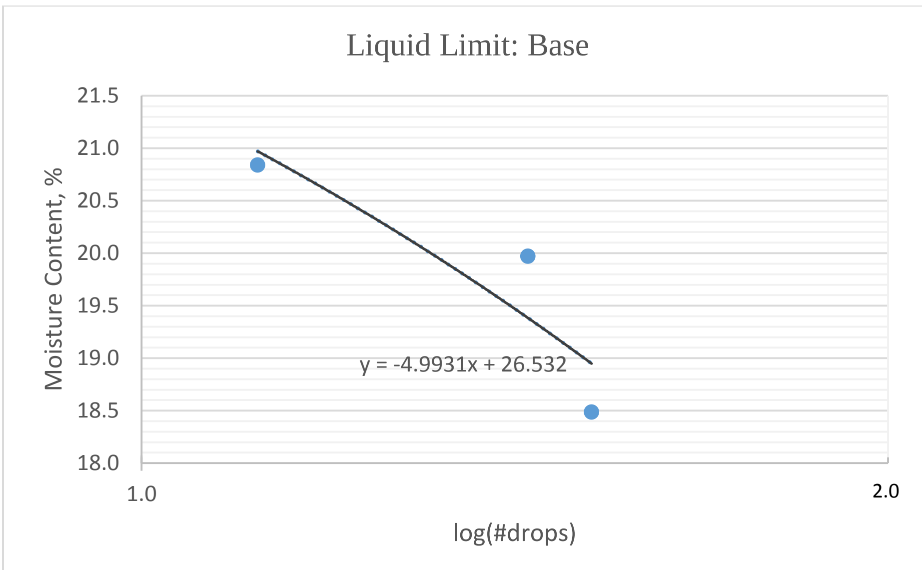


Figure D.25: Codington Co. Old Hwy 81 Liquid Limit – Base -2

Table D.162: Codington Co. Old Hwy 81 Base - Plastic Limit -2								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	N/A – NP							**NP**

Base Plasticity Index = NP

Table D.163: Codington Co. Old Hwy 81 Subgrade - Liquid Limit -2											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	LL
N blows (25-35)	36	16	3.57	10.03	8.33	1.7	4.76	35.7	**1.6**	1.40	**37**
N blows (20-30)	26	17	3.57	12.01	9.71	2.3	6.14	37.5	**1.4**		
N blows (15-25)	18	21	3.57	11.13	9.04	2.09	5.47	38.2	**1.3**		

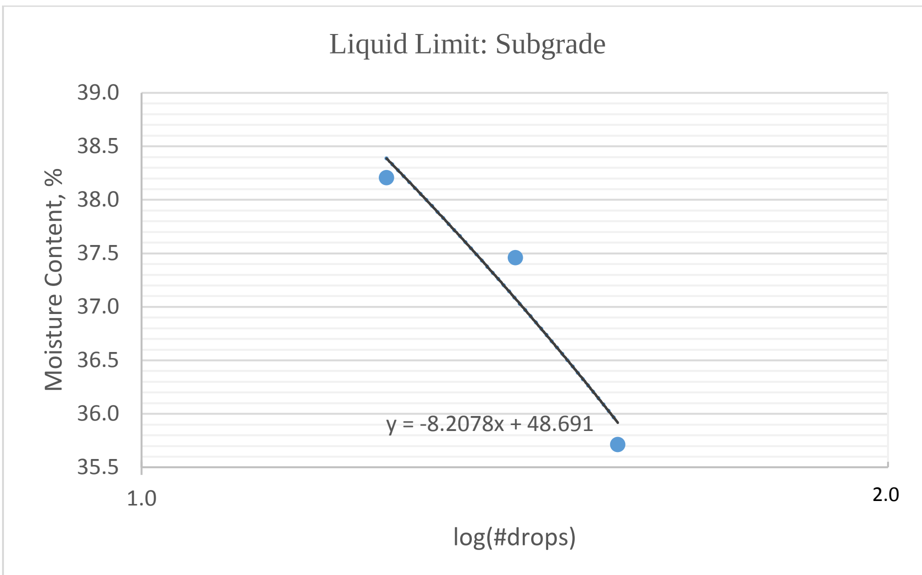


Figure D.26: Codington Co. Old Hwy 81 Liquid Limit – Subgrade -2

Table D.164: Codington Co. Old Hwy 81 Subgrade – Plastic Limit -2								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	G3	3.51	10.91	9.64	1.27	6.13	20.7	**20.8**
Trial 2	F5	3.61	10.46	9.28	1.18	5.67	20.8	

Subgrade Plasticity Index = 16

Gradation Tests:

Table D.165: Codington Co. Old Hwy 81 Base Gradation -2								
Base Aggregate	Total Soil Mass (g) =		6437.5					
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	0	0	100
	1"	0	0	0	0	0	0	100
	3/4"	512.7	551.1	542.4	540.1	95.5	1.48	99
	1/2"	567.2	659.3	818.5	691.9	468.1	7.27	91
	3/8”	491.4	608.7	650.5	660.6	445.6	6.92	84
	No. 4	486.7	811.8	907	849.4	1108.1	17.21	67
	No. 8	686.4	1029.4	1064.1	986	1020.3	15.85	51
	No. 10	464.4	540.5	545.1	523.7	216.1	3.36	48
	No. 30	508.4	1031.9	1009.8	902.9	1419.4	22.05	26
	No. 40	363.4	522.7	500.5	475.2	408.2	6.34	20
	No. 50	548.2	686.7	665.2	647.4	354.7	5.51	14
	No. 100	333.1	462.9	432.6	420.6	316.8	4.92	9
	No. 200	513.3	574.1	549.2	549.4	132.8	2.06	7
	Pan	492.2	497.5	494.8	495.2	10.9	7.0	0
	No.200-Wash					440		

Table D.166: Codington Co. Old Hwy 81 Base 200 Wash -2		
Mass Before (g)	Mass After (g)	Mass Pass No.200
6731	6291	440

Table D.167: Codington Co. Old Hwy 81 Subgrade Gradation -2						
	Total Soil Mass (g) =		680.4			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.4	557	44.6	6.6	93
	No. 10	471.4	520.8	49.4	7.3	86
	No. 40	338.3	453.9	115.6	17.0	69
	No. 200	332.3	464.1	131.8	19.4	50
	Pan	284.4	310.3	25.9	49.9	0
	No.200-Wash			313.8		

Table D.168: Codington Co. Old Hwy 81 Subgrade 200 Wash -2		
Mass Before (g)	Mass After (g)	Mass Pass No.200
969.4	655.6	313.8

Testing Location 3

Pavement Structure:

Table D.169: Codington Co. Old Hwy 81 Layer Thicknesses -3	
Surface Type	Mat
Surface Thickness	11.5"
Base Thickness	8”
Subbase Thickness	N/A

DCP Tests:

Table D.170: Codington Co. Old Hwy 81 DCP: Northbound Lane – Outer Wheelpath -3

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
1	29.1	0	0	0
5	37.5	84	84	21
10	51.7	142	226	28.4
15	60	83	309	16.6
20	83.6	236	545	47.2
22	91.7	81	626	40.5

Table D.171: Codington Co. Old Hwy 81 DCP: Northbound Lane – Shoulder -3

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
1	26	0	0	0
6	30.9	49	49	9.8
10	34.2	33	82	8.25
15	37.2	30	112	6
20	40.5	33	145	6.6
25	44.9	44	189	8.8
30	57.3	124	313	24.8
34	88.5	312	625	78

Table D.172: Codington Co. Old Hwy 81 DCP: Northbound Lane – Outside of Shoulder -3

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
0	25.8	0	0	0
5	35.7	99	99	19.8
10	39.8	41	140	8.2
15	42.1	23	163	4.6
20	45.8	37	200	7.4
25	65.7	199	399	39.8
29	94	283	682	70.75

Moisture Content Tests:

Table D.173: Codington Co. Old Hwy 81 Moisture Content -3							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
19	3.6	70.4	66.74	3.66	63.14	5.8	**5.8**
20	3.54	87.71	82.15	5.56	78.61	7.1	
21	3.57	80.72	77.47	3.25	73.9	4.4	
SUBGRADE							
16	3.56	45.95	38.18	7.77	34.62	22.4	**23.2**
17	3.57	55.18	45.43	9.75	41.86	23.3	
18	3.57	52.45	43.08	9.37	39.51	23.7	

Atterberg Limits Tests:

Table D.174: Codington Co. Old Hwy 81 Base - Liquid Limit -3												
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	31	2	3.57	11.23	9.77	1.46	6.2	23.5	**1.5**	1.40	**25**
N blows (20-30)	28	5	3.55	11.38	9.84	1.54	6.29	24.5	**1.4**		
N blows (15-25)	20	17	3.56	10.29	8.91	1.38	5.35	25.8	**1.3**		

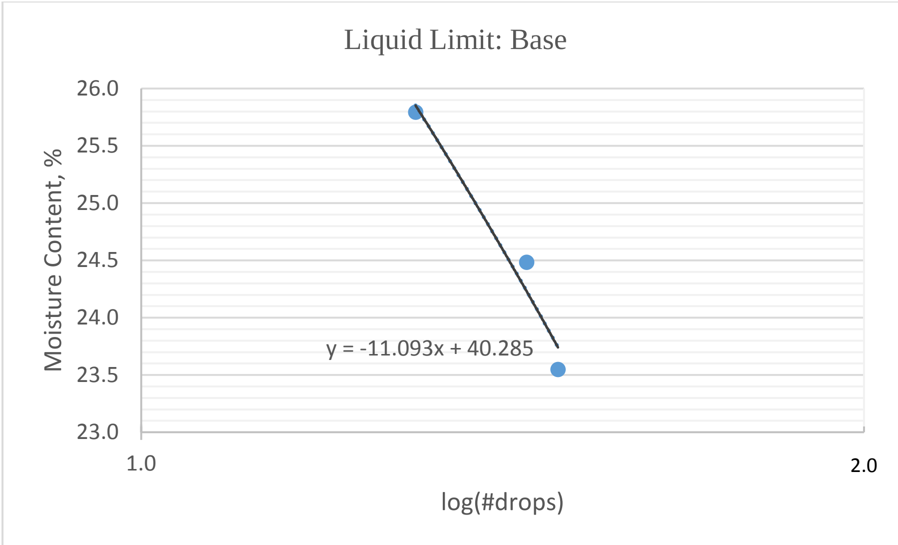


Figure D.27: Codington Co. Old Hwy 81 Liquid Limit – Base -3

Table D.175: Codington Co. Old Hwy 81 Base – Plastic Limit -3								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	4	3.62	11.32	10.31	1.01	6.69	15.1	**14.9**
Trial 2	12	3.54	9.91	9.09	0.82	5.55	14.8	

Base Plasticity Index = 10

Table D.176: Codington Co. Old Hwy 81 Subgrade - Liquid Limit -3											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	33	19	3.6	10.61	8.65	1.96	5.05	38.8	**1.5**	1.40	**40**
N blows (20-30)	28	20	3.55	10.38	8.44	1.94	4.89	39.7	**1.4**		
N blows (15-25)	19	F1	3.53	11.88	9.45	2.43	5.92	41.0	**1.3**		

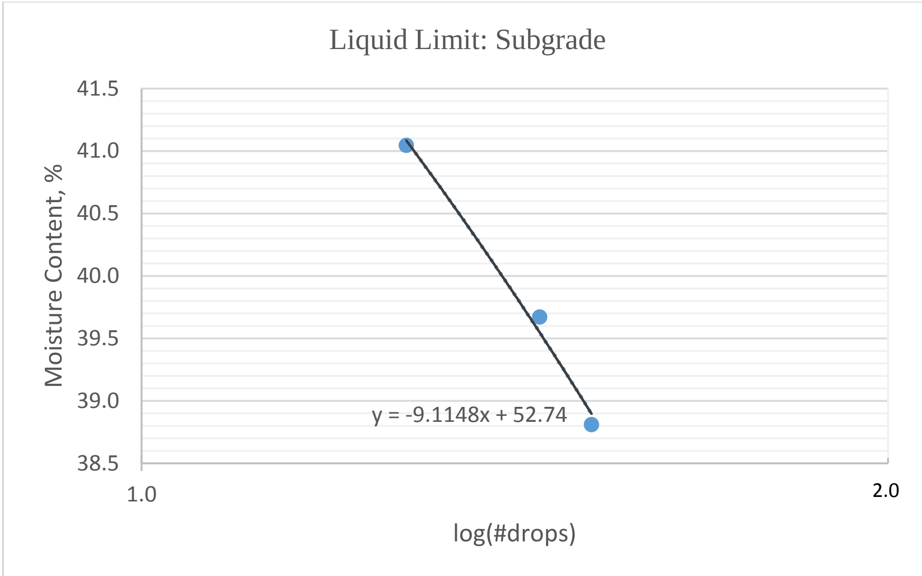


Figure D.28: Codington Co. Old Hwy 81 Liquid Limit – Subgrade -3

Table D.177: Codington Co. Old Hwy 81 Subgrade – Plastic Limit -3								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	F4	3.55	10.23	9.07	1.16	5.52	21.0	**20.8**
Trial 2	G4	3.57	10.4	9.23	1.17	5.66	20.7	

Subgrade Plasticity Index = 19

Gradation Tests:

Table D.178: Codington Co. Old Hwy 81 Base Gradation -3								
	Total Soil Mass (g) =		4718.5					
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	0	100
	1"	0	0	0	0	0	0	100
	3/4"	512.7	621.7	605.6	576.2	265.4	5.62	94
	1/2"	567.3	798.8	668.6	663.5	429	9.09	85
	3/8”	491.4	592.3	538	532.9	189	4.01	81
	No. 4	486.8	719.7	621.6	599.6	480.5	10.18	71
	No. 8	686.5	868.9	821.9	781.6	412.9	8.75	62
	No. 10	464.7	502.8	493.7	485.9	88.3	1.87	60
	No. 30	508.3	816.8	710.8	727	729.7	15.46	45
	No. 40	363.4	478.1	428.1	456.7	272.7	5.78	39
	No. 50	548.3	660.8	607.1	645.5	268.5	5.69	34
	No. 100	332.9	443.6	389.1	443	277	5.87	28
	No. 200	513.3	570.8	541.8	602.4	175.1	3.71	24
	Pan	492.2	522.4	505.1	532.6	83.5	24.0	0
	No.200-Wash					1049		

Table D.179: Codington Co. Old Hwy 81 Base 200 Wash -3		
Mass Before (g)	Mass After (g)	Mass Pass No.200
4997	3948	1049

Table D.180: Codington Co. Old Hwy 81 Subgrade Gradation -3						
	Total Soil Mass (g) =		264.7			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Subgrade Soil	No. 4	512.4	515.4	3	1.1	99
	No. 10	471.4	476.7	5.3	2.0	97
	No. 40	338.3	365.7	27.4	10.4	87
	No. 200	332.3	387.1	54.8	20.7	66
	Pan	284.4	298.1	13.7	66.0	0
	No.200-Wash			161		

Table D.181: Codington Co. Old Hwy 81 Subgrade 200 Wash -3		
Mass Before (g)	Mass After (g)	Mass Pass No.200
485.3	324.3	161

Deuel County, Highway 311 - Original Segment

Table D.182: Deuel Co. Hwy 311 -Original History & Field Observations	
Year Built	1963; original grading and gravel in 1957, 7" base and 2.5" HMA in 1963
Maintenance	Chip seals every 7 years
ADT / ADTT	35 / unkown
Surface Type	Mat
Other Measurements & Observations	

Pavement Structure:

Table D.183: Deuel Co. Hwy 311 -Original Layer Thicknesses	
Surface Type	Mat
Surface Thickness	5"
Base Thickness	5.25"
Subbase Thickness	N/A

DCP Tests:

Table D.184: Deuel Co. Hwy 311 -Original DCP: Southbound Lane – Outer Wheelpath

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
1	25	0	0	0
5	28.5	35	35	8.75
10	33.2	47	82	9.4
15	46.2	130	212	26
20	72.1	259	471	51.8
25	86.9	148	619	29.6
28	93.4	65	684	21.7

Table D.185: Deuel Co. Hwy 311 -Original DCP: Centerline

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
1	40.8	0	0	0
5	42.2	14	14	3.5
10	46.4	42	56	8.4
15	50.9	45	101	9
20	59.3	84	185	16.8
26	80.1	208	393	34.7
30	93.1	130	523	32.5

Table D.186: Deuel Co. Hwy 311 -Original DCP: Northbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	37.4	0	0	0
5	40.3	29	29	7.3
10	43.4	31	60	6.2
15	47.9	45	105	9
20	65.6	177	282	35.4
25	85	194	476	38.8
29	93.7	87	563	21.8

Moisture Content Tests:

Table D.187: Deuel Co. Hwy 311 -Original Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
3	3.55	56.94	54.08	2.86	50.53	5.7	
1	3.55	61.81	58.71	3.1	55.16	5.6	**5.5**
4ab	3.6	92.09	87.59	4.5	83.99	5.4	
SUBGRADE							
y2	3.56	60.58	51.68	8.9	48.12	18.5	
5	3.55	69.26	59.2	10.06	55.65	18.1	**18.4**
774b	3.58	84.51	71.73	12.78	68.15	18.8	

Atterberg Limits Tests:

Table D.188: Deuel Co. Hwy 311 -Original Base - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	30	53c	3.57	10.73	9.5	1.23	5.93	20.7	**1.5**		
N blows (20-30)	24	2a	3.61	12.23	10.71	1.52	7.1	21.4	**1.4**	1.40	**21**
N blows (15-25)	19	4ba	3.56	13.47	11.69	1.78	8.13	21.9	**1.3**		

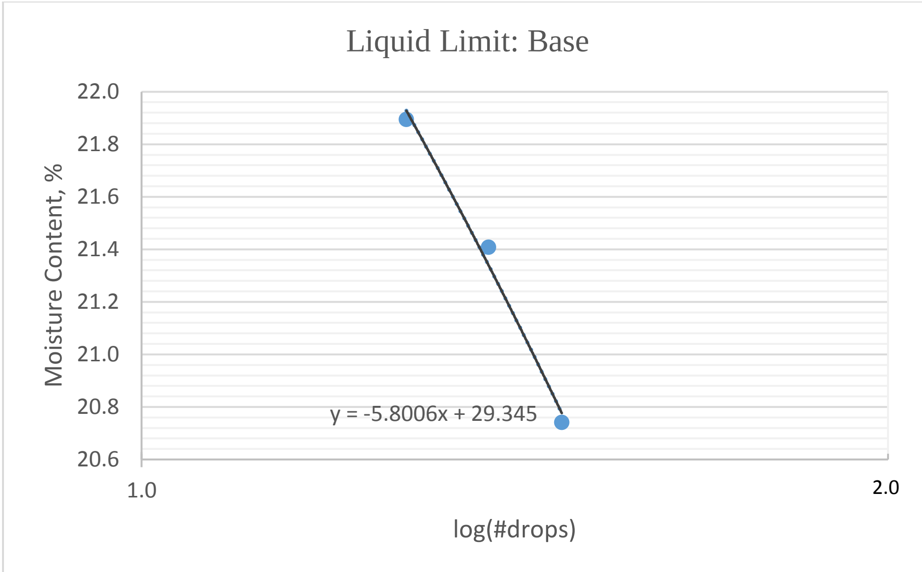


Figure D.29: Deuel Co. Hwy 311 - Original Liquid Limit – Base

Table D.189: Deuel Co. Hwy 311 -Original Base - Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	**N/A – NP**							

Base Plasticity Index = NP

Table D.190: Deuel Co. Hwy 311 -Original Subgrade - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	34	1	3.57	10.84	8.88	1.96	5.31	36.9	**1.5**	1.40	**38**
N blows (20-30)	27	2	3.62	11.28	9.22	2.06	5.6	36.8	**1.4**		
N blows (15-25)	16	2AB	3.6	10.31	8.39	1.92	4.79	40.1	**1.2**		

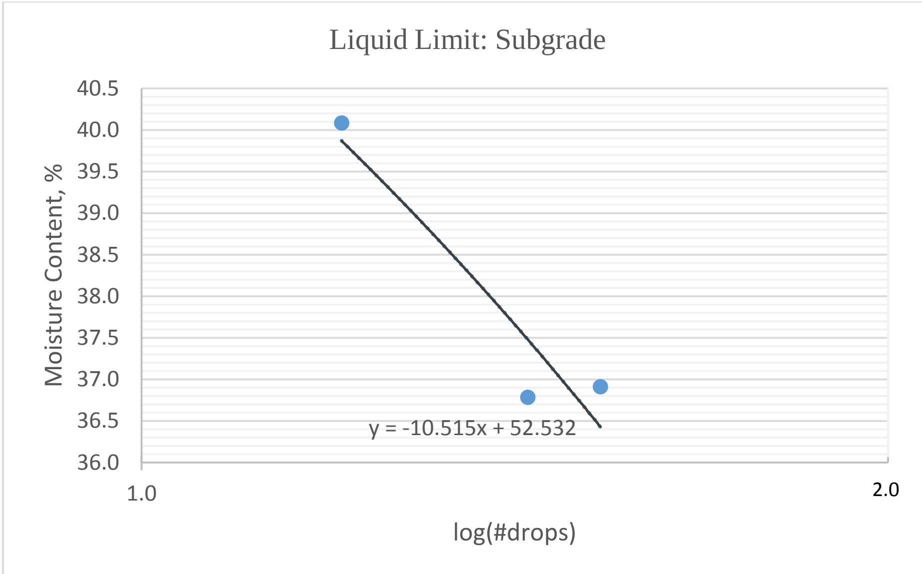


Figure D.30: Deuel Co. Hwy 311 - Original Liquid Limit – Subgrade

Table D.191: Deuel Co. Hwy 311 -Original Subgrade – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	ab2	3.55	11.53	10.36	1.17	6.81	17.2	**17.2**
Trial 2	6	3.57	10.12	9.17	0.95	5.6	17.0	
Trial 3	F1	3.53	10.9	9.81	1.09	6.28	17.4	

Subgrade Plasticity Index = 21

Gradation Tests:

Table D.192: Deuel Co. Hwy 311 -Original Base Gradation							
	Total Soil Mass (g) =		5772.7				
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	100
	1"	490.8	631.5	542	0	0	191.9
	3/4"	562.4	725.6	814.3	562.4	650.2	502.9
	1/2"	491.4	832.9	656.9	491.4	577.3	592.9
	3/8”	537	648.9	632.8	536.8	627.4	298.5
	No. 4	512.5	901	701.6	512.5	666.4	731.5
	No. 8	683.6	1016	844.1	683.4	816.9	626.6
	No. 10	471.4	541.9	506	471.4	502.3	136
	No. 20	379.1	746.2	546.6	378.8	528.7	684.7
	No. 40	338.5	686	486.7	338.6	479.6	636.7
	No. 60	324.4	580.2	428	324.4	430.4	465.4
	No. 100	519.4	668.7	579.3	519.3	585.3	275.3
	No. 200	332.4	396.8	363.9	332.4	374.7	138.2
	Pan	284.4	294.5	289.3	284.4	291.8	22.4
	No.200-Wash				468		

Table D.193: Deuel Co. Hwy 311 -Original Base 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
6056	5588	468

Table D.194: Deuel Co. Hwy 311 -Original Subgrade Gradation						
	Total Soil Mass (g) =		642.3			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Subgrade Soil	No. 4	512.5	522.7	10.2	1.6	98
	No. 10	471.4	489.3	17.9	2.8	96
	No. 40	338.6	393.3	54.7	8.5	87
	No. 200	332.5	459.5	127	19.8	67
	Pan	284.4	301.7	17.3	67.3	0
	No.200-Wash			414.8		

Table D.195: Deuel Co. Hwy 311 -Original Subgrade 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
831.1	516.3	414.8

Deuel County, Highway 311 - Rehab Segment

Table D.196: Deuel Co. Hwy 311 -Rehab History & Field Observations	
Year Built	1989; Rehabilitated original 7" base and 2.5" HMA road - RAP mixed with 3" base, top 3" injected with 1 gal AE200S emulsion per sq. yd., reshaped and recompacted, prime and sealed
Maintenance	Chip seals in 1997, 2002; 2" HMA overlay in 2003; Chip seal in 2010
ADT / ADTT	370 / 26
Surface Type	Mat
Other Measurements & Observations	Elevator in Astoria – trucks use this road

Testing Location 1:

Pavement Structure:

Table D.197: Deuel Co. Hwy 311 -Rehab Layer Thicknesses -1	
Surface Type	Mat
Surface Thickness	3.25"
Base w/ Asphalt Emulsion Thickness	7"
Base Thickness	1.25"
Subbase Thickness	N/A

DCP Tests:

Table D.198: Deuel Co. Hwy 311 -Rehab DCP: Southbound Lane – Outer Wheelpath -1

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
0	30.6	0	0	0
5	31.6	10	10	2
10	32.1	5	15	1
15	32.5	4	19	0.8
20	33	5	24	1
25	33.4	4	28	0.8
30	33.9	5	33	1
35	34.4	5	38	1
40	35.4	10	48	2
45	36.3	9	57	1.8
50	37.4	11	68	2.2
55	38.9	15	83	3
60	40.5	16	99	3.2
65	43.1	26	125	5.2
70	46.4	33	158	6.6
75	52.2	58	216	11.6
80	69.9	177	393	35.4
85	81.5	116	509	23.2
89	92.4	109	618	27.25

Table D.199: Deuel Co. Hwy 311 -Rehab DCP: Centerline -1				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	30.5	0	0	0
5	32	15	15	3.75
10	33.3	13	28	2.6
15	34.4	11	39	2.2
20	35.6	12	51	2.4
25	36.6	10	61	2
30	37.8	12	73	2.4
35	39.1	13	86	2.6
40	40.7	16	102	3.2
45	42.3	16	118	3.2
50	44	17	135	3.4
55	45.7	17	152	3.4
60	47.6	19	171	3.8
65	50.3	27	198	5.4
70	55.3	50	248	10
75	62.1	68	316	13.6
80	81.6	195	511	39
81	90.1	85	596	85

Table D.200: Deuel Co. Hwy 311 -Rehab DCP: Northbound Lane – Outer Wheelpath -1				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	23.7	0	0	0
4	24.1	4	4	1
9	24.9	8	12	1.6
14	25.5	6	18	1.2
19	26	5	23	1
24	26.5	5	28	1
29	27	5	33	1
34	27.6	6	39	1.2
39	28	4	43	0.8
44	28.6	6	49	1.2
49	29.4	8	57	1.6
54	30.1	7	64	1.4
59	31.1	10	74	2
64	32.4	13	87	2.6
69	33.9	15	102	3
74	35.8	19	121	3.8
79	38.8	30	151	6
84	45.9	71	222	14.2
89	63.2	173	395	34.6
94	90.7	275	670	55

Moisture Content Tests:

Table D.201: Deuel Co. Hwy 311 -Rehab Moisture Content -1							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
G	3.53	80.46	78.01	2.45	74.48	3.3	
4*	3.57	56.34	54.49	1.85	50.92	3.6	**3.5**
1	3.53	81.38	78.64	2.74	75.11	3.6	
SUBGRADE							
1B	3.52	68.29	60.6	7.69	57.08	13.5	
51	3.56	82.38	73.38	9	69.82	12.9	**12.7**
2	3.55	73.57	66.16	7.41	62.61	11.8	

Atterberg Limits Tests:

Table D.202: Deuel Co. Hwy 311 -Rehab Base - Liquid Limit -1											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	27	zq	3.55	15.6	13.52	2.08	9.97	20.9	**1.4**		
N blows (20-30)	24	y2	3.57	13.39	11.69	1.7	8.12	20.9	**1.4**	1.40	**21**
N blows (15-25)	17	j	3.59	12.81	11.17	1.64	7.58	21.6	**1.2**		

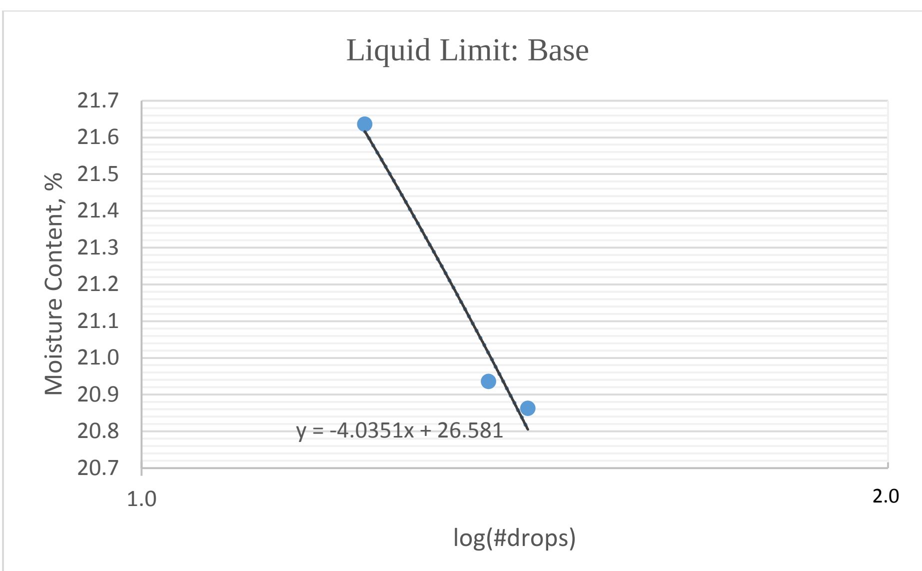


Figure D.31: Deuel Co. Hwy 311 - Rehab Liquid Limit – Base -1

Table D.203: Deuel Co. Hwy 311 -Rehab Base - Plastic Limit -1								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	**N/A – NP**							

Base Plasticity Index = NP

Table D.204: Deuel Co. Hwy 311 -Rehab Subgrade - Liquid Limit -1											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	30	3	3.58	13.77	11.44	2.33	7.86	29.6	**1.5**	1.40	**30**
N blows (20-30)	24	4a	3.57	13.49	11.2	2.29	7.63	30.0	**1.4**		
N blows (15-25)	17	k	3.59	11.83	9.88	1.95	6.29	31.0	**1.2**		

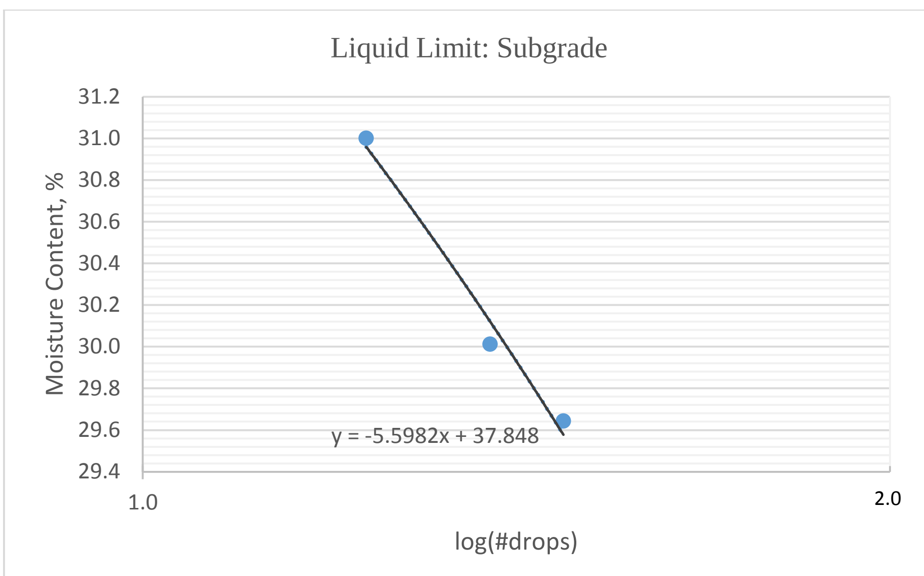


Figure D.32: Deuel Co. Hwy 311 - Rehab Liquid Limit – Subgrade -1

Table D.205: Deuel Co. Hwy 311 -Rehab Subgrade – Plastic Limit -1								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	3	3.56	9.93	9.12	0.81	5.56	14.6	**14.7**
Trial 2	2	3.55	10.09	9.25	0.84	5.7	14.7	

Subgrade Plasticity Index = 15

<u>Gradation Tests:</u>

Table D.206: Deuel Co. Hwy 311 -Rehab Base Gradation -1							
	Total Soil Mass (g) =		3880				
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	100
	1"	490.8	632.4	0	141.6	3.6	96
	3/4"	562.4	712.9	574.4	162.5	4.2	92
	1/2"	491.4	661.6	586.1	264.9	6.8	85
	3/8”	536.9	690.9	638.4	255.5	6.6	79
	No. 4	512.5	830.1	768.1	573.2	14.8	64
	No. 8	683.4	953.3	902.3	488.8	12.6	51
	No. 10	471.4	523	518.8	99	2.6	49
	No. 20	378.9	619	615.7	476.9	12.3	37
	No. 40	338.5	522.8	535.2	381	9.8	27
	No. 60	324.4	459.3	479.2	289.7	7.5	19
	No. 100	519.2	621.8	650	233.4	6.0	13
	No. 200	332.3	391.9	438.2	165.5	4.3	9
	Pan	284.4	292.3	298.6	22.1	8.9	0
	No.200-Wash				324		

Table D.207: Deuel Co. Hwy 311 -Rehab Base 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
4173	3849	324

Table D.208: Deuel Co. Hwy 311 -Rehab Subgrade Gradation -1						
	Total Soil Mass (g) =	746				
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.5	551.1	38.6	5.2	95
	No. 10	471.4	513.8	42.4	5.7	89
	No. 40	338.4	455	116.6	15.6	74
	No. 200	332.5	577.2	244.7	32.8	41
	Pan	284.4	299.7	15.3	40.8	0
	No.200-Wash			288.8		

Table D.209: Deuel Co. Hwy 311 -Rehab Subgrade 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
1034.4	745.6	288.8

Testing Location 2:

Pavement Structure:

Table D.210: Deuel Co. Hwy 311 -Rehab Layer Thicknesses -2	
Surface Type	Mat
Surface Thickness	3.25"
Base w/ Asphalt Emulsion Thickness	5”
Base Thickness	3.5”
Subbase Thickness	N/A

DCP Tests:

Table D.211: Deuel Co. Hwy 311 -Rehab DCP: Southbound Lane – Outer Wheelpath -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	33.5	0	0	0
5	34.6	11	11	3.67
10	36.4	18	29	3.6
15	38.4	20	49	4
20	40	16	65	3.2
25	42.7	27	92	5.4
28	44.5	18	110	6
35	47.4	29	139	4.1
40	51.6	42	181	8.4
45	70.4	188	369	37.6
50	80	96	465	19.2
55	83.5	35	500	7
60	89.6	61	561	12.2
62	93.6	40	601	20

Table D.212: Deuel Co. Hwy 311 -Rehab DCP: Centerline -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	33.8	0	0	0
5	35	12	12	3
10	36.3	13	25	2.6
15	37.3	10	35	2
20	38.4	11	46	2.2
25	39.6	12	58	2.4
30	40.2	6	64	1.2
35	42.2	20	84	4
40	44	18	102	3.6
45	45.6	16	118	3.2
50	47.6	20	138	4
55	50.1	25	163	5
60	54.2	41	204	8.2
65	71	168	372	33.6
70	81.8	108	480	21.6
75	87.6	58	538	11.6
80	94.7	71	609	14.2

Table D.213: Deuel Co. Hwy 311 -Rehab DCP: Northbound Lane – Outside Wheelpath -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
2	22.1	0	0	0
5	23.2	11	11	3.7
10	25.7	25	36	5
15	27.1	14	50	2.8
20	28.1	10	60	2
25	29.7	16	76	3.2
30	31.6	19	95	3.8
35	33.2	16	111	3.2
40	34.7	15	126	3
45	37.1	24	150	4.8
50	40.3	32	182	6.4
55	55.9	156	338	31.2
60	71.5	156	494	31.2
65	76.7	52	546	10.4
70	87.1	104	650	20.8
71	90.2	31	681	31

Moisture Content Tests:

Table D.214: Deuel Co. Hwy 311 -Rehab Moisture Content -2							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
1b	3.61	87.29	83.98	3.31	80.37	4.1	**4.0**
3k2	3.57	82.08	79.17	2.91	75.6	3.8	
SUBGRADE							
2	3.58	62.09	51.94	10.15	48.36	21.0	**20.9**
2b	3.6	67.29	56.34	10.95	52.74	20.8	
6	3.54	73.4	61.35	12.05	57.81	20.8	

Atterberg Limits Tests:

Table D.215: Deuel Co. Hwy 311 -Rehab Base - Liquid Limit -2											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	35	4a	3.57	9.4	8.35	1.05	4.78	22.0	**1.5**	1.40	**22**
N blows (20-30)	30	3b	3.6	11.63	10.2	1.43	6.6	21.7	**1.5**		
N blows (15-25)	16	8b	3.55	11.17	9.79	1.38	6.24	22.1	**1.2**		

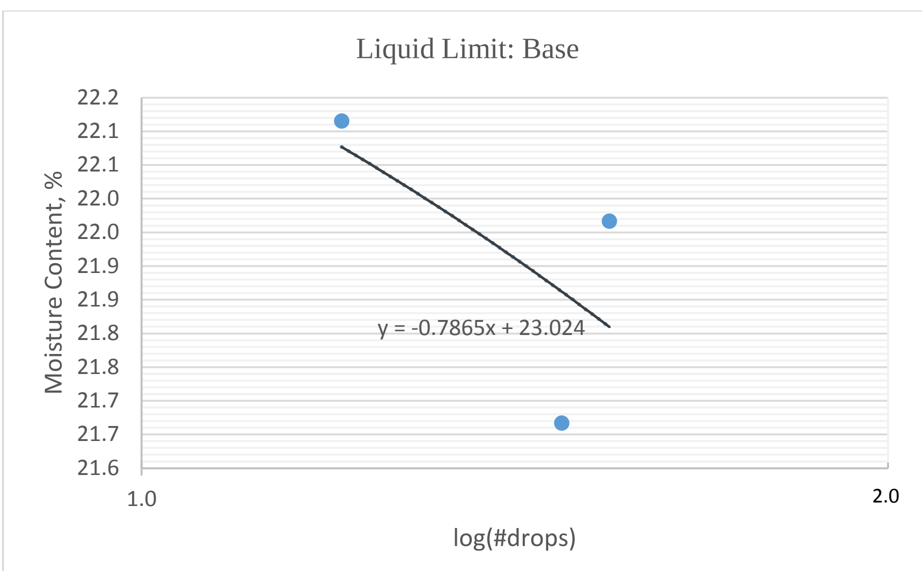


Figure D.33: Deuel Co. Hwy 311 - Rehab Liquid Limit – Base -2

Table D.216: Deuel Co. Hwy 311 -Rehab Base - Plastic Limit -2								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	**N/A – NP**							

Base Plasticity Index = NP

Table D.217: Deuel Co. Hwy 311 -Rehab Subgrade - Liquid Limit -2											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	28	6	3.49	12.39	9.84	2.55	6.35	40.2	**1.4**	1.40	**41**
N blows (20-30)	23	j	3.59	11.79	9.35	2.44	5.76	42.4	**1.4**		
N blows (15-25)	19	ted	3.6	13.15	10.28	2.87	6.68	43.0	**1.3**		

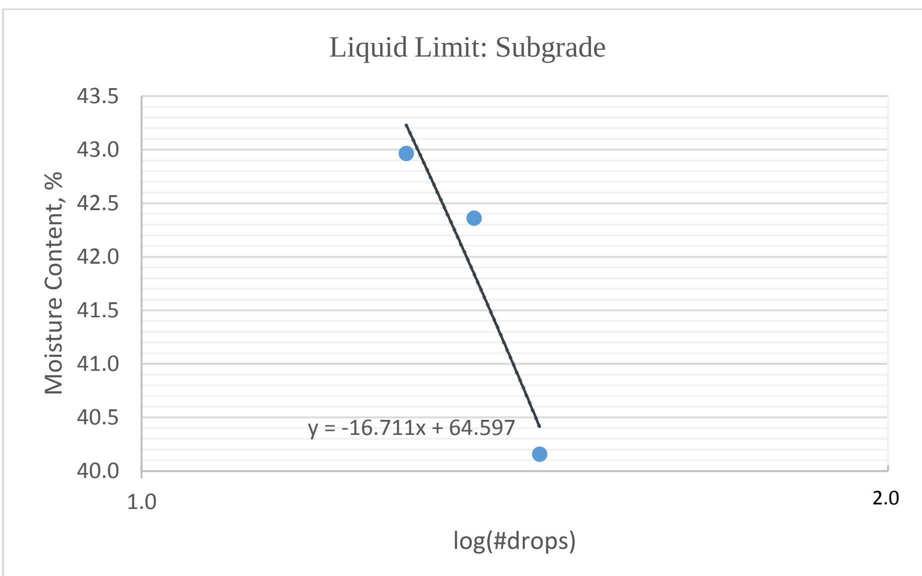


Figure D.34: Deuel Co. Hwy 311 - Rehab Liquid Limit – Subgrade -2

Table D.218: Deuel Co. Hwy 311 -Rehab Subgrade – Plastic Limit -2								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	8b	3.52	10.05	8.94	1.11	5.42	20.5	**20.1**
Trial 2	53c	3.58	9.57	8.58	0.99	5	19.8	

Subgrade Plasticity Index = 21

Gradation Tests:

Table D.219: Deuel Co. Hwy 311 -Rehab Base Gradation -2							
Base Aggregate	Total Soil Mass (g) =		3773.1				
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	0	100
	1"	0	0	0	0	0.0	100
	3/4"	562.4	631.7	594	100.9	2.7	97
	1/2"	491.4	593	577.7	187.9	5.0	92
	3/8"	536.9	626.4	619.3	171.9	4.6	88
	No. 4	512.5	796.3	771.6	542.9	14.4	73
	No. 8	683.4	937	928.2	498.4	13.2	60
	No. 10	471.4	523.7	520.1	101	2.7	58
	No. 20	378.9	646.3	649.5	538	14.3	43
	No. 40	338.5	572.4	599.8	495.1	13.1	30
	No. 60	324.5	494.6	532.4	378	10.0	20
	No. 100	519.3	627.6	668.8	257.8	6.8	13
	No. 200	332.4	380.4	431	146.6	3.9	9
	Pan	284.4	290.6	297.2	19	9.4	0
	No.200-Wash				337		

Table D.220: Deuel Co. Hwy 311 -Rehab Base 200 Wash -2		
Mass Before (g)	Mass After (g)	Mass Pass No.200
4052	3715	337

Table D.221: Deuel Co. Hwy 311 -Rehab Subgrade Gradation -2						
	Total Soil Mass (g) =		680.6			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.5	526.5	14	2.1	98
	No. 10	471.4	495.1	23.7	3.5	94
	No. 40	338.6	428.9	90.3	13.3	81
	No. 200	332.5	525.4	192.9	28.3	53
	Pan	284.4	318.2	33.8	52.9	0
	No.200-Wash			325.9		

Table D.222: Deuel Co. Hwy 311 -Rehab Subgrade 200 Wash -2		
Mass Before (g)	Mass After (g)	Mass Pass No.200
1031.7	705.8	325.9

Harding County, Highway 867

Table D.223: Harding Co. Hwy 867 History & Field Observations	
Year Built	2013; base was treated with Base One
Maintenance	None
ADT / ADTT	34 / unkown
Surface Type	Blotter
Other Measurements & Observations	Open grazing along road – edges broken from cattle; surface shoving out to edge; tire tracks in surface on edges; significant ruts; raveling of surface aggregate

Testing Location 1

Pavement Structure:

Table D.224: Harding Co. Hwy 867 Layer Thicknesses -1	
Surface Type	Blotter
Surface Thickness	1/2"
Base Thickness	6”
Subbase Thickness	N/A

DCP Tests:

Table D.225: Harding Co. Hwy 867 DCP: Northbound Lane – Outer Wheelpath -1

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
0	24	0	0	0
5	28.5	45	45	9
10	32.25	37.5	82.5	7.5
15	37.75	55	137.5	11
20	42.3	45.5	183	9.1
25	50	77	260	15.4
30	72	220	480	44
35	84.75	127.5	607.5	25.5

Table D.226: Harding Co. Hwy 867 DCP: Centerline -1				
Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
0	23.25	0	0	0
5	25	17.5	18	3.5
10	26	10	28	2
15	27	10	38	2
20	29	20	58	4
25	31	20	78	4
30	33	20	98	4
35	35	20	118	4
40	37	20	138	4
45	39.25	22.5	160	4.5
50	42.25	30	190	6
55	45.75	35	225	7
60	48.75	30	255	6
65	52	32.5	288	6.5
70	56.75	47.5	335	9.5
75	62	52.5	388	10.5
80	68.75	67.5	455	13.5
85	77	82.5	538	16.5
90	84.75	77.5	615	15.5

Table D.227: Harding Co. Hwy 867 DCP: Southbound Lane – Outer Wheelpath -1				
Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
0	22.75	0	0	0
5	27.25	45	45	9
10	31	37.5	83	7.5
15	34.5	35	118	7
20	38.25	37.5	155	7.5
25	42.6	43.5	199	8.7
30	45.5	29	228	5.8
35	47.5	20	248	4
40	49.75	22.5	270	4.5
45	52.4	26.5	297	5.3
50	56.5	41	338	8.2
55	62.25	57.5	395	11.5
60	70.25	80	475	16
65	77.5	72.5	548	14.5
70	85	75	623	15

Moisture Content Tests:

Table D.228: Harding Co. Hwy 867 Moisture Content -1							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
4B	3.58	80.45	65.98	14.47	62.4	23.2	**20.2**
4A	3.56	72.79	62.65	10.14	59.09	17.2	
SUBGRADE							
5	3.59	62.17	53.6	8.57	50.01	17.1	**17.2**
Y2	3.56	59.57	51.32	8.25	47.76	17.3	

Atterberg Limits Tests:

Table D.229: Harding Co. Hwy 867 Base - Liquid Limit -1												
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	34	y2	3.56	11.63	9.91	1.72	6.35	27.1	**1.5**	1.40	**30**
N blows (20-30)	28	3	3.59	11.9	9.99	1.91	6.4	29.8	**1.4**		
N blows (15-25)	18	4A	3.55	10.44	8.79	1.65	5.24	31.5	**1.3**		

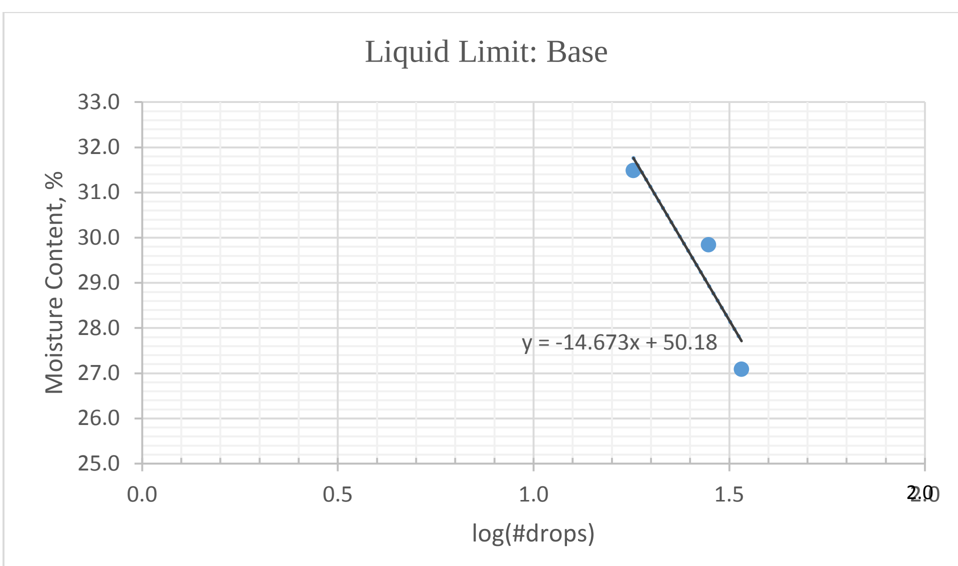


Figure D.35: Harding Co. Hwy 867 Liquid Limit – Base -1

Table D.230: Harding Co. Hwy 867 Base - Plastic Limit -1								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	LL1-3	3.58	11.65	10.65	1	7.07	14.1	**13.6**
Trial 2	3	3.59	11.28	10.39	0.89	6.8	13.1	

Base Plasticity Index = 16

Table D.231: Harding Co. Hwy 867 Subgrade - Liquid Limit -1											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	30	2A	3.6	15.38	12.31	3.07	8.71	35.2	**1.5**	1.40	**37**
N blows (20-30)	24	1B	3.53	14.4	11.39	3.01	7.86	38.3	**1.4**		
N blows (15-25)	18	1	3.56	17.76	13.84	3.92	10.28	38.1	**1.3**		

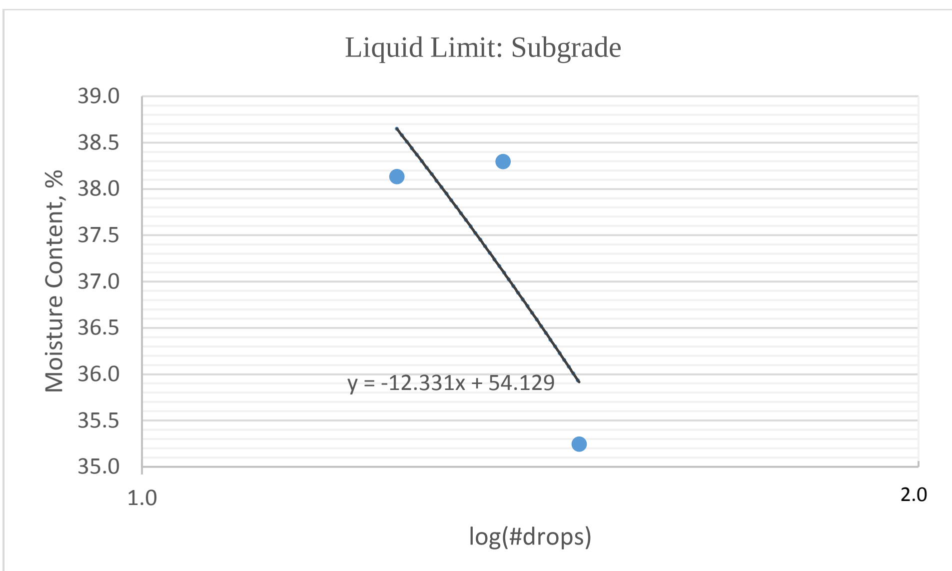


Figure D.36: Harding Co. Hwy 867 Liquid Limit – Subgrade -1

Table D.232: Harding Co. Hwy 867 Subgrade – Plastic Limit -1								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	4A	3.57	9.66	8.95	0.71	5.38	13.2	**14**
Trial 2	2AB	3.6	10.33	9.5	0.83	5.9	14.1	

Subgrade Plasticity Index = 23

Gradation Tests:

Table D.233: Harding Co. Hwy 867 Base Gradation -1						
Base Aggregate	Total Soil Mass (g) =		936.39			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	100
	1"	0	0	0	0	100
	1/2"	491.4	554.2	62.8	6.7	93
	No. 4	512.4	728.7	216.3	23.1	70
	No. 8	683.4	819.3	135.9	14.5	56
	No. 10	471.4	494.5	23.1	2.5	53
	No. 30	602.9	688.2	85.3	9.1	44
	No. 40	338.2	350	11.8	1.3	43
	No. 200	332.4	518.1	185.7	19.8	23
	Pan	284.4	293.3	8.9	23.7	0
	No.200-Wash			213.3		

Table D.234: Harding Co. Hwy 867 Base 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
1287.3	1074	213.3

Table D.235: Harding Co. Hwy 867 Subgrade Gradation -1						
	Total Soil Mass (g) =		262.63			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.6	512.9	0.3	0.1	100
	No. 10	471.5	478.8	7.3	2.8	97
	No. 40	338.4	385.4	47	17.9	79
	No. 200	332.3	387.4	55.1	21.0	58
	Pan	284.4	305.7	21.3	58.3	0
	No.200-Wash			131.82		

Table D.236: Harding Co. Hwy 867 Subgrade 200 Wash -1		
Mass Before (g)	Mass After (g)	Mass Pass No.200
645.7	513.9	131.8

Testing Location 2

Pavement Structure:

Table D.237: Harding Co. Hwy 867 Layer Thicknesses -2	
Surface Type	Blotter
Surface Thickness	3/4"
Base Thickness	8.5”
Subbase Thickness	N/A

There was no subgrade sample obtained at testing location 2.

DCP Tests:

Table D.238: Harding Co. Hwy 867 DCP: Eastbound Lane – Outer Wheelpath -2				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	24.2	0	0	0
5	29.6	54	54	10.8
10	34	44	98	8.8
15	38	40	138	8
20	42.2	42	180	8.4
25	47	48	228	9.6
30	52.3	53	281	10.6
35	57.4	51	332	10.2
40	61.2	38	370	7.6
45	65.1	39	409	7.8
50	68.3	32	441	6.4
55	71	27	468	5.4
60	72.5	15	483	3
65	75.2	27	510	5.4
70	78.9	37	547	7.4
75	81.3	24	571	4.8
80	84.7	34	605	6.8

Table D.239: Harding Co. Hwy 867 DCP: Centerline -2				
Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
0	24	0	0	0
5	27.5	35	35	7
10	29.8	23	58	4.6
15	31.5	17	75	3.4
20	33	15	90	3
25	35	20	110	4
30	37	20	130	4
35	39.5	25	155	5
40	42.25	27.5	182.5	5.5
45	45.5	32.5	215	6.5
50	49	35	250	7
55	52.8	38	288	7.6
60	56.6	38	326	7.6
65	59.8	32	358	6.4
70	62.75	29.5	387.5	5.9
75	65.3	25.5	413	5.1
80	68.7	34	447	6.8
85	71.5	28	475	5.6
90	73.9	24	499	4.8
95	76.3	24	523	4.8
100	78.5	22	545	4.4
105	81.6	31	576	6.2
110	84.6	30	606	6

Table D.240: Harding Co. Hwy 867 DCP: Westbound Lane – Outer Wheelpath -2				
Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
0	25.9	0	0	0
5	34.5	86	86	17.2
10	40.5	60	146	12
15	46.7	62	208	12.4
20	52.8	61	269	12.2
25	59	62	331	12.4
30	66.5	75	406	15
35	73.6	71	477	14.2
40	78.5	49	526	9.8
45	82.4	39	565	7.8
50	85.8	34	599	6.8

Moisture Content Tests:

Table D.241: Harding Co. Hwy 867 Moisture Content -2							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
3B	3.59	80.05	71.94	8.11	68.35	11.9	**11.7**
#6	3.52	76.35	68.85	7.5	65.33	11.5	
SUBGRADE							

Atterberg Limits Tests:

Table D.242: Harding Co. Hwy 867 Base - Liquid Limit -2											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	28	3	3.56	12.43	10.73	1.7	7.17	23.7	**1.4**	1.40	**24**
N blows (20-30)	25	2	3.57	12.76	10.98	1.78	7.41	24.0	**1.4**		
N blows (15-25)	17	1	3.53	9.55	8.36	1.19	4.83	24.6	**1.2**		

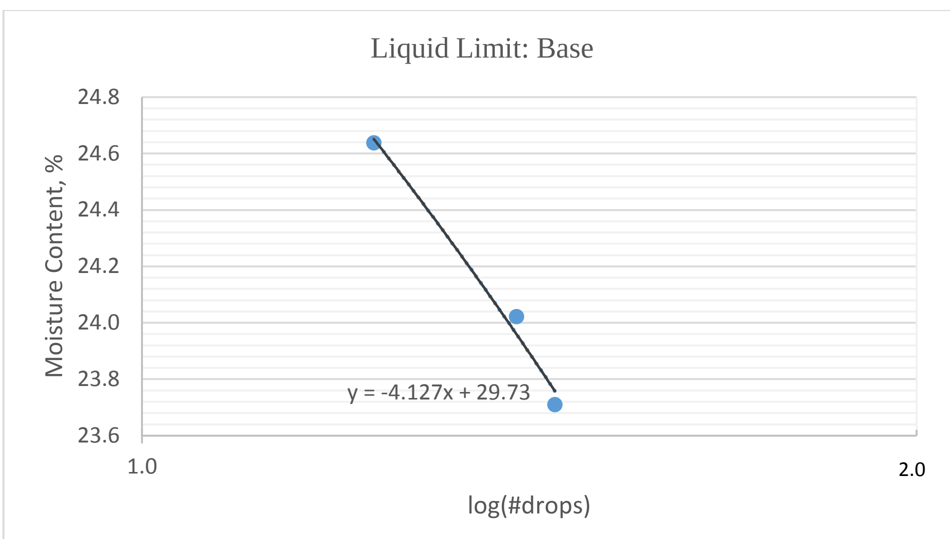


Figure D.37: Harding Co. Hwy 867 Liquid Limit – Base -2

Table D.243: Harding Co. Hwy 867 Base - Plastic Limit -2								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	12	3.62	10.67	9.65	1.02	6.03	16.9	**15.8**
Trial 2	11	3.57	10.82	9.89	0.93	6.32	14.7	

Base Plasticity Index = 8

<u>Gradation Tests:</u>

Table D.244: Harding Co. Hwy 867 Base Gradation -2							
Base Aggregate	Total Soil Mass (g) =		3207				
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0		0	0	100
	1"	490.8	490.8	490.8	0	0	100
	3/4"	562.4	562.4	568.2	5.8	0.2	100
	1/2"	491.4	548.3	519.5	85	2.7	97
	No. 4	512.5	912.4	765	652.4	20.3	77
	No. 8	683.4	937	908.5	478.6	14.9	62
	No. 10	471.4	513	510.2	80.4	2.5	60
	No. 20	378.7	521.1	514.5	278.2	8.7	51
	No. 40	338.2	402	400	125.6	3.9	47
	No. 100	519.4	767.6	763.1	491.8	15.3	32
	No. 200	332.4	511.8	493	339.9	10.6	21
	Pan	284.4	320.7	314.1	66	20.8	0
	No.200-Wash				602		

Table D.245: Harding Co. Hwy 867 Base 200 Wash -2		
Mass Before (g)	Mass After (g)	Mass Pass No.200
3490	2888	602

Lincoln County, Highway 135

Table D.246: Lincoln Co. Hwy 135 History & Field Observations	
Year Built	1961; original gravel in 1959, base and blotter in 1961,
Maintenance	Chip seal in 1970; HMA overlay in 1991
ADT / ADTT	506 / unknown
Surface Type	Mat
Other Measurements & Observations	Rut = 6mm

Pavement Structure:

Table D.247: Lincoln Co. Hwy 135 Layer Thicknesses	
Surface Type	Mat
Surface Thickness	5.6"
Base Thickness	5.4”
Subbase Thickness	N/A

DCP Tests:

Table D.248: Lincoln Co. Hwy 135 DCP: Northbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	39.3	0	0	0
5	41.6	23	23	5.8
10	43.7	21	44	4.2
15	45.6	19	63	3.8
20	49	34	97	6.8
25	59.4	104	201	20.8
30	77.6	182	383	36.4
34	93.4	158	541	39.5

Table D.249: Lincoln Co. Hwy 135 DCP: Centerline				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	37.2	0	0	0
5	39.2	20	20	5
10	41.4	22	42	4.4
15	43.7	23	65	4.6
20	46	23	88	4.6
25	48.8	28	116	5.6
30	55.3	65	181	13
35	71.9	166	347	33.2
40	91.3	194	541	38.8

Table D.250: Lincoln Co. Hwy 135 DCP: Southbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
1	35.1	0	0	0
5	37.1	20	20	5
10	39.2	21	41	4.2
15	41.1	19	60	3.8
20	42.8	17	77	3.4
25	44.6	18	95	3.6
30	46.2	16	111	3.2
35	47.8	16	127	3.2
40	50.1	23	150	4.6
45	52.7	26	176	5.2
50	59.4	67	243	13.4
55	75.6	162	405	32.4
59	92.7	171	576	42.8

Moisture Content Tests:

Table D.251: Lincoln Co. Hwy 135 Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
21	3.57	129.63	126.18	3.45	122.61	2.8	**2.8**
19	3.6	94.89	92.35	2.54	88.75	2.9	
A	3.56	105.89	103.11	2.78	99.55	2.8	
SUBGRADE							
4A	3.57	54.9	44.69	10.21	41.12	24.8	**25.4**
f1	3.53	57.63	46.63	11	43.1	25.5	
3k2	3.56	58.31	47.11	11.2	43.55	25.7	

Atterberg Limits Tests:

The base is nonplastic.

Table D.252: Lincoln Co. Hwy 135 Subgrade - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	32	1	3.59	8.94	7.09	1.85	3.5	52.9	**1.5**	1.40	**54**
N blows (20-30)	23	17	3.57	10.09	7.8	2.29	4.23	54.1	**1.4**		
N blows (15-25)	17	12	3.62	9.66	7.5	2.16	3.88	55.7	**1.2**		

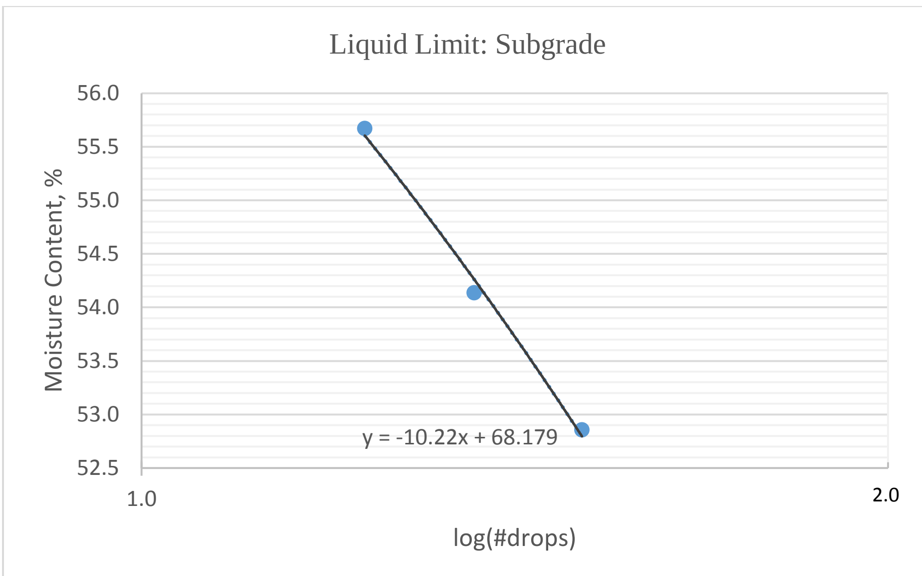


Figure D.38: Lincoln Co. Hwy 135 Liquid Limit – Subgrade

Table D.253: Lincoln Co. Hwy 135 Subgrade – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	4	3.55	10.03	8.88	1.15	5.33	21.6	**21.8**
Trial 2	f5	3.6	10.07	8.9	1.17	5.3	22.1	

Subgrade Plasticity Index = 32

Gradation Tests:

Table D.254: Lincoln Co. Hwy 135 Base Gradation							
	Total Soil Mass (g) =		3679.3				
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Base Aggregate	2"	0	0	0	0	0	100
	1"	576.7	661.7	675.8	85	2.3	98
	3/4"	512.7	657.3	590.2	222.1	6.0	92
	1/2"	567.3	717	625.1	207.5	5.6	86
	3/8”	491.3	571.3	550.5	139.2	3.8	82
	No. 4	486.8	714.4	673.6	414.4	11.3	71
	No. 8	686.4	961.4	945.5	534.1	14.5	56
	No. 10	464.5	538.5	537	146.5	4.0	52
	No. 30	508.2	1017	1038	1038.6	28.2	24
	No. 40	363.2	460.5	468.7	202.8	5.5	19
	No. 50	548.1	621.7	639.3	164.8	4.5	14
	No. 100	333.1	410	430.2	174	4.7	10
	No. 200	513.3	544.6	555.8	73.8	2.0	8
	Pan	492.1	495.8	497.9	9.5	7.5	0
	No.200-Wash				267		

Table D.255: Lincoln Co. Hwy 135 Base 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
4200	3933	267

Table D.256: Lincoln Co. Hwy 135 Subgrade Gradation						
	Total Soil Mass (g) =		712			
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
Subgrade Soil	1/2"	567.2	571.9	4.7	0.7	100
	No. 4	486.7	486.9	0.2	0.0	99
	No. 10	464.4	469.8	5.4	0.8	99
	No. 40	363.3	396.9	33.6	4.7	94
	No. 200	513.3	611.7	98.4	13.8	80
	Pan	492.1	511.7	19.6	80.0	0
	No.200-Wash			549.7		

Table D.257: Lincoln Co. Hwy 135 Subgrade 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
1569.2	1019.5	549.7

Miner County, Railroad Street (Canova)

Table D.258: Miner Co. Railroad St. History & Field Observations	
Year Built	1998; gravel base was left for approximately a month before surfaced with asphalt
Maintenance	3 chip seals
ADT / ADTT	Unkown - minimal / unkown
Surface Type	Mat
Other Measurements & Observations	Elevator located on road

Pavement Structure:

Table D.259: Miner Co. Railroad St. Layer Thicknesses	
Surface Type	Mat
Surface Thickness	6.5"
Base Thickness	15”
Subbase Thickness	N/A

DCP Tests:

Table D.260: Miner Co. Railroad St. DCP: Centerline				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
0	37.1	0	0	0
5	39.8	27	27	5.4
10	41.7	19	46	3.8
15	43.4	17	63	3.4
20	45	16	79	3.2
25	47	20	99	4
30	48.4	14	113	2.8
35	50	16	129	3.2
40	51.7	17	146	3.4
45	53.4	17	163	3.4
50	55.3	19	182	3.8
55	57.5	22	204	4.4
60	59.9	24	228	4.8
65	62.2	23	251	4.6
70	64.7	25	276	5
75	66.6	19	295	3.8
80	68.4	18	313	3.6
85	69.6	12	325	2.4
90	71.1	15	340	3
95	72.5	14	354	2.8
100	74.2	17	371	3.4
105	76.3	21	392	4.2
110	78.4	21	413	4.2
115	80.4	20	433	4
120	82.2	18	451	3.6
125	84	18	469	3.6
130	86.7	27	496	5.4
135	91.4	47	543	9.4

Moisture Content Tests:

Table D.261: Miner Co. Railroad St. Moisture Content

Cup	Cup Mass (g)	Mass Cup + Moist Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average (%)
BASE							
5	3.6	73.28	70.75	2.53	67.15	3.8	**3.8**
#3	3.56	78.38	75.55	2.83	71.99	3.9	
SUBGRADE							
#80	3.62	44.18	40.48	3.7	36.86	10.0	**10.5**
C	3.55	48.21	43.81	4.4	40.26	10.9	

Atterberg Limits Tests:

Table D.262: Miner Co. Railroad St. Base - Liquid Limit

	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	LL
N blows (25-35)	32	3k2	3.56	14.48	12.12	2.36	8.56	27.6	**1.5**	1.40	**29**
N blows (20-30)	29	1-3	3.58	12.02	10.14	1.88	6.56	28.7	**1.5**		
N blows (15-25)	21	D33	3.57	13.58	11.3	2.28	7.73	29.5	**1.3**		

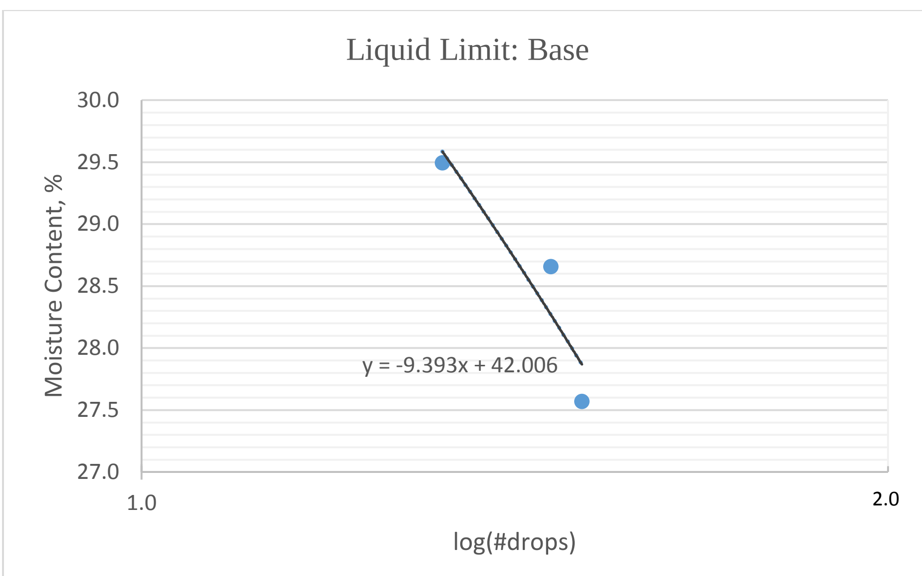


Figure D.39: Miner Co. Railroad St. Liquid Limit – Base

Table D.263: Miner Co. Railroad St. Base – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	3B	3.52	9.68	8.83	0.85	5.31	16.0	**16.5**
Trial 2	AB1	3.51	9.66	8.77	0.89	5.26	16.9	

Base Plasticity Index = 12

Table D.264: Miner Co. Railroad St. Subgrade - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	29	1B	3.53	10.21	8.25	1.96	4.72	41.5	**1.5**	1.40	**42**
N blows (20-30)	22	4AB	3.62	10.82	8.64	2.18	5.02	43.4	**1.3**		
N blows (15-25)	18	3C	3.55	12.24	9.6	2.64	6.05	43.6	**1.3**		

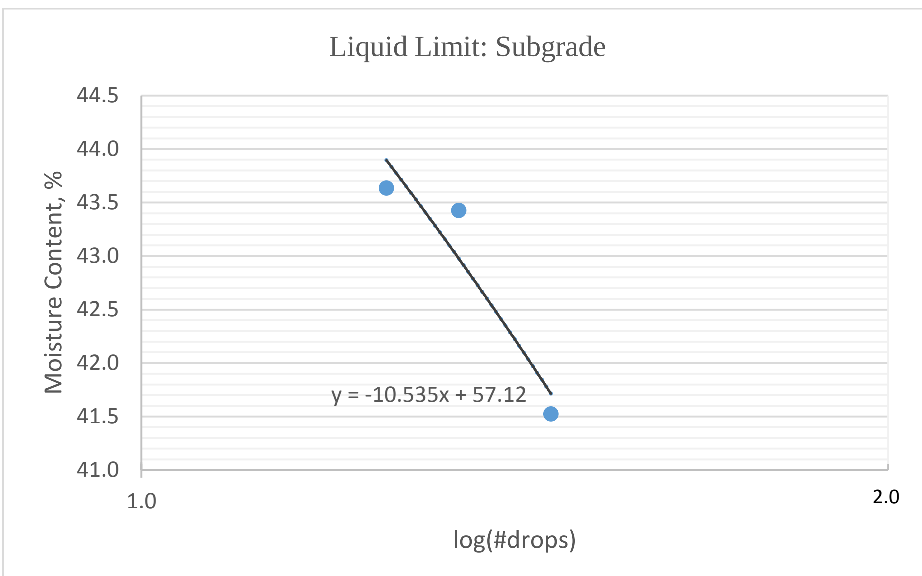


Figure D.40: Miner Co. Railroad St. Liquid Limit – Subgrade

Table D.265: Miner Co. Railroad St. Subgrade – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	T	3.6	9.6	8.8	0.8	5.2	15.4	**15.6**
Trial 2	1	3.55	10.3	9.38	0.92	5.83	15.8	

Subgrade Plasticity Index = 27

Gradation Tests:

Table D.266: Miner Co. Railroad St. Base Gradation							
Base Aggregate	Total Soil Mass (g) =		2678.2				
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	0	100
	1"	0	0	0	0	0	100
	3/4"	562.4	581.8	562.4	19.4	0.7	99
	1/2"	491.4	524	504	45.2	1.7	98
	No. 4	512.6	847.9	689.3	512	19.1	78
	No. 8	683.6	924.4	864.7	422	15.8	63
	No. 10	471.5	519.3	510.4	86.8	3.2	59
	No. 20	379	618.5	567.9	428.4	16.0	43
	No. 40	338.8	514.4	475.2	312.3	11.7	32
	No. 60	364	480.1	458.7	210.9	7.9	24
	No. 100	519.3	600.8	589.7	151.8	5.7	18
	No. 200	332.5	399.8	398.2	133.1	5.0	13
	Pan	284.4	295.2	294.5	20.9	13.3	0
	No.200-Wash				334		

Table D.267: Miner Co. Railroad St. Base 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
2978	2644	334

Table D.268: Miner Co. Railroad St. Subgrade Gradation						
	Total Soil Mass (g) =		320.4			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	512.5	528.7	16.2	5.1	95
	No. 10	471.4	505.4	34	10.6	84
	No. 40	338.3	405.4	67.1	20.9	63
	No. 200	332.6	364.4	31.8	9.9	53
	Pan	284.4	290.1	5.7	38.0	15
	No.200-Wash			116		

Table D.269: Miner Co. Railroad St. Subgrade 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
703.5	587.5	116

Pennington County, Rockerville Road (Rockerville)

Table D.270: Pennington Co. Rockerville Rd. History & Field Observations	
Year Built	1994
Maintenance	Regular chip seals
ADT / ADTT	530 / unknown
Surface Type	Mat
Other Measurements & Observations	

Pavement Structure:

Table D.271: Pennington Co. Rockerville Rd. Layer Thicknesses	
Surface Type	Mat
Surface Thickness	6.75"
Base Thickness	8”
Subbase Thickness	N/A

DCP Tests:

Table D.272: Pennington Co. Rockerville Rd. DCP: Northbound Lane – Outer Wheelpath

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
3	49.6	0	0	0
5	52.8	32	32	16.0
10	59.9	71	103	14.2
15	66	61	164	12.2
20	71.8	58	222	11.6
25	82.1	103	325	20.6
30	85.8	37	362	7.4
35	88.5	27	389	5.4
40	93.7	52	441	10.4

Table D.273: Pennington Co. Rockerville Rd. DCP: Centerline

Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
3	43	0	0	0
5	45.2	22	22	11
10	50.5	53	75	10.6
15	56.9	64	139	12.8
20	63.1	62	201	12.4
25	75	119	320	23.8
30	79.3	43	363	8.6
35	82.7	34	397	6.8
40	85.5	28	425	5.6
45	90.9	54	479	10.8
46	92.5	16	495	16

Table D.274: Pennington Co. Rockerville Rd. DCP: Southbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
3	40.8	0	0	0
5	41.8	10	10	5
10	43.8	20	30	4
15	46.8	30	60	6
21	52.2	54	114	9
26	57	48	162	9.6
31	61.3	43	205	8.6
36	68.9	76	281	15.2
41	79.4	105	386	21
46	82.4	30	416	6
51	84.8	24	440	4.8
56	87.5	27	467	5.4
61	92	45	512	9

Moisture Content Tests:

Table D.275: Pennington Co. Rockerville Rd. Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
2	3.54	68.8	63.19	5.61	59.65	9.4	**9.4**
12	3.58	123.07	113.22	9.85	109.64	9.0	
5	3.54	97.63	89.31	8.32	85.77	9.7	
SUBGRADE							
F3	3.56	70.6	63.53	7.07	59.97	11.8	**12.0**
G4	3.56	61.19	55.16	6.03	51.6	11.7	
PL-#4	3.56	60.54	54.19	6.35	50.63	12.5	

Atterberg Limits Tests:

Table D.276: Pennington Co. Rockerville Rd. Base - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	27	10	3.56	12.88	11.15	1.73	7.59	22.8	**1.4**	1.40	**23**
N blows (20-30)	23	11	3.62	15.05	12.9	2.15	9.28	23.2	**1.4**		
N blows (15-25)	15	12	3.59	12.58	10.79	1.79	7.2	24.9	**1.2**		

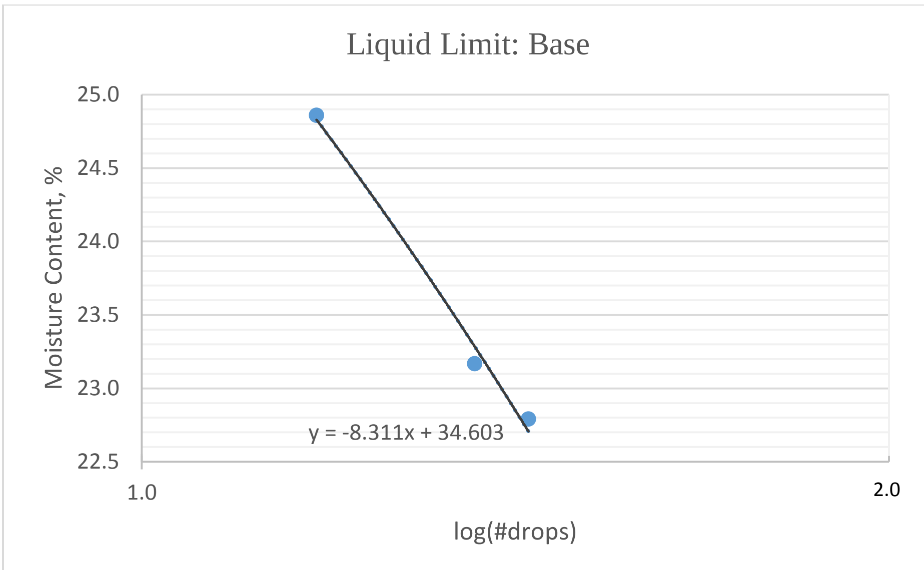


Figure D.41: Pennington Co. Rockerville Rd. Liquid Limit – Base

Table D.277: Pennington Co. Rockerville Rd. Base – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	14	3.59	10.07	9	1.07	5.41	19.8	**19.7**
Trial 2	15	3.59	9.83	8.81	1.02	5.22	19.5	

Base Plasticity Index = 3

Table D.278: Pennington Co. Rockerville Rd. Subgrade - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	29	7	3.59	11.47	9.97	1.5	6.38	23.5	**1.5**	1.40	**24**
N blows (20-30)	24	8	3.54	11.6	10.04	1.56	6.5	24.0	**1.4**		
N blows (15-25)	14	9	3.51	9.96	8.65	1.31	5.14	25.5	**1.1**		

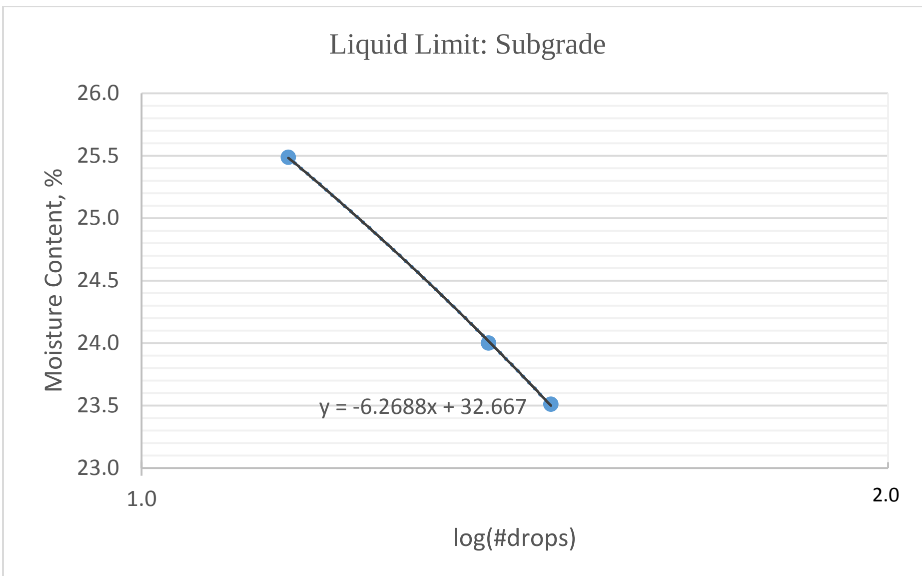


Figure D.42: Pennington Co. Rockerville Rd. Liquid Limit – Subgrade

Table D.279: Pennington Co. Rockerville Rd. Subgrade – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	16	3.6	9.94	8.86	1.08	5.26	20.5	**20.3**
Trial 2	17	3.55	10.26	9.14	1.12	5.59	20.0	

Subgrade Plasticity Index = 4

Gradation Tests:

Table D.280: Pennington Co. Rockerville Rd. Base Gradation							
Base Aggregate	Total Soil Mass (g) =		5789.2				
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	576.7	0	0	0	0	100
	1"	512.7	593.9	552.7	0	0	100
	3/4"	567.1	761.5	733.8	121.2	2.1	98
	1/2"	491.2	691	672.6	361.1	6.2	92
	3/8”	486.8	915.5	756.9	381.2	6.6	85
	No. 4	686.4	994.6	886.9	698.8	12.1	73
	No. 8	464.6	521.9	497.9	508.7	8.8	64
	No. 10	508.4	805.9	685.7	90.6	1.6	63
	No. 30	363.4	437.8	406.1	474.8	8.2	54
	No. 40	548.1	644.1	604	117.1	2.0	52
	No. 50	333	559.7	457.9	151.9	2.6	50
	No. 100	513.4	857.9	733.4	351.6	6.1	44
	No. 200	492.2	643.7	602.3	564.5	9.8	34
	Pan	576.7	0	0	261.6	34.0	0
	No.200-Wash				1707		

Table D.281: Pennington Co. Rockerville Rd. Base 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
6140	4433	1707

Table D.282: Pennington Co. Rockerville Rd. Subgrade Gradation						
	Total Soil Mass (g) =		794.6			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	486.8	673.1	186.3	23.4	100
	No. 10	464.5	516.6	52.1	6.6	93
	No. 40	363.3	419.3	56	7.0	86
	No. 200	513.4	677.7	164.3	20.7	66
	Pan	492.2	559.1	66.9	42.4	23
	No.200-Wash			270.3		

Table D.283: Pennington Co. Rockerville Rd. Subgrade 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
1077.6	807.3	270.3

Pennington County, Bombing Range Road (Scenic)

Table D.284: Pennington Co. Bombing Range Rd. History & Field Observations	
Year Built	2000
Maintenance	Crack seals in 2004, 2010, and 2014; chip seal in 2007; HMA overlay in 2010
ADT / ADTT	663 / unknown
Surface Type	Mat
Other Measurements & Observations	On the edge of the Badlands; 1.25” rut; base may be recycled asphalt

Pavement Structure:

Table D.285: Pennington Co. Bombing Range Rd. Layer Thicknesses	
Surface Type	Mat
Surface Thickness	3"
Base Thickness	8”
Subbase Thickness	N/A

DCP Tests:

Table D.286: Pennington Co. Bombing Range Rd. DCP: Northbound Lane – Outer Wheelpath				
Blows	**Reading (cm)**	**Penetration (mm)**	**Cumulative Penetration (mm)**	**Penetration per Blow**
3	29.6	0	0	0
5	30.1	5	5	2.5
10	30.9	8	13	1.6
15	31.8	9	22	1.8
20	33.1	13	35	2.6
25	34.3	12	47	2.4
30	35.8	15	62	3
35	37.3	15	77	3
40	38.6	13	90	2.6
45	40.1	15	105	3
50	41.8	17	122	3.4
55	43.4	16	138	3.2
60	45.3	19	157	3.8
65	47.2	19	176	3.8
70	49.1	19	195	3.8
75	51.4	23	218	4.6
80	52.1	7	225	1.4
85	57.6	55	280	11
90	62.8	52	332	10.4
95	70.6	78	410	15.6
100	91.2	206	616	41.2

Table D.287: Pennington Co. Bombing Range Rd. DCP: Centerline				
Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
3	29.7	0	0	0
5	30.4	7	7	3.5
10	31.5	11	18	2.2
15	32.6	11	29	2.2
20	33.2	6	35	1.2
25	34.4	12	47	2.4
30	35.2	8	55	1.6
35	36.3	11	66	2.2
40	37.5	12	78	2.4
45	38.6	11	89	2.2
46	40.2	16	105	16
55	41.7	15	120	1.67
60	43.2	15	135	3
65	44.8	16	151	3.2
70	46.4	16	167	3.2
75	48	16	183	3.2
80	49.5	15	198	3
85	50.9	14	212	2.8
90	52.6	17	229	3.4
95	54.7	21	250	4.2
100	57	23	273	4.6
105	60	30	303	6
110	64.1	41	344	8.2
115	69.6	55	399	11
120	87	174	573	34.8
122	93.6	66	639	33

Table D.288: Pennington Co. Bombing Range Rd. DCP: Southbound Lane – Outer Wheelpath				
Blows	Reading (cm)	Penetration (mm)	Cumulative Penetration (mm)	Penetration per Blow
2	35.8	0	0	0
5	37.1	13	13	4.3
10	39.6	25	38	5
15	42	24	62	4.8
20	45	30	92	6
25	48.7	37	129	7.4
30	52.5	38	167	7.6
35	57.6	51	218	10.2
40	63.4	58	276	11.6
45	74.8	114	390	22.8
50	93.8	190	580	38

Moisture Content Tests:

Table D.289: Pennington Co. Bombing Range Rd. Moisture Content							
Cup	**Cup Mass (g)**	**Mass Cup + Moist Soil (g)**	**Mass Cup + Dry Soil (g)**	**Mass Water (g)**	**Mass Soil (g)**	**Moisture Content (%)**	**Average (%)**
BASE							
17	3.58	98.98	95.01	3.97	91.43	4.3	
774B	3.6	94.84	91	3.84	87.4	4.4	**4.4**
2AB	3.59	91.59	87.75	3.84	84.16	4.6	
SUBGRADE							
7	3.55	68.76	58.63	10.13	55.08	18.4	**19.5**
5	3.55	88.74	74.21	14.53	70.66	20.6	

Atterberg Limits Tests:

Table D.290: Pennington Co. Bombing Range Rd. Base - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	33	4	3.53	10.9	9	1.9	5.47	34.7	**1.5**		
N blows (20-30)	26	5	3.57	10.61	8.72	1.89	5.15	36.7	**1.4**	1.40	**37**
N blows (15-25)	22	6	3.58	10.98	8.93	2.05	5.35	38.3	**1.3**		

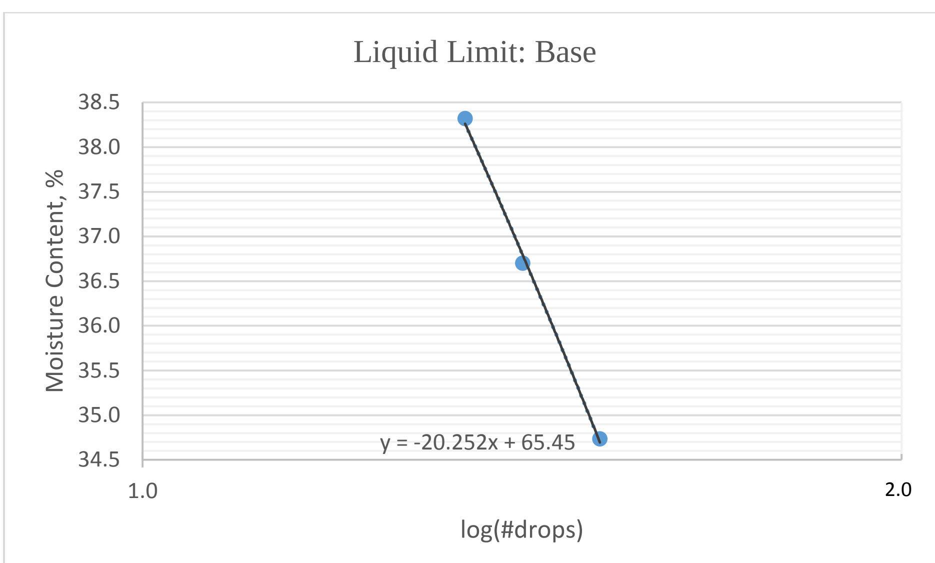


Figure D.43: Pennington Co. Bombing Range Rd. Liquid Limit – Base

Table D.291: Pennington Co. Bombing Range Rd. Base – Plastic Limit							
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	13	3.56	10.44	9.54	0.9	5.98	15.1	**15.2**
Trial 2	14	3.5	10.17	9.28	0.89	5.78	15.4	

Base Plasticity Index = 22

Table D.292: Pennington Co. Bombing Range Rd. Subgrade - Liquid Limit											
	N	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Log(#drops)	log(25)	**LL**
N blows (25-35)	32	1	3.54	9.51	7.25	2.26	3.71	60.9	**1.5**	1.40	**63**
N blows (20-30)	28	2	3.56	10.58	7.87	2.71	4.31	62.9	**1.4**		
N blows (15-25)	20	3	3.54	8.98	6.85	2.13	3.31	64.4	**1.3**		

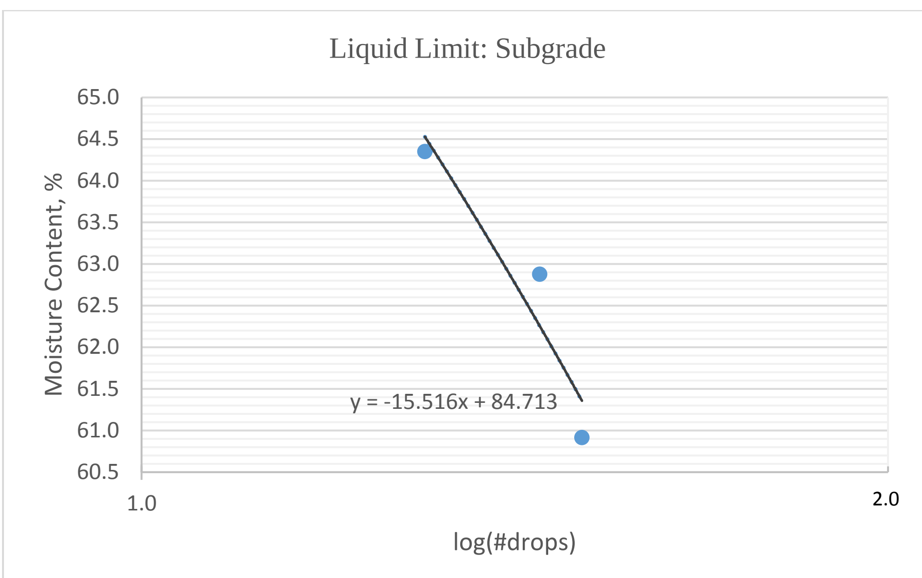


Figure D.44: Pennington Co. Bombing Range Rd. Liquid Limit – Subgrade

Table D.293: Pennington Co. Bombing Range Rd. Subgrade – Plastic Limit								
	Cup	Mass Cup (g)	Mass Cup + Wet Soil (g)	Mass Cup + Dry Soil (g)	Mass Water (g)	Mass Soil (g)	Moisture Content (%)	Average
Trial 1	2ab	3.6	9.83	8.88	0.95	5.28	18.0	**18.0**
Trial 2	774b	3.59	9.73	8.79	0.94	5.2	18.1	

Subgrade Plasticity Index = 45

Gradation Tests:

Table D.294: Pennington Co. Bombing Range Rd. Base Gradation								
Base Aggregate	Total Soil Mass (g) =		6383.2					
	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	2"	0	0	0	0	0	0	100
	1"	576.7	576.7	576.7	605.9	29.2	0.5	100
	3/4"	512.7	632.5	611.5	530.9	236.8	3.7	96
	1/2"	567.2	694.6	695.8	596.4	285.2	4.5	91
	3/8”	491.3	652.3	608.8	546.6	333.8	5.2	86
	No. 4	486.7	901.7	745.2	628.2	815	12.8	73
	No. 8	686.4	1011.4	957.5	828.7	738.4	11.6	62
	No. 10	464.5	540.3	533.7	500.3	180.8	2.8	59
	No. 30	508.4	1063.4	962.2	746.8	1247.2	19.5	39
	No. 40	363.3	511.5	494	435.1	350.7	5.5	34
	No. 50	548.2	666.9	664.7	611.6	298.6	4.7	29
	No. 100	333.3	466	456.7	409.4	332.2	5.2	24
	No. 200	513.6	596.2	611.2	579.2	245.8	3.9	20
	Pan	492.1	510.3	507.9	508.4	50.3	20.1	0
	No.200-Wash					1232		

Table D.295: Pennington Co. Bombing Range Rd. Base 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
6671	5439	1232

Table D.296: Pennington Co. Bombing Range Rd. Subgrade Gradation						
	Total Soil Mass (g) =		644.1			
Subgrade Soil	Sieve	Mass Sieve (g)	Mass Sieve + Soil (g)	Mass Soil Retained (g)	Percentage Retained (%)	Percentage Passed (%)
	No. 4	486.8	513.4	26.6	4.1	100
	No. 10	464.5	488.2	23.7	3.7	96
	No. 40	363.3	419.4	56.1	8.7	88
	No. 200	513.4	578.4	65	10.1	78
	Pan	492.2	503.4	11.2	73.6	4
	No.200-Wash			462.8		

Table D.297: Pennington Co. Bombing Range Rd. Subgrade 200 Wash		
Mass Before (g)	Mass After (g)	Mass Pass No.200
937.1	474.3	462.8

APPENDIX E: SUFACE CONDITION ASSESSMENT DATA

Table E.1: Aurora – E. 262nd Street Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.2: Aurora – W. 262nd Street Surface Condition Assessment							
	Category 3		Category 2		Category 1		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.3: Aurora – 386th Avenue Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.4: Beadle – Broadland Road Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.5: Bowman – 154th Avenue Surface Condition Assessment

	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.6: Brown – Highway 14 Surface Condition Assessment

	Category 3		Category 2		Category 1		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.7: Brown – Highway 17 Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.8: Clay – Saginaw Avenue Surface Condition Assessment

	Category 3		Category 2		Category 1		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.9: Codington – Old Highway 81 Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.10: Deuel – Highway 311 Original Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.11: Deuel – Highway 311 Rehab Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.12: Harding - Highway 867 Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	Extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.13: Lincoln – Highway 135 Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.14: Miner – Railroad Street Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.15: Pennington – Rockerville Road Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

Table E.16: Pennington – Bombing Range Road Surface Condition Assessment							
	Category 3		**Category 2**		**Category 1**		
	Excellent	**Very Good**	**Good**	**Fair**	**Poor**	**Very Poor**	**Failed**
Rating	100-86	85-71	70-56	55-41	40-26	25-11	10-0
Weathering	may be some present (low end)	partially		noticeable - detrimental effect			
Oxidized		partially	noticeable				
Raveling			noticeable				
Shoving			may be some at intersections				
Cracks	smooth and generally free of any distress; minor-hairline	low-medium severity: <1/8", may be minor spalling or faulting		> 1/2", deterioration prevalent; 100' cracking per 1000 sq. ft	pieces of AC missing; 200' cracking per 1000 sq. ft	severely cracked and disintegrated	severely cracked and disintegrated
Transverse Cracks		visible	1/4 - 1/2", may have some spalling				
Longitudinal Cracks		visible	1/4 - 1/2", may have some spalling				
Block Cracks		may appear but not greatly deteriorated		common, at least medium severity			
Alligator/Fatigue Cracks			present in wheelpaths	medium-high severity in wheelpaths	high severity is common	extensive	extensive
Rutting		may be minor in outer wheelpaths	more pronounced: may be > 1/2"	more pronounced: may be > 1/2"	> 1/2" common	can be > 3/4"	can be > 3/4"
Patching			minor-result of surface distresses or utility settlements				
Potholes					present	extensive	extensive
Edge					may be deteriorated		
Rideability					typically poor		
			Highlighted box represents condition of road				

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