DEPARTMENT OF TRANSPORTATION

Chapter 2: Investigation

MnDOT Pavement Design Manual

July 10, 2019

Chapter 2 - MnDOT Pavement Design Manual, July 11, 2019

Contents

Introduction

This chapter contains standards and recommendations for performing an investigation to assess the condition of an existing roadway to determine the project design parameters.

Section 200: Falling-Weight Deflectometer (FWD)

The falling-weight deflectometer (FWD) is a device used to evaluate pavement and pavement layer stiffness. It is a trailer-mounted (or truck-mounted) device that operates by dropping a weight on to the pavement and measuring the resulting pavement deflection at various points away from the load. Various computations may be performed on the deflection data to evaluate the pavement's integrity, its overall stiffness, and the stiffness of its constituent layers. FWD may also be used to evaluate PCC joint load transfer.

Photo 200.1 – FWD in the process of testing.

MnDOT FWD sensor spacing and drop sequences are shown in the chapter appendix (**Section 299.5: FWD testing**).

FWD testing, that is intended to be analyzed with the TONN2010 or ELMOD programs, is normally performed in the summer and early autumn months when the pavement is unaffected by frost or thaw-weakening. In the northern districts (D1, D2, D3, D4) testing is normally performed from June 1st to October 15th. In the southern districts (Metro, D6, D7, D8) testing is normally performed June 1st to November 1st.

FWD testing of PCC joint load transfer is preferred to be performed in the fall with temperatures <70 °F. Testing should not be performed when there is evidence of joint "lock-up." Joint "lock-up" is when heat expansion of the pavement slabs causes the pavement joints to narrow to a degree that there is a high amount of aggregate interlock that isn't always present.

Typically, MnDOT districts will be asked to file requests for FWD testing the winter before the testing season so that the operators can be most efficiently scheduled. However, testing may be requested at any time.

MnDOT districts may request FWD testing by sending a completed non-destructive testing request form to the Non-Destructive Testing Supervisor. The form and the Non-Destructive Testing Supervisor's contact information are available on the FWD page of the MnDOT Pavement Design website.

Several options are available to analyze FWD data depending on purpose. These options include:

- TONN2010 method (evaluation of HMA pavements)
- ELMOD back-calculation(evaluation of HMA and PCC pavement layer moduli)
- Load Transfer Efficiency (evaluation of PCC pavement joints)

Explanations of these analysis options and their use are contained in the following sections.

1. TONN2010 method (evaluation of HMA pavements)

TONN2010 is the product of research project “Allowable Axle Loads on Pavements” (Final Report #2011-02) performed by Peter Bly, Derek Tompkins, Lev Khazanovich of the University of Minnesota which was further refined in research project “Implementing TONN2010” (Final Report # 2014RIC16) by W. James Wilde of Minnesota State University, Mankato

TONN2010 is a program that, using falling-weight deflectometer data (FWD), calculates the load carrying capacity of HMA roadways and the moduli of the road’s HMA, aggregate base and subgrade layers. The TONN2010 analysis uses many the models and standards that MnPAVE-Flexible uses and is conceptually similar to MnPAVE-Flexible but backwards (i.e. MnPAVE-flexible is used to determine the pavement section necessary to carry a load and TONN2010 determines the load that a pavement section can carry).

After entering the necessary inputs and starting TONN2010, the analysis begins by determining the moduli of the constituent pavement layers. TONN2010 doesn’t perform a full back-calculation process to accomplish this but instead interpolates the moduli from previously performed back-calculation basins contained in the “backdefl.txt” file. Next TONN2010 adjusts the moduli of the HMA layer to reflect what it would be at a standard temperature of 72°F.

After the moduli are calculated and the HMA modulus is adjusted, the critical pavement responses (strains and deflections) are computed using the layered elastic program MnLAYER (Khazanovich and Wang 2010). The responses are computed for five seasons (with the pavement moduli adjusted to reflect the season). After the critical responses are determined for each season, the damage analysis is performed using the 20-year design ESALs. Damage analysis for TONN2010 involves: 1) Asphalt pavement fatigue cracking damage analysis; 2) subgrade rutting damage analysis, 3) base shear failure analysis, and 4) base deformation analysis. This analysis is very similar to how MnPAVE-Flexible analyzes pavement designs and it uses the same models.

TONN2010 reports the calculated moduli of each of the layers (with the HMA layer moduli adjusted to a standard 72°F), the subgrade R-value (which is calculated from the subgrade moduli), and TONN2010 load capacity in tons (which is based on whichever damage criteria that results in the lowest rating).

A. Installing TONN2010

The TONN2010 program is available on the MnDOT Pavement Design website on the “Software” page.

This link contains an installation program that will create a “C:\TONN2010” directory and place the “backdefl.txt” and “tonn2020.dll” files in it. The TONN2010 Excel spreadsheet may be renamed, copied, or moved to any directory.

If the install program won’t run on your computer, follow the link to “install TONN2010 components manually” on the “Software” page of the MnDOT Pavement Design website. This will open a webpage that will provide directions and links to install the program manually.

B. FWD Data

The TONN2010 spreadsheet is made to process FWD data from Dynatest FWDs with 9 or 10 geophones. It is designed to read Access (.mdb) data files made by the FWD or Excel FWD data files that are made by the MnDOT pavement design unit from Dynatest FWD data files. The program will automatically convert Metric (SI) data into English units.

C. Analyzing FWD data with TONN2010

FWD data, from either an Access file or a MnDOT FWD Excel data file can be loaded into TONN2010 and analyzed. If FWD data is already loaded into TONN2010, it can be re-analyzed without having to reload the data.

(1) If not already done, install TON2010; follow the steps in the installation section.

(2) If the data has not already been loaded, then load the FWD data

- Click on the “Get FWD Data” and the “Get FWD Data Form” will appear.
- Click on either “Load Access (mdb.) Data” or “Load ‘TONN’ Excel (.xls*) Data File.”
- Navigate to the FWD data file with the browse form that will appear. Click open.
- A drop-down box will appear on the “‘get FWD Data Form”. With this drop-down, select which of the FWD drops to use (FWDs collect data from several drops at each test location at different weights). The standard is to use the last drop that rounds to 9,000lbs (e.g., if drop 1 is 9,234, drop 2 is 9,456 and drop 3 is 12,056, select drop 2).

(3) Fill-in inputs

- Previous day's max and min temp.
  The MnDOT Non-destructive Testing Supervisor normally fills this in before sending out the FWD Excel data file and so it should load with the FWD data. If it's not present, use a weather website (such as Weather Underground) to look up the weather history for the day before the FWD testing occurred (the test date is given at the top of TONN2010). Input the previous day's minimum and maximum temperature so that the average temperature may be calculated.

- HMA Thickness

  Fill in cell A11 and the click on 'fill' box next to it to fill in the HMA thickness column (column E). The program actually reads the HMA thickness in column E where the HMA thickness for individual test locations may be edited.

  NOTE: TONN2010 can only analyze HMA thicknesses from 2 to 12 inches. HMA Thickness of less than 2 inches will not be read and the analysis will stop. HMA Thicknesses greater than 12 inches will be analyzes as 12 inches.

- Base Thickness

  This is the material below what is considered HMA and above what is considered as subgrade. In general it should be the thickness of everything between the HMA and above the subgrade (see discussion section).

  Fill in cell A14 and the click on 'fill' box next to it to fill in the Base Thickness column (column H). The program actually reads the Base Thickness in column H where the thickness for individual test locations may be edited.

  NOTE: TONN2010 can only analyze base thicknesses from 3 to 48 inches. Base thicknesses less than 3 inches will not be read and the program will stop analyses. Base thicknesses greater than 48 inches will be analyzed as 48 inches.

- Design ESALs

  The standard is to use the roads predicted 20-year accumulated flexible ESALs.

  Fill in cell A17 and the click on ‘fill’ box next to it to fill in the ESAL column (column I). The Design ESALs in Column I may be edited for individual test locations.

- County

  Select the county where the FWD testing occurred from the drop-down box.

(4) Run TONN2010

Click on the “Run TONN2010” box. Calculation will stop and a message will appear if any required inputs are absent.

(5) Wait

Calculating takes 1-2 seconds per test location so it may take a while to calculate all the data. A message saying “Calculating TONN2010, Please wait” will appear during calculation which will disappear when calculation is completed.

(6) View results

Results are shown for each test location for the TONN2010 Capacity in Tons, the HMA moduli adjusted to 72°F, the base and subgrade moduli, and the subgrade moduli shown as R-value.

The TONN2010 capacities 85th percentile (85% of readings are greater) value is normally reported as the final value. For all other values, the average is used.

NOTE: An outlier criterion is used to highlight data that may be considered as an outlier. Since the TONN2010 rating is reported as the 85th percentile, this is useful to highlight unusually weak spots. Where the average is reported, the highlighted values should be deleted to prevent skewing the average.

D. After the TONN2010 analysis has been completed.

(1) **Make KML file.** TONN2010 can produce a KML file of the results that may be viewed using Google Earth.

- Click on the “Make KML File” box.

- A box will appear asking “value to plot” which is the value that will appear with the test location on the finished map. Choose either the TONN Rating or the R-value then click “select and continue.”

- With the browse form that will appear, navigate to a location to save the KML file, enter a file name, and click save. A file with the selected filename and the .kml extension will be written to the selected location.

- A message announcing that the KML file was “Successfully Converted” will appear. Click ‘OK” to close the message.

- The KML file can be introduced to Google Earth by either

  - Open Google Earth and then find the KML file using the file menu.
  - Open Google Earth and then drag the KML file into the Google Earth window.
  - Right-click on the KML file and then choose “open with” and the select Google Earth.

  NOTE: Creating the KML file requires accurate GPS locations recorded during FWD testing. Any data points with missing coordinates cannot be mapped.

(2*)* **Overlay Design.** TONN2010 has the capability to estimate the thickness of a HMA overlay necessary for the roadway to be rated as a 10-ton road by TONN2010.

- Click on the “Begin Overlay Design” button.

- The “Overlay Design” sheet will appear.

- The user may choose the desired ton-rating and percentile of the roadway after application of the overlay but MnDOT standard is a 10-tons at 85th percentile (i.e. 85% of the individual test points are equal to or greater than 10 tons).

- The roadway may be split into up-to five segments. A separate overlay design will be performed for each segment. Use the two charts to decide where to divide the roadway based on existing pavement strength, pavement layer thicknesses and ESALs.

- Click on the “Run Overlay Module”.

- The estimated overlay thickness will be calculated and displayed. A calculated overlay thickness of more than 5 inches will display only as “>5”.

(3*)* **Estimate Number of ESALs for 10-ton Rating.** If the TONN2010 analysis has been completed and the ESALs are the same for all locations, then TONN2010 can estimate the number of ESALs that could be used in the analysis to result in a 10-ton rating. This is referred to as an estimate because only two of the distresses that are used to calculate the ton-rating are sensitive to traffic, if the ton-rating of a location or locations is the result of a non-traffic sensitive distress then the calculation cannot be exact. Please, check the estimate by performing the TONN2010 analysis using the estimated ESALs.

- Click the "Estimate Number of ESALs for 10 ton Rating" button.
- A reminder about the need to have the TONN2010 analysis completed and ESALs the same for all points will appear. Click 'OK' to continue.
- Wait for TONN2010 to calculate.
- The calculated estimate will appear in as a message box. Click 'OK' to close the box.
- Confirm the estimate by entering it as the number of design ESALs and clicking the "RUN TONN2010" Button.

E. TONN2010 Discussion

This program can only analyze a 3-layer pavement with HMA, base, and subgrade. Judgment must be used to determine which layer an existing material should be attributed to. A general rule would be to include bound materials with HMA, any aggregate base (e.g. CL 5, CL 5Q, or CL 6) ***and*** sub-base (e.g. CL 3, CL 4, Select Granular Material, and Granular Material) with base, and the material that the R-value should represent with subgrade.

The procedure that determines the layer moduli is dependent on having accurate thickness data. It is especially sensitive to the HMA thickness and it should be within an inch or two of the actual thickness. It is much less sensitive to inaccuracies in the base thickness but it should still be accurate to within a few inches.

The program can only analyze 20 different segments. A new pavement segment occurs anytime there is a change in HMA thickness, base thickness, or design ESALs. If there are more than 20 an error will be reported and the analysis will stop.

This program performs a process to calculate layer moduli that is similar to back-calculation and has some of its properties and limitations.

- Subgrade moduli are the most stable values of the calculated moduli and least sensitive to inputs.
- HMA moduli are the second most stable values. If the program has accurate thickness values and the FWD was able to collect accurate data then this value should be also be accurate. HMA moduli are sensitive to having accurate HMA thickness and may be affected by pavement that is difficult for the FWD to collect good data from (e.g. cracked, material problems).
- Base is the least stable of the layers and the hardest to determine the moduli. This layer is sandwiched between two other layers and tends to “take-up the slack” of the calculation of their moduli. This layer’s moduli often have a very high standard deviation and the calculated moduli may be affected by a portion of the moduli of an adjacent layer being attributed to it. Values tend to be more stable with newer HMA and accurate layer thicknesses.

2. ELMOD back-calculation (analysis of HMA and PCC pavement)

   ELMOD is a commercially available FWD back-calculation program designed to calculate the elastic moduli of pavement layers from FWD pavement deflection data. The MnDOT Pavement Design Unit (Office of Materials and Road Research) has licensed copies of this program and can perform the analysis if requested. It may be used to analyze deflection data collected from HMA or PCC pavements. But it isn't recommended to design pavements using soil moduli derived from testing PCC pavements because the back-calculated moduli are often much greater than the actual moduli.

   MnDOT Pavement Design Unit personnel will perform FWD testing required for ELMOD back-calculation. Tests are usually taken every 1/10 of a mile in the outside wheel path (the same as used for the TONN method). Additionally, any data that has been previously collected for the TONN method can usually be analyzed with ELMOD.

   ELMOD requires accurate information on the number and thickness of the layers in the pavement section which must be provided by the analysis requester. The ELMOD analysis will be performed by MnDOT Pavement Design Unit personnel and the results will be e-mailed to the requester as an Excel spreadsheet.

3. Load Transfer Efficiency (evaluation of PCC pavement joints)

   Load transfer efficiency (LTE) is the measure of how well a load is distributed across a PCC joint or crack. It is provided by a combination of the pavement's base, aggregate interlock, and any dowel bars. It is an important property of PCC pavements because poor load transfer creates high slab stresses, which contributes to faulting, pumping, and corner breaks.

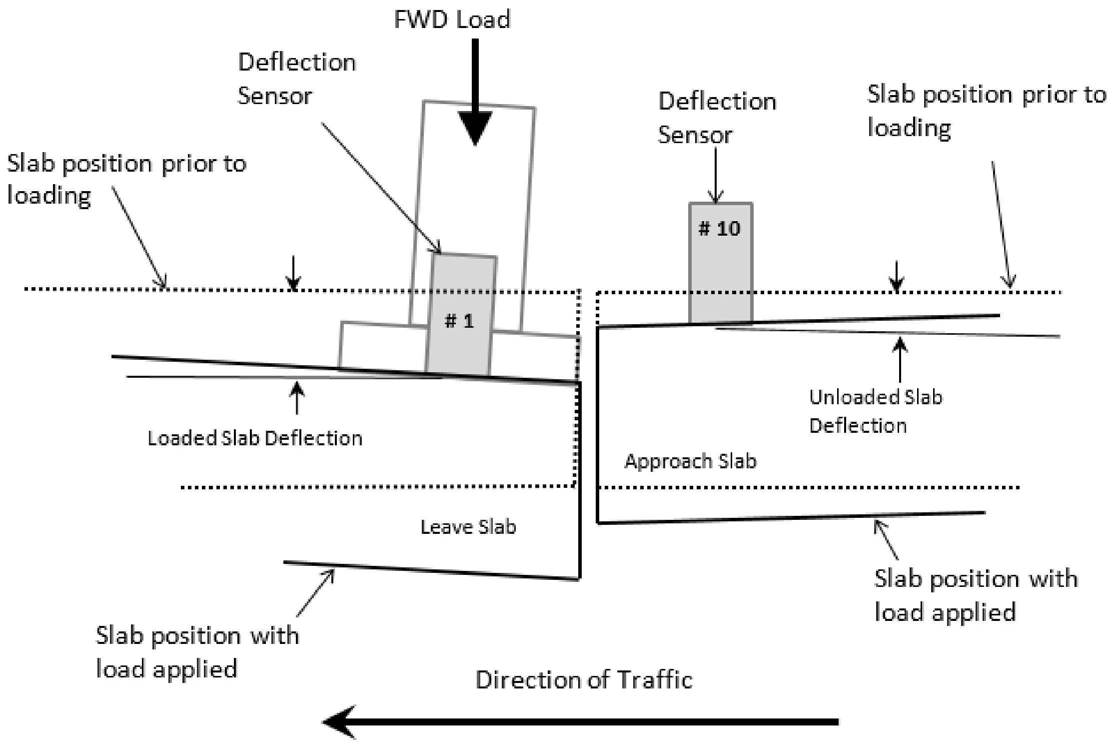
   LTE is measured by dropping the FWD weight on one side of a joint (or crack), then recording the subsequent pavement deflections at the location of the weight's impact and on the un-loaded side of the joint (see **Figure 200.3**). The ratio of the unloaded slab's deflection to the loaded slab's deflection multiplied by 100 is reported as the load transfer efficiency (LTE). **Table 200.3**, based on AASHTO guidance, is used to categorize LTE results. Care should be taken when applying this table to pavements with relatively small deflections; it may classify pavements as having "Poor" LTE, but the joints may have low differential deflections and may perform well. The data collected for LTE analysis may also be analyzed to detect potential voids under the PCC.

Table 200.3 – LTE Categories

LTE	Category
70% or Greater	Good
50% to 70%	Marginal
Less than 50%	Poor

MnDOT Pavement Design Unit (Office of Materials and Road Research) personnel will perform the FWD testing required to calculate LTE. The standard testing frequency is to test a minimum of 10 joints per mile and a minimum of 30 joints per project (unless a different frequency or the testing of cracks is requested). The standard test location is to load the leave-slab at the outside wheel path. MnDOT Pavement Design Unit personnel will perform the LTE analysis, and the pavement deflections and the calculated LTE will be e-mailed to the requester as an Excel spreadsheet.

Figure 200.3 - Diagram of LTE testing.



Section 210: Friction Testing

The MnDOT Office of Materials and Road Research operates one Dynatest pavement friction tester. This device indicates pavement friction by measuring the force that prevents a non-turning (i.e. locked-up) tire from sliding on the pavement's surface. This is an important parameter because inadequate friction may lead to more occurrences of skid-related accidents. It may also be an important parameter when evaluating materials and construction practices.

The Pavement Friction Tester is a two-wheeled trailer towed by a pick-up truck. It conforms to **ASTM E-274 "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire"** specifications. MnDOT's pavement friction tester has one smooth tire and one ribbed tire and can perform testing with either one. Ribbed tires are considered to be less sensitive to pavement macrotexture and water film depth than smooth tires and to be more sensitive to pavement microtexture.

During testing, the device is driven at a constant speed of 40 mph. When a test is taken, pumps are activated that spray water in front of the test wheel. The brakes on the test wheel are then activated and the horizontal and vertical forces acting on the wheel are measured. This data is used to calculate the Friction Number (FN).

Friction testing may be performed whenever pavement temperatures are warm enough that the water sprayed during testing won't freeze and become a hazard. MnDOT districts may request friction testing by sending a completed non-destructive testing request form to the MnDOT Non-Destructive Testing Supervisor. The form and the Non-Destructive Testing Supervisor's contact information are available on the "Friction" page of the MnDOT Pavement Design website.

The test results will be e-mailed to the requester. Contact the MnDOT Pavement Design Unit (Office of Materials and Road Research) to discuss the results.

Section 220: Borings

Borings are taken for foundation surveys, to evaluate aggregate and borrow sources, and to survey the soils of the road alignment. Borings required for a foundation survey are usually performed by the MnDOT Foundation Unit (Office of Materials and Road Research) or consultant. Other borings are taken by district personnel or district-contracted consultants. District personnel typically limit their boring depths to less than 15 feet to avoid any special licensing that may be required to fill deeper borings.

1. Types of borings

   A. **Undisturbed samples**, defined as intact specimens of material that are minimally altered from their in situ condition, are required to test for those properties that are controlled by the overall material mass, such as strength and permeability. Undisturbed soil samples and rock cores required for foundation design are usually obtained by the MnDOT Foundations Unit (Office of Materials and Road Research).

   B. **Disturbed samples (Auger Borings)**, defined as samples that are broken up and/or remolded, that can be used for determining properties that are controlled by the individual components of the material such as the grain-size distribution and Atterberg limits. District or district-contracted consultants typically collect disturbed samples.

      Disturbed samples are obtained using augers having a minimum diameter of 3.75 inches and in accordance with **AASHTO T 203 – "Standard Specification for Soil Investigation and Sampling by Auger Borings."** The augers are rotated and advanced into the soil the desired distance. They are then withdrawn without rotating (i.e., pulled dead) from the hole and the soil is removed for examination and testing or samples may also simply be obtained from the auger cuttings.

2. Types of boring surveys

   A. Foundation survey

      Data for the design of bridges, large culverts (i.e., culverts having a cross-section of more than 80 square feet), retaining walls, special roadway embankment designs on soft, compressible soils, and buildings are obtained from a Foundation Survey. Notify the MnDOT Foundations Unit (Office of Materials and Road Research) of the need to perform a Foundation Survey. The MnDOT Foundations Unit is responsible for scheduling these surveys and will provide all drilling and sampling, laboratory testing, and foundation recommendations. In addition, the MnDOT Foundations Unit will provide piezometer and/or slope inclinometer installations where detailed stability analyses need to be performed. The District Materials/Soils Engineer may be involved in reading the piezometers and slope inclinometers and performing other data gathering to assist the MnDOT Foundations Unit.

      Small culverts, defined as those with a cross-section of less than 80 square feet in size, may be investigated by the district. A minimum of three borings should be planned on a section along the culvert alignment in these situations or as specified by the District Materials/Soils Engineer. The borings should be extended to provide field identification and groundwater information to at least 5 feet below the proposed culvert bottom.

B. Borrow source survey

Potential borrow sources should be explored by sufficient borings to determine the quantity and quality of borrow materials and the level of the ground water table. Borings should be extended 3 feet past the depth of planned excavation and spaced on a 100-foot grid pattern, or closer in the case of non-uniform deposits. Typically, disturbed samples are collected but the MnDOT Foundations Unit (Office of Materials and Road Research) may be contacted to obtain undisturbed samples if accurate shrink/swell factors are desired.

Field-identify the materials in each boring (see **Section 220.5 – field-identification**) on at least one sample from each major material in the survey area, perform a soils classification (see **Section 220.3.A: soils classification**), and if the material is granular, also perform a mechanical analysis (see **Section 220.3.B: mechanical analysis**).

C. Aggregate source survey

Proposed aggregate sources should be explored with a number of borings sufficient to determine the quantity and quality of aggregate available. Use an 8 to 12-inch diameter auger in order to have a sufficient diameter to retrieve a representative sample of the potential aggregate source material. These borings are usually spaced on a 100-foot grid pattern; although the grid should have closer spacing in erratic deposits and may be less frequent in uniform areas.

A representative sample of the granular material should be taken from each hole for each substantial change in the appearance of the material, along with at least one sample for each 10 feet of penetration. Field-identify all materials (see **Section 220.5: field-identification**) and perform a mechanical analysis on each sample (see **Section 220.3.B: mechanical analysis**). Samples from auger-bored holes deeper than 40 feet are not considered reliable because of the disturbance and displacement of materials as they rise on the auger.

D. Soils survey

A soils survey is the sampling and testing of subsurface soils to identify and characterize the existing soil, rock, groundwater, aggregate base/subbase, and pavement conditions. The soil sampling typically consists of disturbed borings (augers) and occasionally test-pits or hand augers.

The primary purpose of a soil survey is to discover subsurface materials and conditions that may affect construction or may negatively affect roadway performance and should be addressed in design. This includes discovering the limits of poor foundation soils (soils that contain peat, marl, >5% organic material by weight) or areas of wet conditions (any area where the soils are described as “wet” in the boring logs). These materials often require removal and replacement with a suitable material or constructing a drainage system. A soils survey will also help to identify any frost susceptible soils (silt) that may be addressed with the design thickness of the aggregate base, subbase, and engineered soil. Additionally, a soil survey will help establish the suitability of material for re-use as embankment and establish the stability of any slopes.

Borings should be deep enough to develop the engineering data required for analysis and should penetrate major soil horizons, frost depth, and frost-susceptible materials. Borings should be taken to a depth of at least 5 feet below the proposed bottom of subcut and at least 5 feet below existing ground in fill sections. At least one boring in each fill section should extend to a depth equal to the height of the proposed fill.

The extent of the soils survey and testing performed on the recovered material is dependent on the scope of the project. The following section describes the minimum boring intervals on a road alignment and the tests to be performed. However, additional borings may be required for slopes or to establish the limits of swamps or other areas of wet or poor foundation soils. Wet areas or poor foundation soils may be indicated by localized poor pavement performance, nearby standing water or vegetation associated with wet conditions (e.g. tamarack, cattails or rushes).

(1) New construction/reconstruction

Take auger borings approximately every 100 feet along the proposed alignment (the District Materials/Soils Engineer may extend the interval to 200 feet if the subsurface materials are uniform). On divided highways the borings on the two roadways may be staggered.

Field-identify the materials in each boring (see **Section 220.5: field-identification**). Perform a soils classification (see **Section 220.3.A: soil classification**) on at least one sample from each major material encountered in the survey area and perform a mechanical analysis (see **Section 220.3.B: mechanical analysis**) on at least one sample of each major granular material per mile.

The boring interval must be adjusted if the following conditions are encountered:

Bedrock. Boring intervals must be decreased and additional borings taken on a cross-section when there is evidence of bedrock. The number of borings required depends on the anticipated rock variability and length of cut. When there is evidence of bedrock above the proposed bottom of subcut, rock coring will be required. Requests for geological work, geophysical work, and/or rock coring should be made through the MnDOT Geology Unit (Office of Materials and Road Research), with copy to the MnDOT Foundations Unit (Office of Materials & Road Research). District-contracted consultants are required to perform this work as per contract.

Swamp areas. These are areas of poor foundation soils and/or wet conditions that are often associated with a swamp or swampy areas. Boring intervals must be decreased and additional borings taken on a cross-section to determine the extent and composition of swamp areas. Poor foundation soils contain peat, marl, >5% organic material by weight, or other soils as directed by the District Materials/Soils Engineer. Wet conditions are any area where the soils are described as “wet” in the boring logs. A minimum of three borings are required for each cross-section when relatively uniform swamp bottoms are encountered. These borings are taken at the centerline and on each side of the roadway, typically, halfway between the shoulder P.I. and the toe of the slope. At least one boring should extend 15 feet below the apparent swamp bottom to provide adequate evidence against a false bottom. In swamp areas with variable non-uniform bottoms the boring strategy should be modified to include additional borings. In cases of widening existing embankments constructed on previously consolidated soft ground, attention to borings in proposed toe areas is advised to ensure that the widened embankment is not unstable. Resistance soundings, which consist of advancing the augers without sampling and recording the level where resistance is felt (assumed bottom of swamp), may be used to supplement boring information. District-contracted consultants are required to perform this work as per contract.

Scheduling of work in swampy areas is important. It may be easier to access the site during winter months when the swampy area is frozen. If it is determined that soil boring of the swamp will result in injury to persons or damage to adjacent facilities, or if a floated embankment is desired, the MnDOT Foundations Unit (Office of Materials and Road Research) should be contacted to obtain undisturbed samples, install piezometers, and/or perform stability studies.

Deep or side-hill cuts. Care should be taken in determining the soil and water conditions present whenever deep or side-hill cuts of ≥ 30 feet deep are proposed. In such areas, boring intervals must be reduced, and borings must be taken along the centerline as well as the edge of the roadway. Where general instability could create a problem, borings should be placed on sections perpendicular to the centerline on the uphill side of the cut. Where buildings or structures are located adjacent to the crest of slope, the MnDOT Foundations Unit (Office of Materials and Road Research) should be notified so that undisturbed sampling, piezometer installation, and/or stability studies can be performed.

(2) Full-depth reclamation (FDR), stabilized full-depth reclamation (SFDR), rubblization, and crack and seat

Take an auger boring approximately every ½ mile. Field-identify (see **Section 220.5: field identification**) the materials in each boring. Perform a soils classification (see **Section 220.3.A: soils identification**) on at least one sample from each major material in the survey area and perform a mechanical analysis (see **Section 220.3.B: mechanical analysis**) on at least one sample of each major granular material per mile. A larger auger diameter or removal of pavement sections may be necessary to recover samples of granular material that contain over-size material.

Subgrade corrections. Additional borings may be required to establish the limits of any identified subgrade corrections. Subgrade corrections are areas that are identified to correct specific unstable conditions in the subgrade of an existing road (e.g., frost heaves, subgrade failures, and settlements). A sufficient number of borings should be taken to determine the depth and limits of the area required for repair. At a minimum, one boring must be taken within the repair area to establish the depth and one boring from beyond each side of the repair to establish limits.

(3) HMA or PCC Overlays

Borings are only needed to establish the limits of any subgrade corrections (see the previous section, **Section 220.2.D (2)**).

3. Soil tests

The following section discusses many of the tests that can be performed by the district or the Office of Materials & Road Research on soil samples obtained for input into the design process. Reference is made to the Grading and Base Manual and/or MnDOT Lab Manual for detailed descriptions of the tests. All testing of undisturbed samples to determine engineering properties (including R-value) is performed by the MnDOT Office of Materials & Road Research.

A. Soil classification

Classify soil samples using the triaxial chart according to the **MnDOT Grading and Base Manual Section 5-692.603.d** and the **MnDOT Lab Manual Section 1302 – Particle Size Analysis of Soil**.

The AASHTO Soils Classification System (see **Section 299.1 - AASHTO Soils Classification**) and the Unified Soils Classification System (see **Section 299.2 - Unified Soils Classification**) are two other common classification systems. A correlation between these two classification systems with soil classification according to the triaxial chart is shown in **Table 299.3**.

B. Mechanical analysis

A mechanical analysis consists of a sieve analysis of a sample's coarser portion and a hydrometer analysis of its fine-grained portion. This analysis is used to classify the soil and may determine the suitability of the soil for an engineering application. The method for performing sieve analysis is in the **MnDOT Grading and Base Manual Section 5-692.215** and the **MnDOT Lab Manual Section 1200**. This test is based on **AASHTO T 27**. The procedure for performing the hydrometer test is in **MnDOT Lab Manual Section 1302**. This test is based on **AASHTO T 88**.

C. R-value

The R-value (resistance value) test is a materials stiffness test. The R-value is calculated from the ratio of an applied vertical pressure to the developed lateral pressure and is a measure of the materials resistance to plastic flow. Values could range from 0 to 100, where 0 is the resistance of water and 100 is the resistance of steel. It is performed in the laboratory on material recovered from borings. Specific instruction on the method normally used by the MnDOT can be found in the **MnDOT Lab Manual Section 1307**.

The R-value test is performed to define a soil's stiffness for pavement design. R-values tests are often not performed because projects frequently have historical R-values or because R-values may be estimated with the FWD (see **Section 200: falling-weight deflectometer (FWD)**). However, if there are no historical R-value data and the FWD cannot be used (the FWD must perform tests on HMA for R-value testing) then the soil's stiffness must be determined by R-value tests.

The sampling rate for R-value testing varies according to soil type and is shown in **Table 220.1.**

Table 220.1 - R-value Sampling Frequency Guidelines

Major Soil Texture*	Recommended Minimum Sampling Rate	Minimum Number of Total Sample
Sands	0 (assume a value of 70) **	0**
Clays, Clay Loams	1 every 2 miles	3
Sandy Loams (non-plastic to slightly plastic)	3 per mile	5
Silt Loams	3 per mile	5
Silty Clay Loams	3 per mile	5
Sandy Loams (Plastic)	3 per mile	5
Sandy Clay Loams	3 per mile	5

* Major soil texture refers to a soil texture significant enough in areal extent to economically justify a change in pavement design.

** If the percentage passing the No. 200 (75 µm) sieve exceeds 15%, then sample and select a Design R-value in the same manner as for clay, clay loams. This means that a sufficient number of gradation checks of the sand areas will have to be made to determine if stabilometer tests are required.

Note: Samples should be representative of the upper 5 feet of the proposed road grade as much as possible.

D. Soil fertility

Soil fertility tests are run by the MnDOT Office of Materials & Road Research on soils to determine acceptability for topsoil and planting soil and which fertilizer to use. The types of tests run are gradation, pH and organic content, phosphorus, potassium and soluble salts.

Use the following sampling rates

- Where the topsoil is to be removed and replaced to provide a growing medium, samples should be taken at the rate of one per mile from the full depth of the topsoil to be removed. Additional samples are required if there is a major change in soil type.
- If the topsoil is not being replaced, samples should be taken from all horizons that will be exposed and provide a growing medium. In this case, the sampling rate must be one per mile.

E. Organic content

The organic content of a soil sample is determined by using **AASHTO T 267**. **AASHTO T 194** must be used if the suitability of the soil for growth is desired.

F. Moisture

The moisture content of a soil sample is most commonly determined by either the oven or the calcium carbide gas pressure (speedy moisture) method. These methods are presented in the **MnDOT Grading and Base Manual Section 5-692.250**. They are based on **AASHTO T 217** (speedy moisture) and **T 265** (drying oven).

G. In situ strength

The in situ strength of aggregate or granular layers may be tested using a Dynamic Cone Penetrometer (DCP). This test is performed by dropping a standard weight to drive a pointed tip into the material being tested and counting the number of blows per inch of penetration. This test is frequently performed in a core hole. Specific instruction on the method used by MnDOT can be found in the **MnDOT Grading and Base Manual Section 5-692.255**.

H. Atterberg Limits

Atterberg Limits are used to determine the plasticity index (PI) of soil which is necessary to classify the soil. The plasticity index is determined according to the **MnDOT Lab Manual Chapters 1303 and 1304**.

4. Sample sizes

   Minimum sample size required for various tests are given in **Table 220.2**.

Table 220.2 - Required Sample Sizes.

Test	Size
Mechanical analysis of granular material	20-30 lb.
Mechanical analysis for cohesive material	10 lb.
Mechanical analysis and moisture-density for cohesive material	25-30 lb.
Fertility	10 lb.
R-value determination	60 lb.
pH for soil	1 lb. in clean plastic or glass container

5. Field identification

   Identification of soil types in the field, which is typically limited to an estimate of texture, plasticity, and color, is normally done without the benefit of major equipment, supplies, or time. It is necessary for a general assessment of sites during field reconnaissance activities and during the initial phases of more detailed work, such as the investigation of an emergency remediation or a planned geotechnical or pavement survey. It may, in some instances, be the only effort ever expended towards identifying the encountered soils, but in most cases it will serve as an aid in assigning more detailed laboratory tests.

   With increased experience, field personnel should become more competent and skilled in accurately classifying the encountered soils based solely on field techniques. Regardless of experience level, however, laboratory testing must be performed to validate and sharpen the field technician's ability.

   Perform soil field identification according to the following sections of the **MnDOT Grading and Base Manual**

   - **Section 5-692.603.e – Field Determination of Texture**
   - **Section 5-692.603.f – Feel and Appearance of Soil Mass**
   - **Section 5-692.604 – Secondary Classifiers**
   - **Section 5-692.605 – Organic Soils**

6. Format for boring survey notes

   Visual observations, the sequence of materials encountered in the borings, and the results of field tests must be carefully and accurately recorded. Most organizations use a paper or electronic "boring log," "record of subsurface exploration," or some similarly titled form for this purpose. MnDOT strongly recommends that each District Soils Engineer keep such data in a uniform, organized, and retrievable manner.

   The record of each boring in the “boring log” should be capable of standing alone, complete with all of the following information, entered in the order given:

   - Project identification and number
   - Boring location, typically by roadway station and offset left or right of centerline
   - Method of drilling and sampling (e.g., flight augers with grab samples)
   - Date of start and completion
   - Names of drill crew members
   - Surface elevation
   - Depth of materials encountered and description (see the MnDOT Geotechnical Manual Section 5.4.2).
   - Sample locations
   - Ground water information when encountered and at recorded times after drilling
   - Other pertinent information and/or general observations

   The accuracy of the recorded information is important because it becomes the basis for subsequent design recommendations. For example, the level of silt seams may impact frost design, wet or saturated layers may impact dewatering or drainage requirements, and shear planes or other discontinuities may impact slope stability.

   An example of a field log can be found in **Figure 3-2** of the **MnDOT Geotechnical Manual**.

7. Abbreviations

   Standard terms and abbreviations are desirable, both for saving time when describing soil samples and for ease of interpretation of field notes, profiles, etc., by others. The following terms and abbreviations (see **Table 220.3**) are approved by MnDOT for use in describing samples and preparing field notes.

Table 220.3 – Approved terms and abbreviations

Term	Abbreviation	Term	Abbreviation
<u>Heading/Location Terms</u>		**<u>Heading/Location Terms</u>**	
Trunk Highway	TH	State Project No	SP
Station	Sta	Control Section	CS
Reference Point	RP	County Road	CR
Offset	OS	County State Aid Highway	CSAH
Left	LT	Soils Engineer's Name	SEngr
Right	RT	Section	Sec
Centerline	C/L	Township	Twp
Plus	+	Range	Rng
Northbound	NB	Decimal Point	.
Southbound	SB	One-quarter	1/4
Eastbound	EB	One-half	1/2
Westbound	WB	Three Quarters	3/4
Feet	FT	Plus/Minus	+/-
Tenths	Tenths	Approximate	Approx
Kilometers	km	Question Mark	?
Meters	m	In place	Inp
Millimeters	mm		
Months	Mo	**<u>Surfacing Terms</u>**	
Materials Eng.’s Name	MEngr	Concrete	CONC
Crew’s Name	Crew	Bituminous	BIT
A thru Z	UPPER CASE	Aggregate	AGG
Ramp	Ramp	Bit. Treated Base	BTB
Loop	Loop		
Frontage Road	FR		
Service Drive	SrDr		
Source Name/Number	Srce		
Mainline	ML		
Shoulder	SHLD		

Term	Abbreviation	Term	Abbreviation
Material Terms		**Color & Shade Terms**	
Gravel	G	Black	blk
Sand	S	Brown	brn
Sand and Gravel	S&G	Grey	gry
Loamy Sand	LS	Yellow	yel
Loamy Sand and Gravel	LS&G	Tan	tan
Sandy Loam	SL	Blue	blu
Loam	L	White	wht
Silt	Si	Green	grn
Silt Loam	SiL	Red	red
Silty Clay Loam	SiCL	Orange	orng
Clay Loam	CL	Dark	dk
Sandy Clay Loam	SCL	Light	lt
Clay	C		
Silty Clay	SiC	**Textural Terms**	
Sandy Clay	SC	Very Fine	VF
		Fine	F
Boulder Terms		Coarse	Cr
Limestone	Lmst		
Sandstone	Sst	**Plasticity Terms**	
Dolostone	Dolo	slightly plastic	slpl
Shale	Shale	non-plastic	nonpl
Boulder (over 3”)	Bldr	plastic	pl
		highly plastic	hpl
Moisture Terms			
Dry	dry		
Damp	damp		
Moist	moist		
Wet	wet		
Saturated	sat		

Term	Abbreviation	Term	Abbreviation
Consistency		**Descriptors**	
Very soft	Vsoft	Deteriorated	Det
soft	soft	stripped	Strpd
firm	firm	sound	Snd
stiff	stiff	Unsound	UnSnd
Very stiff	Vstiff	weathered	wx
hard	hard	Bedrock	bedrock
very hard	Vhard	debris	debris
		chips	chips
Compaction Terms		seams	seams
Very loose	Vloose	layers	layers
loose	loose	marbled	mrbl
medium dense	meddense	mottled	mtld
dense	dense	fill	fill
Very dense	Vdense	cut	cut
		fat	fat
Water Condition		frozen	frzn
water level	H2O	ice lenses	icelns
Flowing Artesian	FlArt	ice	ice
perched water	perch	topsoil	ts
		slope dressing	sd
Peat Classification		wood	wood
Peat	peat	woody	woody
spongy	spongy	roots	roots
fibrous peat	fpeat	shells	shells
semi-fibrous peat	sfpeat	Iron Oxide Stained	IOS
well-decomposed peat	wdpeat	till	till
partially-decompose peat	pdpeat		

Term	Abbreviation	Term	Abbreviation
Miscellaneous		**Equipment**	
with	w/	Auger Truck	AT
without	w/o	Hand Auger	HA
variable	var	50# Sounding Hammer	50SH
natural	nat	20# Sounding Hammer	20SH
Not Applicable	N/A	Portable Auger	PA
and	&	Dynamic Cone Penetrometer	DCP
or	or		
to	to	**Comments**	
included	inc	Do not use periods	
Gas Smell	GasSm	Keep UPPER & lower case letters	
Road tar	RdTar		
sample	smpl		
Soil ID	SID		
R-value	RVal		
Gradation	Grad		
Fertility	Fert		
Extraction	Xtract		
at	@		
Time of drilling	TOD		
hour	hr		
no return	noret		
poor return	prret		
fluid	fluid		
REFUSAL	REFUSAL		

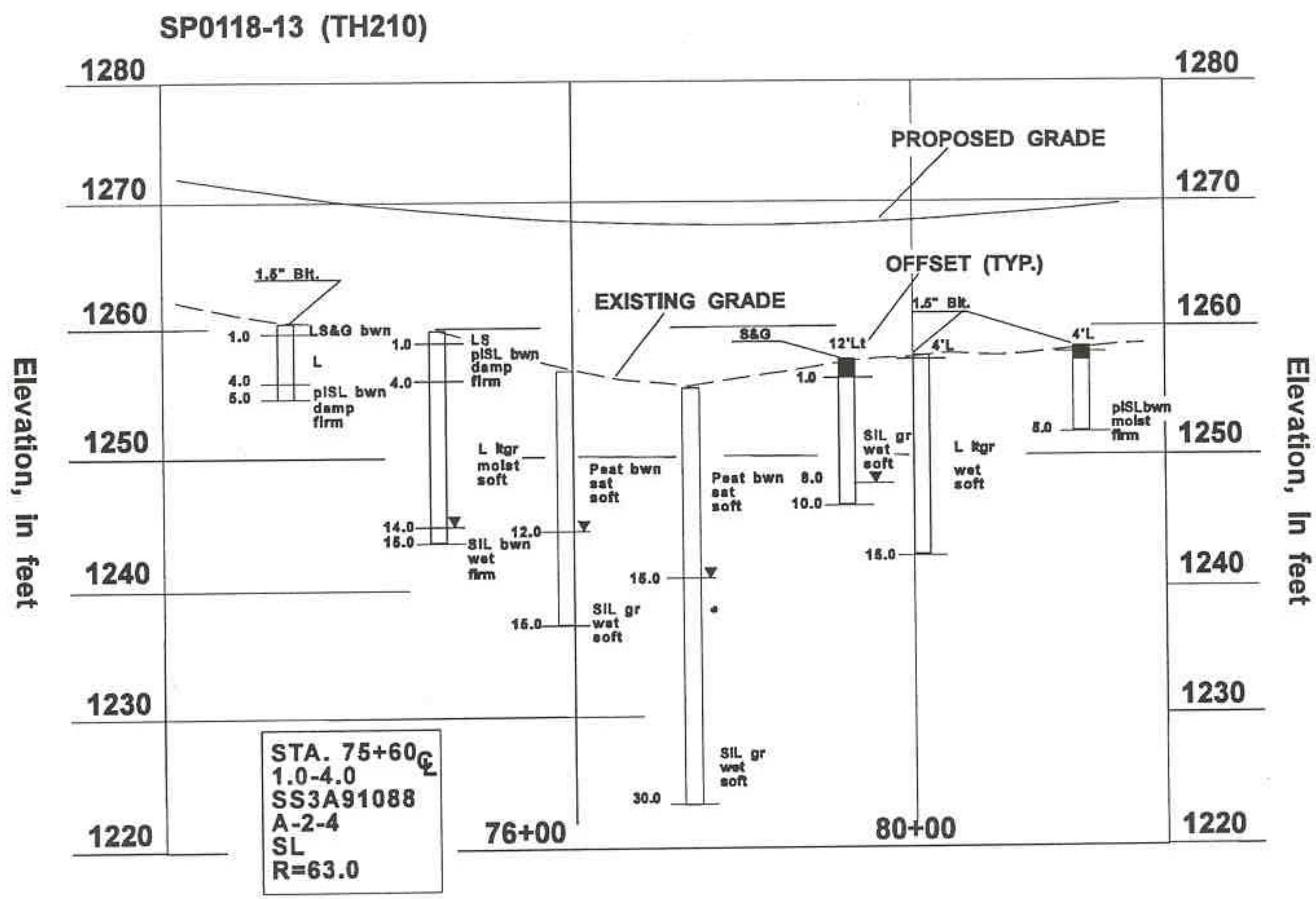
8. Soils profile or cross-section

   A soils profile or cross-section will help to visualize the physical relationship between the existing soil or pavement conditions and the new roadway. This diagram is a profile or cross-section of the information obtained during the performed surveys. It should be drawn to scale, such as 1 inch equals 5 to 10 feet vertically and 1 inch equals 20 to 100 feet horizontally, depending on the detail and complexity of the project. The following information should be included:

   - Project identification
   - Existing and proposed grades, and/or existing ground lines
   - Boring locations, including station and offset
   - Existing pavement and subgrade conditions, including interpreted stratigraphy
   - Ground water
   - Pertinent test results

   A soils profile or cross-section must be submitted as part of the MDR on projects where there is significant soils work. For projects that do not typically require extensive soils information, such as overlays, a soils profile is not necessary. **Figure 220.1** is an example of a properly prepared soils profile.

Figure 220.1 - Example soils profile.



Note: Boring hole representations by straight lines or bars and depiction of soil types by colors or symbols are discretionary with the District.

9. Sealing or backfilling borings

   A. Borings 15 feet or greater must be drilled and sealed in accordance with Minnesota Department of Health regulations and only by personnel licensed and equipped to do so legally.

   B. Borings less than 15 feet shall be backfilled with the drill cuttings, on-site soils, or imported material, with a texture and permeability similar to materials encountered in the boreholes. Imported backfill materials are required to have a lower permeability than material encountered. The borehole shall be completely filled from the bottom or cave-in depth to the original ground surface. Tamping or compacting the backfill material shall be performed as necessary to minimize voids or backfill subsidence. Backfilling must be performed after completion of the borehole.

      Note: Borings must not be permitted in known or suspected contaminated areas regardless of boring depth or groundwater elevation. If contamination of any type is noted while drilling, work must be stopped and the next level supervisor contacted immediately for further instructions.

   The MnDOT Foundations Unit (Office of Materials and Road Research) may be contacted regarding any questions concerning borings.

Section 230: Cores

This section discusses pavement cores collected to evaluate existing pavement. Cores collected for construction inspection/acceptance are not within the scope of this manual.

1. PCC

   Coring existing PCC pavement is most often performed when there are special concerns, such as poor pavement materials, to determine the nature and extent of cracking, or to determine the suitability of the existing PCC pavement for recycling as PCC aggregate. Generally, coring is not required for new/reconstruction or unbonded overlay projects.

   PCC pavement cores may be taken on or off a crack or joint. A core taken off a crack or joint will provide the pavement thickness and may be used for materials analysis. A core taken on a joint or a crack may show joint or crack deterioration that is not visible from the surface and may be useful in determining a cause of PCC deterioration.

   Contact the MnDOT Concrete Engineering Unit (Office of Materials and Road Research) to discuss the use and location of any PCC coring.

2. HMA

   HMA pavement coring may be performed to establish the thickness of the pavement and its condition. The cores may be collected from locations off-cracks, to establish HMA pavement thickness and pavement condition, or on-cracks in the HMA pavement, to establish the depth and condition of the crack. In addition to coring, GPR testing (see **Section 240: GPR**) may be performed to establish a continuous record of HMA pavement thickness.

   A. Off-crack cores

      Cores taken off-cracks in intact HMA pavement are necessary to establish the pavement thickness. This is important for pavement thickness design, FWD data analysis, GPR data analysis, and for calculating removal quantities. In addition to indicating pavement thickness, these cores can also show the general condition of the HMA, including the presence of stripped or debonded layers

      Collect these cores from the middle of the lane and try to be at least 6 feet away from any crack.

B. On-crack cores

Cores taken on-cracks are used to establish the depth and condition of the crack. This may be useful to assess the overall pavement condition, establish the depth of milling, and the degree of pre-overlay repair.

Core possible top-down cracks (typically occurring in the wheel-path) to determine their depth. Milling depth may be adjusted to completely remove this distress. Other types of cracks may be cored to determine if milling will reveal hidden deterioration. Often HMA pavement cracks exhibit stripping and are wider near the bottom of the pavement. These cracks may need to be repaired after milling or they may possibly make the roadway a poor candidate for certain types of rehabilitation techniques.

Collect on-crack cores in the vicinity of off-crack cores so that they may be compared.

C. The minimum recommended coring interval and the recommended use of GPR for different project types is shown the following table.

Table 230.1 - Minimum HMA Pavement Coring Intervals & for Use of GPR

	Off-crack Cores	On-crack Cores	GPR
New/Reconstruction	1 per mile**	0	No
FDR/SFDR	1 per mile*	0	Yes
CIR	1 per mile*	1 per mile	Yes
PCC Overlay	1 per mile*	1 per mile	Yes
HMA Overlay	1 per mile	1 per mile	No

* Increase coring to two per mile if no GPR data will be collected.

** Not necessary if there is sufficient data from boring logs to develop a HMA pavement removal quantity.

Section 240: Ground Penetrating Radar (GPR)

GPR is a non-destructive testing tool used to map the subsurface conditions. GPR works by emitting radar waves from an antenna of a type and frequency that are able to penetrate the ground and into subsurface layers. They are reflected back and give indications when the waves encounter an interface of materials with differing electrical properties. GPR antennas may be either “air-launched” or “ground-coupled” depending on the application.

1. Types of antennas

   A. Air-launched antennas are mounted so that they do not come into contact with the ground. They are typically on a vehicle and can collect data at highway speeds depending on the application. Typically, GPR can image to a depth of three to five feet depending on the frequency of the antenna being used and the properties of the materials but ambient electrical interference, the presence of water, or dense/highly conductive material will tend to obscure the image.

      Although sampling density may be limited in high-speed data collection, these antennas work well for determining the thickness of pavement and (in most cases) aggregate base layers. The GPR data may also indicate stripping in the HMA pavement. They are less effective for imaging PCC pavements when PCC is installed over electrically similar base materials.

   B. Ground-coupled antennas are operated on or very near the surface and are often dragged across the ground manually. Higher sampling density can be obtained due to the slower speed of the antenna over the surface. Ground-coupled antennas are normally used for locating subsurface objects. The depth and clarity of the image depends on the frequency of the antenna used and materials encountered. There are various antennas available with different frequencies that can image different depths and resolutions. Subsurface water and dense/highly conductive materials tend to obscure the imaging; however, ground-coupled antennas are much less susceptible to ambient noise. These antennae work well to determine layer thicknesses and interfaces, locate steel in PCC pavements and bridges, and locate buried structures or subsurface voids.

2. Use of GPR

   It is recommended to use GPR to determine the HMA pavement thickness for full-depth reclamation (FDR), stabilized full-depth reclamation (SFDR), cold in-place recycling (CIR) and whitetopping projects (see Table 230.1). For these types of projects, the thickness of the existing pavement is critical and unlike coring, GPR images the pavement thickness continuously and can produce thickness data of the pavement (and potentially the base layer) as needed - up to the GPR’s maximum sampling density.

   HMA cores are necessary to refine and improve the accuracy/precision (calibrate) of the interpreted GPR data. Provide the core locations to the GPR operators so that they can run the radar directly over those core locations. The GPR data will then be calibrated using those cores. If no cores were collected prior to GPR data collection, or more information is needed, collect cores from locations based on the GPR data, such as thin/thick sections or areas with unusual readings. The GPR operator and analyst should be provided with any pavement section data.

3. Collecting GPR Data

Contract a consultant to collect and analyze GPR data to determine pavement and/or base depth. Use the "Consultant GPR Scope of Work" document, located on the MnDOT Pavement Design website, to develop the scope of work when using a consultant.

The preparation of the scope is crucial and is dictated by the type of survey desired – depth(s) of target(s), size(s) of target(s). Shallow, highly-detailed surveys are required for smaller defects (cracks, voids) and these typically are best handled by a high-frequency, ground-coupled antenna.

When setting up the scope of services it is important to consider the type and level of detail required in the interpreted results. Data interpretation time is the main cost-driver in a consultant GPR contract. Carefully consider the needs for your specific project

If a consultant cannot be contracted because of time or some other constraint, the MnDOT Office of Materials and Road Research has the necessary equipment and is capable of performing the testing and analysis on a case-by-case basis.

The MnDOT Research Unit (Office of Materials and Road Research) has a variety of GPR antennas that may be useful to determine layer thicknesses & interfaces, locate steel in PCC pavement or indicate the location of buried structures. They may also be used to indicate the existence of subsurface voids or other anomalies. Contact the MnDOT Research Unit to discuss the feasibility of GPR testing for a particular application and to request testing.

Section 250: Traffic Data

1. A signed traffic forecast is required for all projects that will construct more than ½ mile of pavement in the **DL≥20** pavement design categories (see **Chapter 7: pavement-type Selection** for pavement design categories). To obtain a signed traffic forecast, contact the District Traffic Forecaster or the Office of Transportation System Management – Traffic Forecasting Section.

2. Projects that will construct less than a ½ mile of pavement in the **DL>20** pavement design categories or that will construct pavement in the **DL<20** pavement design categories (see **Chapter 7**) do not need a signed traffic forecast, but should have a traffic forecast developed using the most up-to-date copy of the "ESAL FORECASTING TOOL," available on the pavement design website.

3. The following table summarizes the traffic data requirements:

Table 250.1 – Traffic Data Requirements

Pavement Design Category	Length	Traffic Data
DL≥20	> ½ mile	Signed Forecast
DL≥20	< ½ mile	Estimate with ESAL Forecasting Tool
DL<20	All	Estimate with ESAL Forecasting Tool

4. The "ESAL FORECASTING TOOL" is an Excel spreadsheet that contains data collected from Vehicle Classification (VC) sites on state roads in Minnesota. This historic data is used to estimate current traffic and future accumulated ESALs. To use the "ESAL FORECASTING TOOL"

   A. Click on the "enable" box on the orange bar if it appears near the top of the spreadsheet.
   B. Enter the "Base Year" in cell B4.
   C. Left-click on the orange "FIND SITES" button at the upper-right of the spreadsheet. Clicking this button opens a form to select the appropriate VC site.
   D. Fill in the "ROUTE #" text button; do not include the route designation (e.g., MN, US, I).
   E. Left-click on the down-arrow of the drop-down list. This will open a drop-down list of the available VC sites for the previously entered route #, and the reference points (RPs) of the limits that the data directly applies. Choose the VC site that most closely applies to the segment that the forecast is being performed for. A map of the VC sites is located on the "MAP" tab of the spreadsheet to aid in selecting VC sites.
   F. Left-click on the "CLOSE FORM" button.
   G. Use the average (design lane) ESALs or the (two-way) HCADT that appear in row 23 of the spreadsheet. The AADT Growth Rate may be used to approximate the HCADT growth rate.

Section 260: Roadway Construction History

Roadway Construction History includes the year, project number, limits, width, and depth of all pavement construction activities in a road's history. This information is useful in evaluating the type and thickness of the pavement layers and their suitability for use with the proposed project. It is required data in all Pavement Design Memoranda (PDM) and Materials Design Recommendations (MDR) for pavement projects. The format for reporting is contained in the PDM and MDR templates. The following are suggested sources to get Roadway Construction History information.

1. The highway pavement management application (HPMA) includes past construction activities, pavement thickness, and project identification number (S.P.). Follow steps 1-9 but skip steps 7, 7A and 7B of **Section 280.1** to view this data.

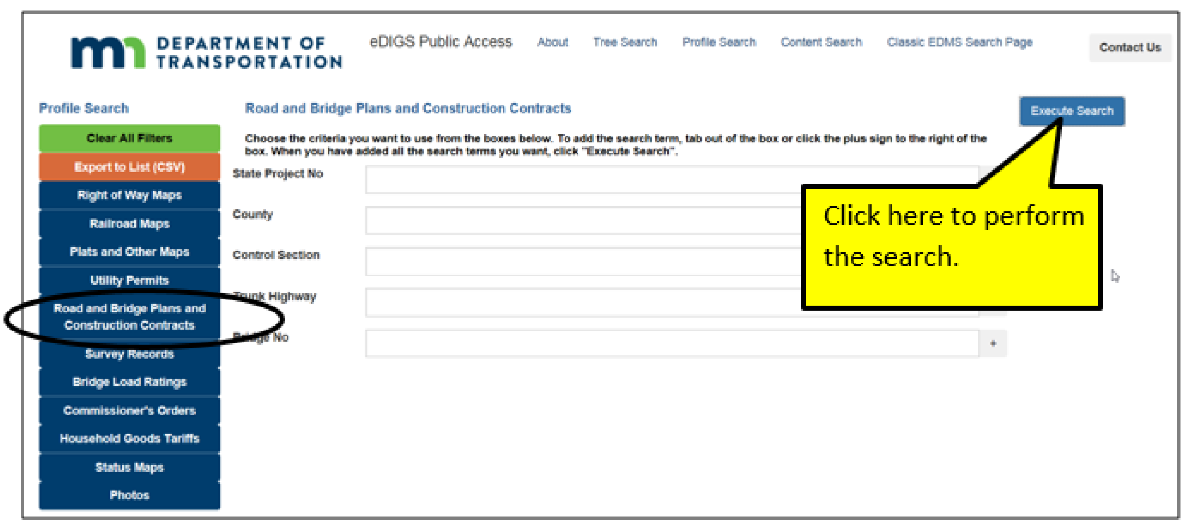
2. The construction project log contains an index of historic construction and maintenance of mainline state roads. The construction history of each control section is indexed by district then county.

   Clicking on a control section number will open up a webpage that contains construction and maintenance history for the entire control section. Note the year, project number, type, thickness, and remarks of activities that occurred within the project limits. Maintenance activities are not required to be included in the roadway construction history of the MDR/PDM.

3. View the historical project plans to confirm and supplement the data in the construction project log or the roadway history file. Historical project plans are available for viewing on the MnDOT eDIGS (Electronic Document Information GUI Search) internal and external sites. Contact the district if the plans are not available on eDIGS.

   To use the eDIGS site select "Road and Bridge Plans and Construction Contracts" from the left side of the page (see **Figure 250.1**). When the search form opens, enter a State Project No. and click on "Perform Search" near the top of the form. The search will show a list of files available for viewing. Any pop- up blocker may need to be disabled.

Figure 250.1 – The Internal eDIGS Search Screen.



Section 270: Visual Condition Assessment

A visual condition assessment is an evaluation of the condition and distresses apparent at the pavement surface. It is an effective method of choosing which types of rehabilitation options are reasonable for a roadway and determining repair strategies. A visual condition assessment is required as part of the project's MDR and PDM. The following tables list common distresses that may affect a project and should be included in the MDR/PDM.

Additional information and standards are available in the **Distress Identification Manual for the LTPP (4th Revised Edition)**.

Table 270.1 – Description of HMA pavement distresses.

Distress Type	Description
Fatigue Cracking (Alligator Cracking)	A series of interconnected cracks with a pattern that resembles an alligator's skin or chicken wire. Typically, the result of fatigue failure caused by excessive loading or weak pavement structure. Generally, assumed to initiate at the bottom of the pavement.
Block Cracking	Interconnected cracks with a rectangular pattern. Cracks range from 1' to 10' apart. Associated with aged pavements and "dry" HMA mixes.
Edge Cracking	Cracks along the edge of a HMA pavement. Often the result of poor drainage and/or lack of support.
Longitudinal Cracking (wheel path)	Cracks predominately parallel to the road's center-line and located in a wheel path. Typically, a load related distress that initiates at the pavement's surface.
Longitudinal Cracking (non-wheel path)	Cracks predominately parallel to the road's center-line and located outside the wheel paths. Generally, not a load related distress but may be caused by a lack of stability in the road structure.
Reflective Cracking	Cracks in HMA overlays that are initiated by joints or cracks in the existing HMA or PCC pavement.
Transverse Cracking	Cracks perpendicular to the road's centerline. Typically, caused by temperature induced stresses. These cracks may degrade and 'cup' (i.e. the area around the crack depresses) which is a significant cause of pavement roughness.
Patch/Patch Deterioration	Area where the initial pavement has been replaced or additional material has been applied.

Distress Type	Description
Rutting	A longitudinal depression of a wheel path. Rutting is a load induced distress caused by excessive loading or an insufficient or unstable pavement structure.
Shoving	Longitudinal displacement of an area of the pavements surface. Generally seen in areas of braking or accelerating vehicles. Caused by unstable HMA pavement that may be the result of the HMA mix having too high asphalt content, too much fine aggregates, or too much smooth or rounded aggregates.
Bleeding	Excess asphalt binder on the pavement surface. May be caused by too much binder used in the HMA mix, surface treatment, or tack coat.
Polished Aggregate	Smooth, slippery surface caused by traffic wearing away the surface binder and polishing off the sharp edges of HMA's coarse aggregate. Polishing is seen with soft aggregates.
Raveling	Rough, pitted surface caused by the dislodging of aggregate and binder. May be caused by mix segregation, low mix density, stripping (i.e. removal of binder by moisture), and aging of the asphalt binder.
Lane-to-Shoulder Drop off	Settlement of the shoulder lower than the traveled lane.
Pumping	Seeping or pumping of water and fine aggregate from beneath the pavement through pavement cracks. Caused by water collecting under the pavement through cracks or a high water table and unable to drain away.

Table 270.2 – Description of PCC pavement distresses.

Distress Type	Description
Corner Breaks	A crack from a transverse joint to a longitudinal joint (or edge of pavement) within half a slab's length of a slab's corner. Caused by load repetitions and exacerbated by slab loss of support, poor load transfer, and curling stresses.
Durability Cracking ('D' Cracking)	A series of closely spaced cracks parallel to a joint. Caused by aggregates with poor freeze-thaw properties.
Longitudinal Cracking	Cracks parallel to the road's centerline. May be caused by, late sawing of longitudinal joints, ground movements, or curling and traffic stresses.

Distress Type	Description
Transverse Cracking	Cracks perpendicular to the road's centerline. At mid-slab, it is generally a load induced distress but closer to the joints it may indicate late sawing of the transverse joints.
Joint Seal Damage	Loss of the ability of a joint seal to keep water and incompressible material from entering a sealed joint.
Joint Spalling	Cracking, breaking or chipping of the edge of a joint or crack. May be caused by, high traffic, misaligned dowel bars, poor PCC properties, or the joint was sawed too early.
Map Cracking/Scaling	Map cracking is a series of hairline cracks in the very surface of the PCC pavement that may result in the loss of material from the pavement surface (scaling). May be caused by over-finishing or deicing chemicals but may also indicate alkali-silicate reaction (ASR).
Polished Aggregates	Smooth, slippery surface caused by traffic wearing away the surface mortar and polishing off the sharp edges of the PCC's coarse aggregate. Polishing is seen with soft aggregates.
Blowups	Lifting and shattering of PCC pavement at a joint or crack. The result of insufficient room for the thermal expansion of the PCC pavement.
Faulting	A difference in the height of adjacent PCC slabs at a joint or crack. Typically the approach slab (the slab where traffic approaches the joint) is higher than the leave slab. Faulting may be prevented/minimized by having good slab load transfer and stable, non-erodible support.
Punchouts (CRCP)	Spalling, breaking-up, or faulting of an area of CRCP pavement that is enclosed by two transverse cracks, a longitudinal crack and the edge of pavement. Associated with too little steel reinforcement or corrosion of the steel reinforcement.
Lane-to-Shoulder Drop off/Separation	Difference in elevation of the shoulder and the outside of the PCC mainline or a widening of this joint. Usually caused by settling of the shoulder.
Patch/Patch Deterioration	Area where the initial pavement has been replaced or additional material has been applied.
Pumping	Seeping or pumping of water and fine aggregate from beneath the pavement through pavement cracks. Caused by water collecting under the pavement through cracks or a high water table and unable to drain away.

Table 270.3 – Description of distresses of special areas.

Distress Type	Description
Frost Heaves/Boils	Frost heaves are areas where the pavement has been pushed-up higher than the surrounding pavement by frost lenses during freezing temperatures. Frost boils are areas of pavement distress caused by trapped water in thawing pavement during melting temperatures. These areas are usually only apparent seasonally and will need to be reported by personnel familiar with the road’s condition in the winter, such as maintenance personnel.
Subgrade Failures	They may often be identified as isolated areas of alligator cracking (HMA) or panels with crescent-shaped cracks (PCC) with a depression or deformation of the pavement’s surface.

Section 280: Pavement Management System

The highway pavement management application (HPMA) is MnDOT's pavement management system software, which contains a database of roadway properties, performance, and history. It also is used to analyze pavement performance and develop various funding scenarios based on pavement decision trees and performance prediction models. For more information and the availability of the program, contact the MnDOT Pavement Management Unit (Office of Materials and Road Research).

Additional information about pavement distresses and how they are reported in the HPMA is contained in the MnDOT Distress Identification Manual.

1. The HPMA is often useful for designing pavements because it contains a description of the present pavement, past construction, pavement performance indicators and pavement distresses. Much of this data is required to be included in MDRs and PDMs.

   A means to view this data for a project can be found in HPMA by following these steps:

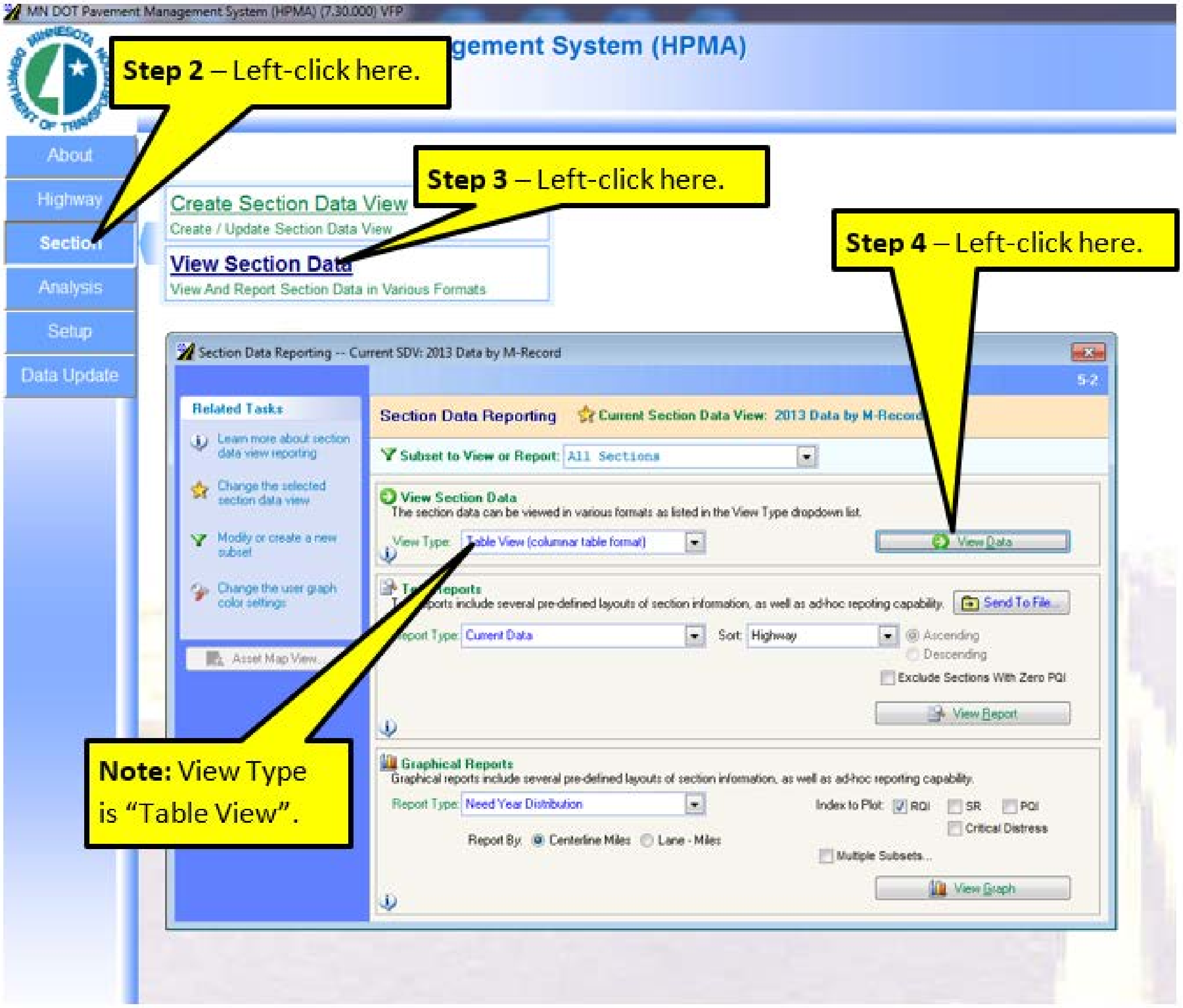
   STEP 1. Open HPMA.

   STEP 2. Left-click on "Section" (see **Figure 280.1**).

   STEP 3. Left-click on "View Section Data" (see **Figure 280.1**).

   STEP 4. Left-click on "View Data" (see **Figure 280.1**).

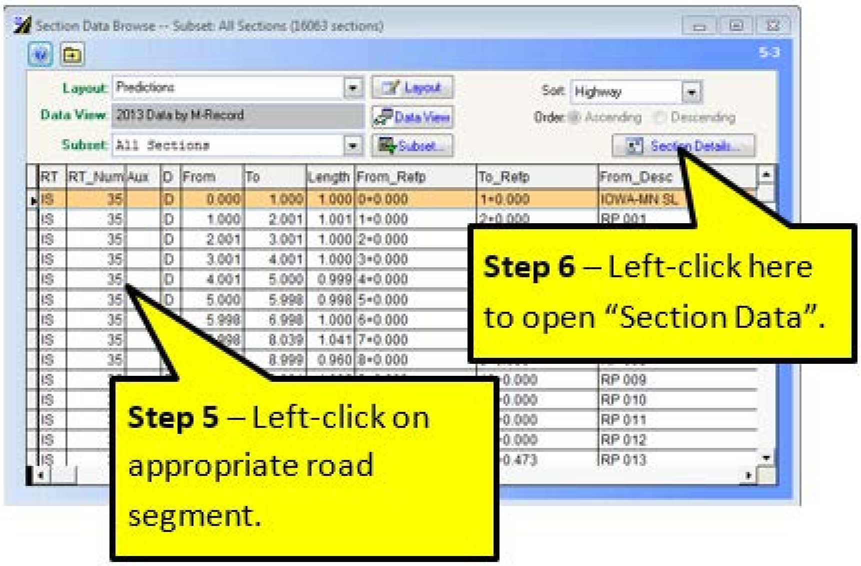
Figure 280.1 – View of HPMA for steps 2, 3 & 4.



STEP 5. Left-click on the appropriate road segment (see **Figure 280.2**).

STEP 6. View the roadway section by left-clicking on "Section Details" (see **Figure 280.2**); this brings up the "Section Data" screen.

Figure 280.2 – View of HPMA for steps 5 & 6.



STEP 7. In the "Section Data" screen, left-clicking on "Performance" (see **Figure 280.3**) will display performance and distress data.

STEP 7A. Predicted future performance indicators of the current pavement and any selected rehabilitation may be viewed by left-clicking "Plot" in the index models area (see **Figure 280.4**).

STEP 7B. Predicted performance indicators of a future activity may be viewed by using the following steps (see **Figure 280.5**):

1. Checking the "Include future activity" check box
2. Choosing an activity
3. Selecting a year for the activity
4. Refreshing the graph display

STEP 8. In the "Section Data" screen, left-clicking on "History" (see **Figure 280.3**) will show past construction activities and condition indexes.

STEP 9. In the "Section Data" screen, left-clicking on "View Data" (see **Figure 280.3**) will show past construction activities, pavement thickness, and project identification number (S.P.).

Figure 280.3 – View of "Section Data" screen for step 7, 8 & 9.

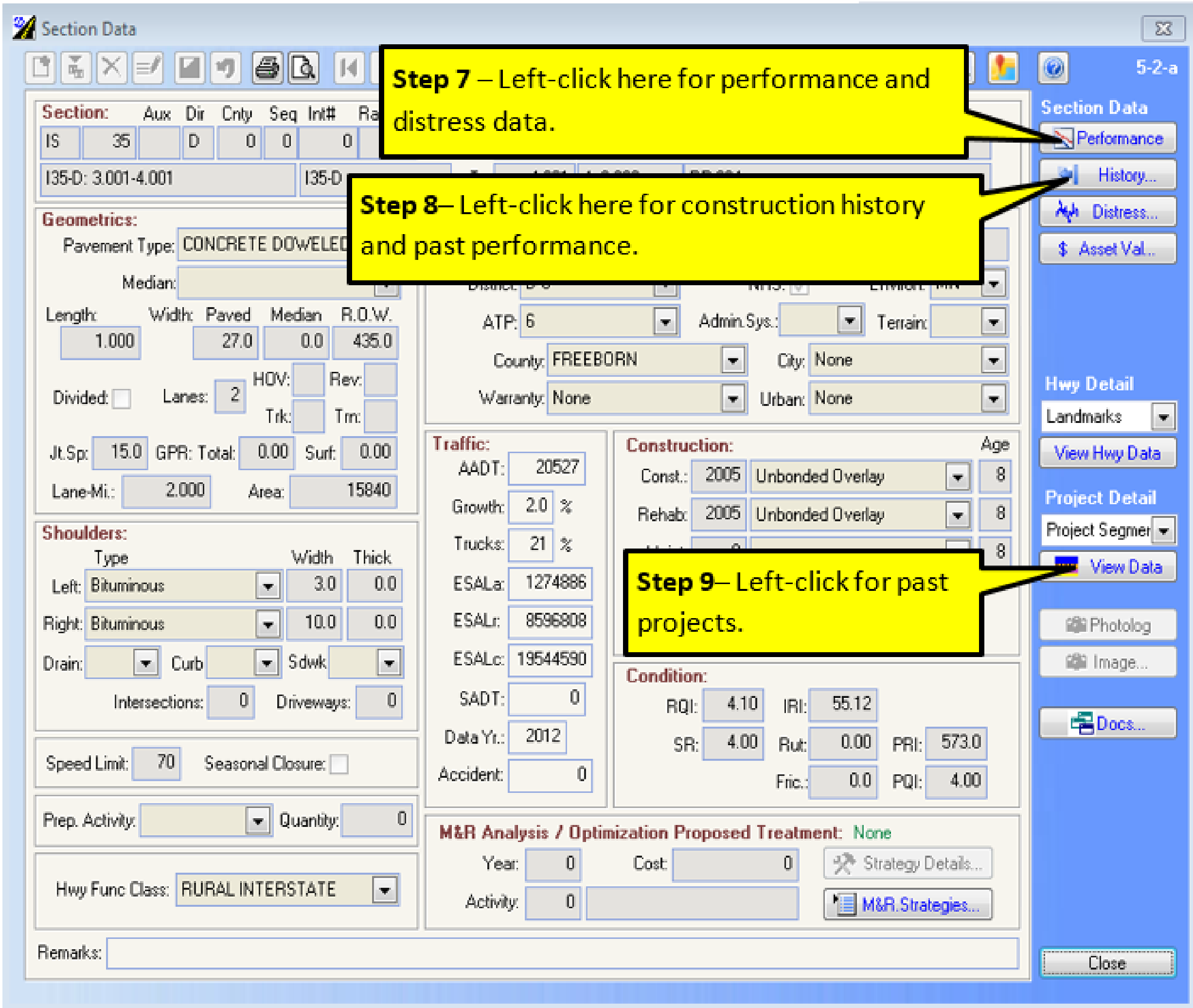


Figure 280.4 – View of "Section Performance Data" screen.

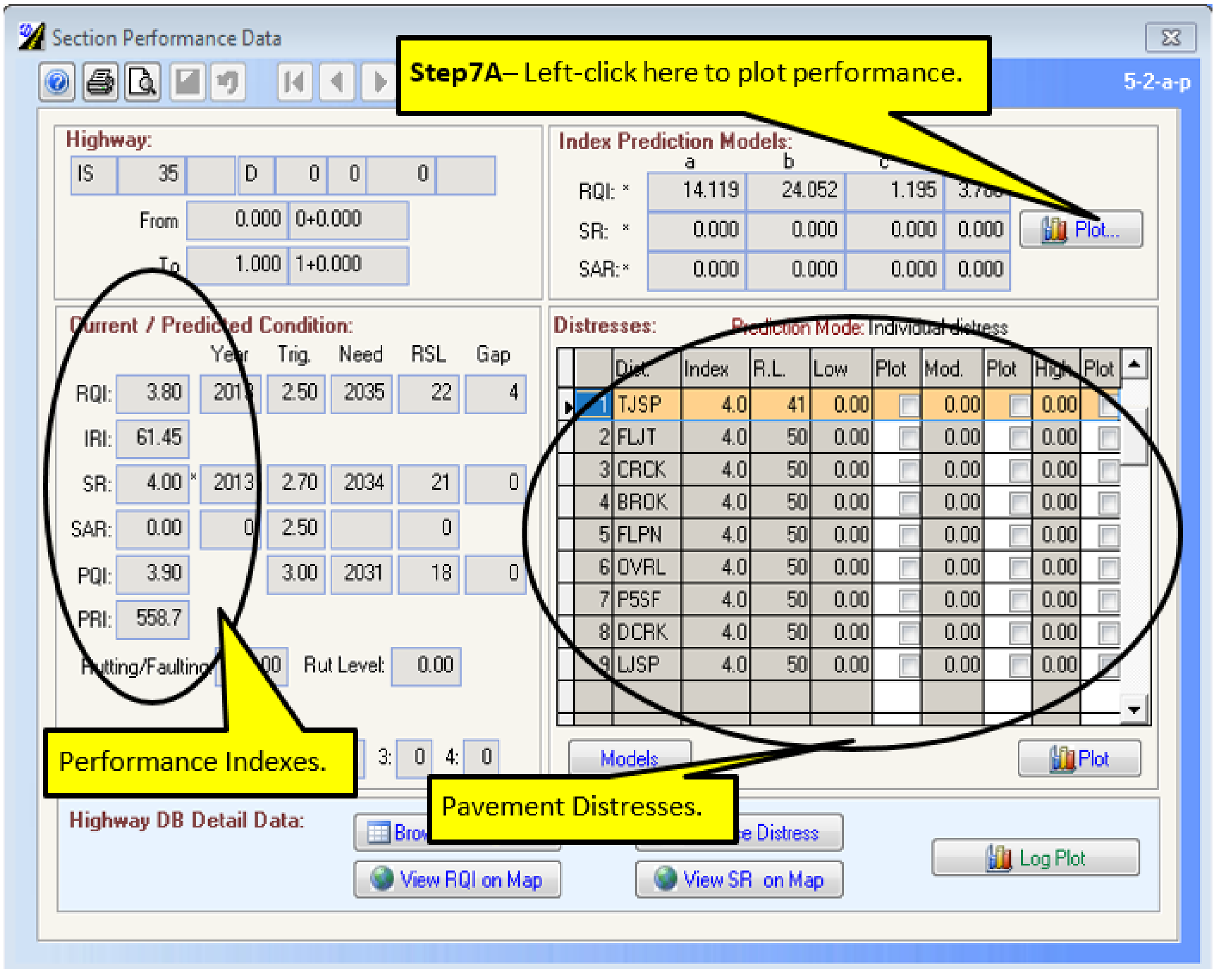
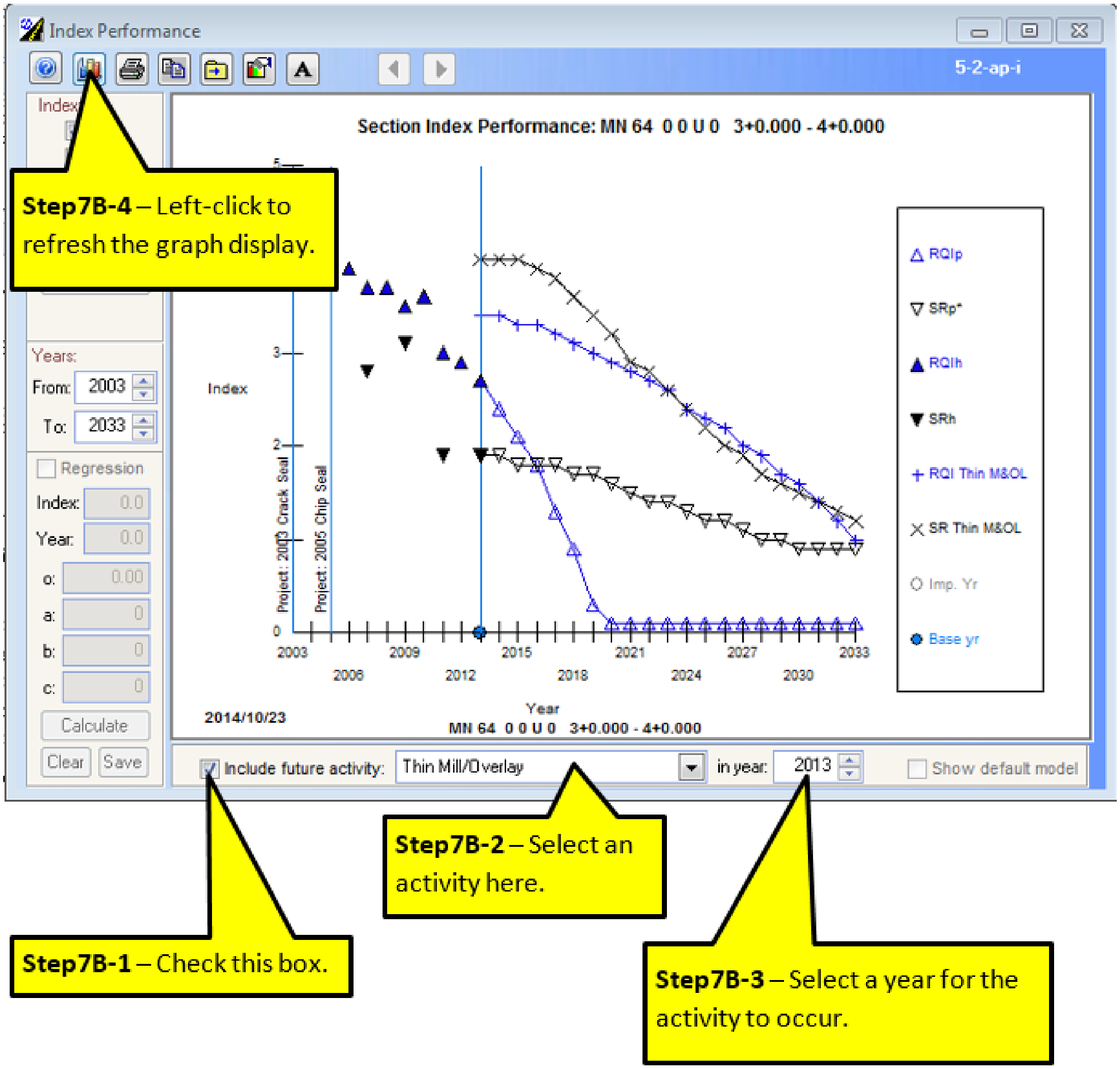


Figure 280.5 – View of the “Index Performance” screen.



2. HPMA reports the performance of the roadway using several indices which may be viewed by following steps 1-6 of **Section 280.1** and as shown on **Figure 280.4**. The following is a brief explanation of the indices that are required to be reported in MDRs and PDMs.

   A. IRI: International Roughness Index

      IRI is a ride or roughness index that is calculated from the pavement profile (using a quarter-car mathematical model) that is reported in inches/mile. IRI is the index that is used in MnDOT ride specifications (specification 2399) to measure the ride of newly constructed pavements.

   B. RQI: Ride Quality Index

      The RQI is MnDOT's ride or roughness index. It uses a 0.0 – 5.0 rating scale, the higher the value, the smoother the road. It is a conversion of IRI based on the perception of ride of a panel of volunteers.

      Most new construction projects have an initial RQI slightly over 4.0. The minimum RQI value used in the HPMA decision model to trigger rehabilitation is 2.5. This does not mean the road is un-drivable at this level but rather that it has deteriorated to a point where most people feel it is uncomfortable to drive and it is in need of major rehabilitation.

      The following table contains the descriptive names for RQI categories.

Table 280.1 - Ride Quality Index (RQI) Performance Categories.

Descriptive Category	RQI Range
Very Good	5.0 – 4.1
Good	4.0 – 3.1
Fair	3.0 – 2.1
Poor	2.0 – 1.1
Very Poor	1.0 – 0.0

C. SR: Surface Rating

The SR is MnDOT’s crack and surface distress index. It uses a 0.0 – 4.0 rating scale with a SR of 4.0 representing a brand new road with no distresses. As the type, amount and severity of the various distresses increase, the SR decreases. The pavement distresses that make up the SR are determined by trained raters from the MnDOT Pavement Management Unit (Office of Materials and Road Research) using the criteria contained in the **MnDOT Distress Identification Manual**.

Table 280.2 – Surface Rating (SR) Performance Categories.

Descriptive Category	SR Range
Good	2.5 – 4.0
Fair	1.7 - 2.4
Poor	0.0 -1.6

D. PQI: The Pavement Quality Index

$$PQI = \sqrt{RQI * SR}$$

The PQI is MnDOT’s overall pavement condition index. It combines the RQI and SR to give an overall performance indicator and ranges from 0.0 to about 4.5.

Table 280.3 – Pavement Quality Index (PQI) Performance Categories.

Descriptive Category	PQI Range
Good	2.8 – 4.5
Fair	1.9 - 2.7
Poor	0.0 - 1.8

3. Pavement distresses are included in the HPMA data. Pavement distresses are collected by the pavement management van and rated according to the **MnDOT Distress Identification Manual**. Pavement distress data may be viewed by following steps 1-6 of **Section 280.1** and as shown on **Figure 280.4**. The following tables give descriptions of the distresses and their abbreviations.

Table 280.2 - HMA pavement distresses as reported by HPMA.

Name	Abbreviation	Description
Transverse Crack	TRAN	Cracks predominantly perpendicular to the pavement centerline.
Longitudinal Crack	LONG	Cracks predominantly parallel to the pavement centerline.
Multiple Cracking	MULT	A pattern of cracks dividing the pavement into approximately rectangular blocks. The size of the blocks ranges from 6 inches to approximately 3 feet across. This type of distress normally covers the entire pavement surface.
Alligator Cracking	ALLI	A series of interconnected cracks forming many-sided, sharp-angled pieces, six inches or less in size typically located in the wheel paths or where traffic loads are concentrated.
Rutting	RUTS	A longitudinal surface depression located in the wheel path. It may also have associated transverse displacement.
Raveling & Weathering	RAVL	Wearing away of the pavement surface in hot mix asphalt concrete caused by the dislodging of aggregate particles and/or the loss of the asphalt binder. Raveling generally occurs in the wheel paths and weathering in the non-traffic areas.
Patching	PTCH	A portion of the pavement surface, 1 foot or greater in width, and in either wheel path. If the patch is full width of the lane being surveyed it must be less than 50 feet in length. If not, it is considered to be an overlay.
Longitudinal Joint Cracking	LJNT	Cracks predominantly along the pavement centerline, lane division lines or the lane to shoulder division.

Table 280.3 - PCC pavement distresses as reported by HPMA.

Name	Abbreviation	Description
Transverse Joint Spall	TJSP	Cracking, breaking, chipping or fraying along the transverse joint or edge of a slab. Joints that have bituminous patches are also considered as spalled.
Faulted Joints	FLJT	A difference in elevation of at least 0.25 inches across a transverse joint.
Cracked Panels	CRCK	A panel or slab with cracks resulting in the panel being divided into three or less pieces. The cracks must be at least 2 feet long for the slab to be counted as cracked.
Broken Panels	BROK	A panel or slab with cracks resulting in the panel being divided into four or more pieces. The cracks must be at least 2 feet long for the slab to be counted as broken.
Faulted Panels	FLPN	A difference in elevation of at least 0.25 inches across a transverse crack within a slab.
Overlayed Panels	OVRL	Panel with a HMA overlay.
Patched Panels	P5SF	A portion of the pavement surface, at least 5 sq.ft., that has been removed and replaced or had additional material applied and is in a deteriorated condition. A deteriorated condition is defined as any bituminous patch or a concrete patch showing deficiencies such as spalling or raveling at the edges or within the patch.
Durability Cracking (D-cracking)	DCRK	A series of closely spaced, crescent shaped, hairline cracks that appears in a concrete slab adjacent and roughly parallel to transverse cracks and joints, longitudinal joints and free edges of slabs. Dark coloring often exists around the cracking pattern and surrounding area.
Longitudinal Joint Spall	LJSP	Cracking, breaking, chipping or fraying along the longitudinal joint or edge of a slab. Joints that have bituminous patches are also considered as spalled.

Section 299: Appendix for Chapter 2

1. AASHTO Soils Classification

   In 1928, the Bureau of Public Roads introduced a classification system with eight soil groups, designated A-1 through A-8, to be used for assessing the suitability of road subgrade materials. Major revisions to the system, most recently in 1987, have resulted in the chart shown in **Table 299.1**. This system is based on the proportion of grain diameters falling between sieve Nos. 10, 40, and 200 (2.0mm, 0.425mm, and 75 µm) as well as the soil's plasticity. It is a quick, rational method for categorizing both undisturbed natural soil and fill in terms of its performance as a subgrade material. The system has been found to be applicable in areas with vastly different soil types and origins. In addition to the seven classifications shown in **Table 299.1**, an eighth classification, Group A-8, has been added to include highly organic soils (peat or muck). Soils in this classification are identified visually rather than by gradation and Atterberg limits.

Table 299.1 - AASHTO Classification of soils and soil-aggregate mixtures (from AASHTO M 145-91).

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.

There are three broad types under which the AASHTO groups and subgroups are divided. These are "granular" (A-1, A-3, and A-2), "silt-clay" (A-4 through A-7), and "highly organic" (A-8) materials. The transitional group, A-2, includes soils which exhibit the characteristics of both granular and silt-clay soils, making subdivision of the group necessary for adequate identification of material properties. A more detailed discussion of the AASHTO groups is included in **Section 5-692.606 of the MnDOT Grading and Base Manual**.

The engineering considerations for granular and silt-clay soils are significantly different. The following discussion highlights major differences between these two types.

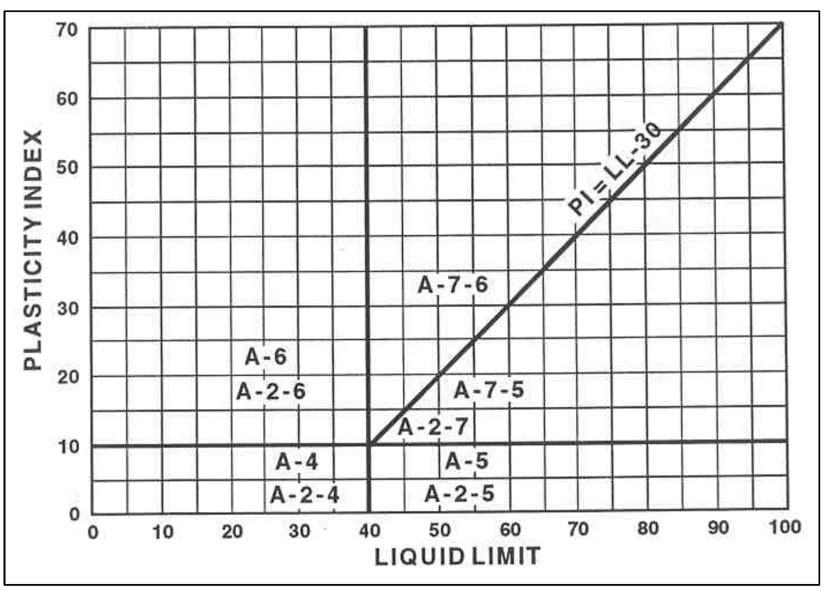
A. Granular. Granular materials include mixtures of rock fragments ranging from fine to coarse grained. Granular materials may include a non-plastic to slightly plastic soil binder, but are limited to 35 percent or less of the soil passing the No. 200 (75 µm) sieve. MnDOT's Specification 3149 limits granular backfill to no more than 20 percent passing the No. 200 (75 µm) sieve. Granular materials generally provide the most desirable subgrade.

It is possible, however, that some granular materials near the silt-clay boundary may have characteristics unsuitable for roadways in the presence of water. This is because capillarity (or a chemical affinity for water) may induce a volume change or softening of the material. In addition, frost heave becomes a concern in materials with high silt contents. Therefore, the elevation of the ground water table should be carefully considered when the subgrade is composed of these transitional soils.

B. Silt-clay. Silt-clay materials are soils having more than 35 percent passing the No. 200 (75 µm) sieve. The behavior of these soils is dominated by the fines in the soil mass. Silt-clay materials (A-4 through A-7) can provide suitable road subgrades when their shortcomings are accounted for by proper design or construction practices. Subgrades classified as A-6 or A-7 usually dictate a thickened pavement section and strictly maintained grading tolerances. A-7 materials are generally considered the poorest performers with regard to roadway construction.

Determining the AASHTO classification of a soil is a two-step process. First, the soil is categorized into one of the eight major “A” groups using the gradation limits set in **Table 299.1**. Generally, the lower-numbered soils to the left of the chart are more preferable subgrade materials than those on the right. However, this is not always true: A-3 materials usually out-perform A-2 materials. A subdivision of some of the major groups is necessary to account for varying characteristics, e.g., A-2-6 and A-2-7. These classifications can be checked graphically using **Figure 299.1**.

Figure 299.1 - Relationship between liquid limit and plasticity index for silt-clay groups*



* From AASHTO M 145-91.

Two examples of obtaining the proper classification of a soil using the AASHTO system (**Table 299.1**) are given below:

Example 1. What is the classification of a soil sample with 75% passing the No. 10 (2.0 mm) sieve, 55% passing the No. 40 (0.425 mm) sieve, and 12% passing the No. 200 (75 µm) sieve, a liquid limit of 20, and a plasticity index of 4?

Start at the left of **Table 299.1** and move to the right. The soil is granular because 35% or less passes the No. 200 (75 µm) sieve. The soil is not an A-1-a because 50% or more passes the No. 10 (2.0mm) sieve, not an A-1-b because 50% or more passes the No. 40 (0.425 mm) sieve and not an A-3 because 10% or more passes the No. 200 (75 µm) sieve. However, it meets all of the requirements of an A-2-4 because 35% or less passes the No. 200 (75 µm) sieve, its liquid limit is 40 or less, and its plasticity index is 10 or less. The soil should be classified as an A-2-4.

Example 2. What is the classification of a soil sample with 100% passing the Nos. 10 and 40 (2.0 mm and 0.425 mm) sieves, 72% passing the No. 200 (75 µm) sieve, a liquid limit of 45, and a plasticity index of 25?

Start at the left of **Table 299.1** and move to the right. The soil is a silt-clay because 36% or more passes the No. 200 (75 µm) sieve. The soil is not an A-4 because its liquid limit is 40 or more, not an A-5 because its plasticity index is 10 or more, and not an A-6 because its liquid limit is 40 or more. However, it meets all of the requirements of an A-7 because 36% or more passes the No. 200 (75 µm) sieve, its liquid limit is 41 or more, and its plasticity index is 11 or more. Furthermore, the soil should be classified as an A-7-6 because its plasticity index (25) is larger than its liquid limit minus 30 (15).

The subgrade quality of silt-clay soils can vary from poor to good within each major group. Therefore, a group index (G.I.) is added to the group symbol found in **Table 299.1** to indicate the plastic properties of the fines passing the No. 200 (75 µm) sieve. Calculation of this group index is the second and final part of the AASHTO classification. Generally, the higher the value of the group index for a given group classification the poorer the performance as a subgrade material. Therefore, a group index of zero (0) indicates a "good" subgrade material and a group index of 20 or more indicates a "poor" subgrade material.

The formula used to compute the group index is

Equation 299.1

$$G.I. = (F - 35)\,[0.2 + 0.005\,(LL - 40)] + 0.01\,(F - 15)\,(PI - 10)$$

Where:

G.I. = group index, reported as a positive whole number or zero

F = percentage passing the No. 200 (75 µm) sieve, expressed as a whole number
(This percentage is based only on the material passing the 3.0 inch (75 mm) sieve)

LL = liquid limit

PI = plasticity index

Note that only the second term, which accounts for the effect of the plasticity index, is used for the group classifications of A-2-6 and A-2-7.

The group index is added in parenthesis after the group symbol, i.e., A-4(5) or A-7-5(17), etc. Two examples are given below:

Example 1. What is the complete classification of an A-7-5 with 80% passing the No. 200 (75 µm) sieve, a liquid limit of 90, and a plasticity index of 50?

The G.I. = (80 - 35) [0.2 + 0.005 (90 - 40)] + 0.01 (80 -15) (50 - 10) = 46.

Therefore, the complete classification is A-7-5(46).

Example 2. What is the complete classification of an A-2-7 with 30% passing the No. 200 (75 µm) sieve, a liquid limit of 50, and a plasticity index of 30?

Using only the second term in **Equation 299.1**, the G.I. = 0.01 (30 - 15) (30 - 10) = 3.

Therefore, the complete classification is A-2-7(3).

The influence of fine content, plasticity, and liquid limit on group index is shown graphically in **AASHTO M145-91**.

The following descriptions provide profiles of each of the groups within the AASHTO classification system shown in **Table 299.1**:

Group A-1 includes well-graded gravel through fine sand with little or no non-plastic binder. Subgroup A-1-a includes stone fragments and gravel, with or without fines. Subgroup A-1-b includes predominantly coarse sand with or without fines. When properly placed and compacted, these materials perform well as road subgrades, as they are free draining and possess ample strength when properly placed.

Group A-2 consists of transitional granular materials, all of which have less than 35 percent fines. Subgroups A-2-4 and A-2-5 have fines that are silty (non-plastic). Subgroups A-2-6 and A-2-7 have fines that are similar to A-6 or A-7 soils; that is, the fines are more plastic. A-2 soils, usually having group indices up to four, may range from good to fair as road subgrade. Frost susceptibility begins to be a problem in the A-2 soils, especially where the water table is in proximity to the zone of yearly frost depth.

Group A-3 is mostly poorly graded fine sand with few fines. Typical examples include blow sand, some beach sands, or poorly graded stream or river sand with minimal gravel content. A-3 soils are relatively free draining and possess desirable strength characteristics, but they may be somewhat difficult to compact due to their uniformity.

Group A-4 soils are non-plastic to moderately plastic silts. Sand and gravel contents can range up to 64 percent. Group indices usually range up to eight, with lower values indicative of higher gravel and/or sand contents. Again, where drainage is poor and free water is available to the silty subgrade, frost heave should be considered as a significant factor affecting the desirability of this material.

Group A-5 soils are similar in grain-size distribution to A-4 soils, but have higher liquid limits, indicative of diatomaceous or micaceous soils. The elastic nature of these soils, especially in the absence of sand, causes group indices to be higher than the A-4 soils, perhaps as high as 12. Frost considerations are, again, a significant factor affecting usage of these soils as road subgrade.

Group A-6 soils are clays, usually plastic with 75 percent or more passing the No. 200 (75 µm) sieve. With increasing sand content, up to 64 percent, the group index may be held low; but the group index can range up to 16 if the soil is devoid of sand. Usually, significant changes of volume will occur between dry and wet states. These materials may compact sufficiently at proper moisture content, but they will generally require a thicker pavement section to provide a non-yielding road surface. Frost considerations are usually outweighed by their affinity for water and the resulting volume changes and strength reductions that can result.

Group A-7 soils may be very elastic and plastic, subject to very high volume change with variations in moisture content. Strength can be low to high, but all A-7 soils are quite impermeable. A-7 soils are only utilized as road subgrade where nothing else is available.

Group A-8 soils are highly organic peats or mucks. These soils are highly undesirable for road subgrades and generally require removal.

2. Unified Soils Classification

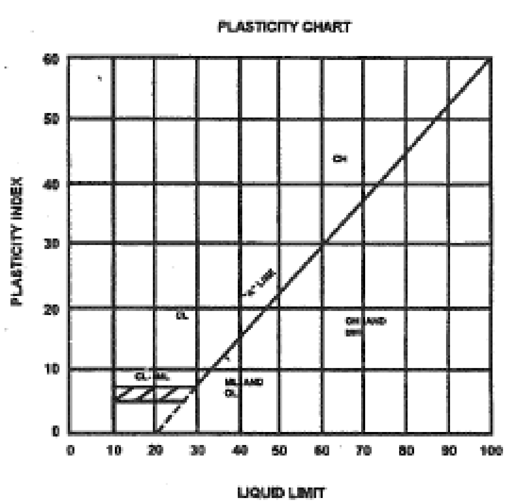
Another classification system used widely is the Unified Soil Classification System (USCS). The present system, modified by the U.S. Army Corps of Engineers and the Bureau of Reclamation, was introduced during World War II by Casagrande of Harvard University to assist engineers in the design and construction of airfields. As with the AASHTO system, the USCS utilizes grain-size distribution and plasticity characteristics to classify soils. The USCS, however, categorizes soils into one of 15 major soil groups that additionally account for the shape of the grain-size distribution curve.

Table 299.2 shows the USCS classification system along with the criteria for associating the group symbol, such as "CL," with the soil. In this chart, D_{60} refers to the diameter of the soil particles where 60 percent of the sample would be finer. Similarly, D_{10} relates to the maximum diameter of the finest 10 percent of soil, by weight.

Table 299.2 - Unified Soil Classification System Chart.*

UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM D-2487)

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES	LABORATORY CLASSIFICATION CRITERIA		
COARSE GRAINED SOILS (MORE THAN HALF OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE)	GRAVELS (MORE THAN HALF OF COARSE FRACTION IS GREATER THAN NO. 4 SIEVE SIZE)	CLEAN GRAVELS (LITTLE OR NO FINES)	GW	WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	DETERMINE PERCENTAGES OF SAND AND GRAVEL FROM GRAIN-SIZE CURVE, DEPENDING ON PERCENTAGE OF FINES (FRACTION SMALLER THAN NO. 200 SIEVE), COARSE-GRAINED SOILS ARE CLASSIFIED AS FOLLOWS: LESS THAN 5 PERCENT - GW, GP, SW, SP MORE THAN 12 PERCENT - GM, GC, SM, SC 5 TO 12 PERCENT - BOARDERLINE CASES REQUIRING DUAL SYMBOLS (b)	Cu= D60/D10 GREATER THAN 4; Cc= (D30)^2/(D10 * D60) BETWEEN 1 AND 3	
			GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES		NOT MEETING ALL GRADATION REQUIREMENTS FOR GW	
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)	(a) GM d / u	SILTY GRAVELS, GRAVEL-SAND MIXTURES		ATTERBERG LIMITS BELOW "A" LINE OR P.I. LESS THAN 4	ABOVE "A" LINE WITH P.I. BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS
			GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES		ATTERBERG LIMITS BELOW "A" LINE WITH P.I. GREATER THAN 7	
	SANDS (MORE THAN HALF OF COARSE FRACTION IS SMALLER THAN NO. 4 SIEVE SIZE)	CLEAN SANDS (LITTLE OR NO FINES)	SW	WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES		Cu= D60/D10 GREATER THAN 6; Cc= (D30)^2/(D10 * D60) BETWEEN 1 AND 3	
			SP	POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES		NOT MEETING ALL GRADATION REQUIREMENTS FOR SW	
		SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)	(a) SM d / u	SILTY SAND, SAND-SILT MIXTURES		ATTERBERG LIMITS BELOW "A" LINE OR P.I. LESS THAN 4	LIMITS PLOTTING IN HATCHED ZONE WITH P.I. BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS
			SC	CLAYEY SAND, SAND-CLAY MIXTURES		ATTERBERG LIMITS BELOW "A" LINE P.I. GREATER THAN 7	
FINE GRAINED SOILS (MORE THAN HALF OF MATERIAL IS SMALLER THAN NO. 200 SIEVE SIZE)	SILTS AND CLAYS (LIQUID LIMIT LESS THAN 50)		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS, OR CLAYEY SILTS WITH SLIGHT PLASTICITY	PLASTICITY CHART		
			CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS			
			OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY			
	SILTS AND CLAYS (LIQUID LIMIT GREATER THAN 50)		MH	INORGANIC SILTS, MICACEOUS OR DIOTOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS			
			CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS			
			OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS			
	HIGHLY ORGANIC SOILS		Pt	PEAT AND OTHER HIGHLY ORGANIC SOILS			



a) Division of GM and SM groups into subdivisions of d and u are for roads and airfields only. subdivision is based on Atterberg limits; suffix d used when L.L. is 28 or less and the P.I. is 6 or less; the suffix u used when L.L. is greater than 28.
b) Borderline classifications, used for soils possessing characteristics of two groups, are designated by combinations of group symbols. For example: GW-GC, well graded gravel-sand mixture with clay binder.

* After U.S. Army Corps of Engineers, Waterways Experiment Station, TM 3-357, 1953)

The plasticity chart shown in the lower right-hand portion of **Table 299.2** is a graphical representation of the USCS based solely on the plastic and liquid limits (**MnDOT's Geotechnical Manual Section 4.8.1**) of the material passing the No. 40 (0.425mm) sieve. Clays will plot above the "A-line" and silts below. The chart further divides the clays and silts into low (less than 50) and high liquid limits.

Two examples of using **Table 299.2** to obtain the soil's proper Unified Classification are:

<u>Example 1</u>. What is the classification of a soil sample with 88% passing the No. 4 (4.76mm) sieve, 38% passing the No. 200 (75 µm) sieve, a liquid limit of 15, and a plastic limit of 4?

Initially, it is determined that the soil is coarse grained because more than half (62%) is retained on the No. 200 (75 µm) sieve. It is then determined to be a sand because more than half of the 62% that is retained on the No. 200 (75 µm) sieve passes the No. 4 (4.76mm) sieve. Since there is more than 12% passing the No. 200 (75 µm) sieve, the soil is a sand with fines. The intersection of the liquid limit (15) and plasticity index (15 - 4 = 11) is above the "A line" on the plasticity chart. Therefore, the soil is an <u>SC</u>.

<u>Example 2</u>. What is the classification of a soil sample with 77% passing the No. 200 (75 µm) sieve, a liquid limit of 44, and a plastic limit of 18?

Initially, it is determined that the soil is fine grained because more than half (77%) passes the No. 200 (75 µm) sieve. The intersection of the liquid limit (44) and plasticity index (44 - 18 = 26) indicates a classification of <u>CL</u>.

3. Correlation of classification systems

The triangular textural, AASHTO and USCS classification systems all associate pertinent engineering properties with identifiable soil groupings. However, each system defines soil groups in a slightly different manner. For example, the triangular textural and AASHTO classification systems distinguish gravel from sand at the No. 10 (2.0 mm) sieve, whereas the USCS uses a break at the No. 4 (4.76 mm) sieve. The same coarse-grained soil could, therefore, have different percentages of gravel and sand in the triangular textural and USCS classification systems.

Because of such differences, a direct correlation of these soil classifications cannot be made. However, it is possible to make a general comparison as shown in **Table 299.3**

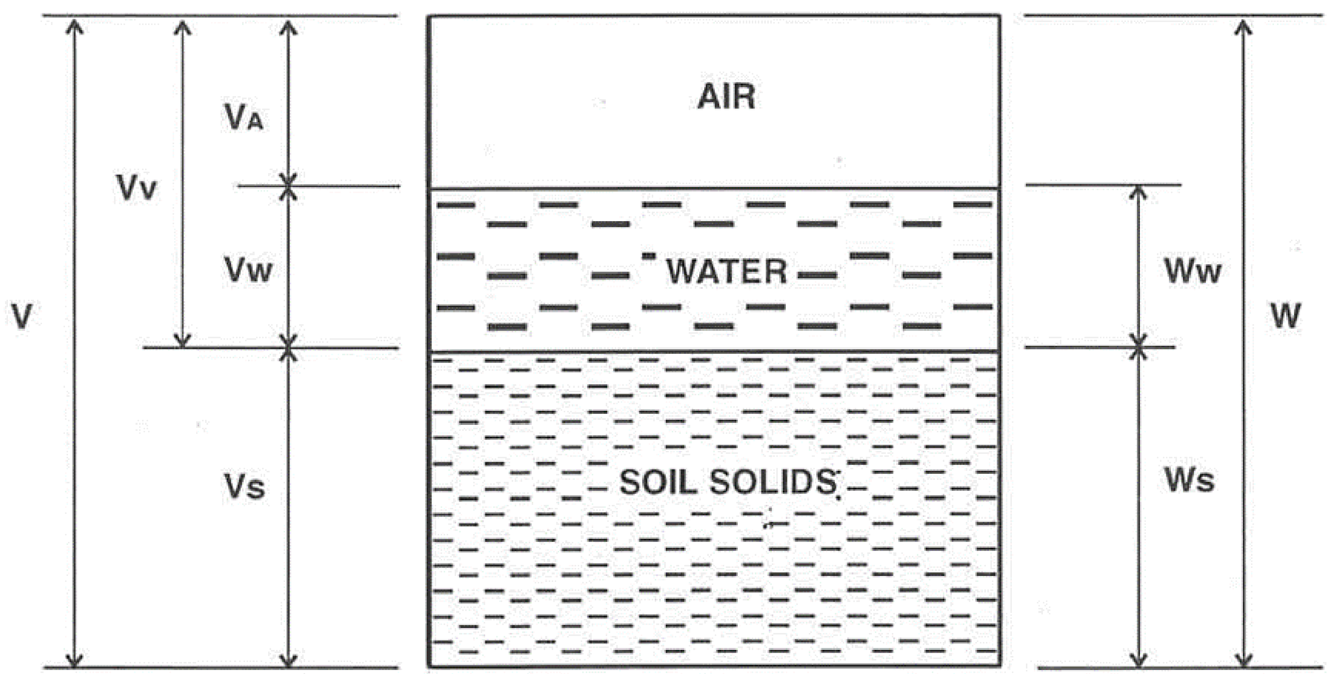
Table 299.3 - Approximate Equivalent Classifications.

MnDOT Triangular Textural	AASHTO (Group Index)	Unified (USCS)
Gravel	A-1-a(0)	GW, GP
Sand	A-1-b(0)	SW, SP
Coarse Sand	A-1-a, A-1-b(0)	SW, SP
Fine Sand	A-1-b, A-3(0)	SW, SP
Loamy Sand	A-2-4, A-2-5(0)	SM, SC
Sandy Loam (Slightly Plastic)	A-2-4, A-2-6, A-2-7(0)	SM, SC
Sandy Loam (Plastic)	A-4(0-4)	SM, SC
Loam	A-4(0-4)	ML, OL, MH, OH
Silt Loam	A-4(0-4)	ML, OL, MH, OH
Silt	A-4	ML, OL, MH, OH
Sandy Clay Loam	A-6, A-5(0-16)	SC, SM
Clay Loam	A-6(0-16)	ML, OL, CL, MH, OH, CH
Silty Clay Loam	A-6, A-5(0-16)	ML, OL, CL, MH, OH, CH
Sandy Clay	A-7, A-7-6(0-20+)	SC, SM
Silty Clay	A-7, A-7-5(0-20+)	OL, CL, OH, CH
Clay	A-7(0-20+)	CL, CH, OH, OL

4. Volume and weight relationships

Soil is comprised of a mixture of soil solids, water, and air. The relative proportion of each of these constituents determines many of the properties of the soil. A soil block diagram, with symbols for each of its volume and mass components, is shown in **Figure 299.3.**

Figure 299.3 - Volume and weight relationships for soil.



The Moisture content is the ratio of the weight of water to that of the dry soil solids, expressed as a percent. It is determined as follows:

Equation - 299.2

$$w = \frac{W_w}{W_s} * 100$$

where:

w = moisture content (%)

W_s = dry weight of solids (gm)

W_w = weight of water (gm)

Table 299.4 - Typical Moisture Contents*

Material	Moisture Content, w (%)
Gravel	2-10
Sand	5-15
Silts	5-40
Clays	10-50 (or more)
Organic (Peat)	> 50

* Terzaghi, K. and Peck, R. B., "Soil Mechanics in Engineering Practice"

The porosity is the ratio of the volume of voids to the total volume and may be expressed as either a percent or decimal. It is determined as follows:

Equation - 299.3

$$n = \frac{V_v}{V}$$

where:

n = porosity

V_v = volume of voids (cm^3)

V = total volume, (cm^3)

The degree of saturation is the ratio of the volume of water to the total volume of voids, expressed as a percent. It is determined as follows:

Equation - 299.4

$$S = \frac{V_w}{V_v} \times 100$$

where:

S = saturation (%)

V_w = volume of water (cm^3)

V_v = volume of voids (cm^3)

The void ratio is the ratio of volume of voids to volume of solids and may be expressed as a percent or decimal. It is determined as follows:

Equation 299.5

$$e = \frac{V_v}{V_s} \times 100$$

where:

e = void ratio

V_v = volume of voids (cm^3)

V_s = volume of solids (cm^3)

The density, or unit weight, of the soil mass is further divided into moist density and dry density. Moist density is the weight of water and soil solids divided by the volume of the soil mass. Dry density is the weight of only the soil solids divided by the volume of the soil mass. These values are determined using the following formulas:

Equation - 299.6

$$Y_m = \frac{W_w + W_s}{V}$$

or

Equation - 299.7

$$Y_d = \frac{Y_m}{1 + \frac{w}{100}}$$

where:

Y_m = moist density (pcf or (kg/m^3))

Y_d = dry density (pcf or (kg/m^3))

W_s = weight of solids (lb. or (kg))

W_w = weight of water (lb. or (kg))

W = moisture content (%)

V = total volume (ft^3 or (m^3))

Table 299.5 - Typical Dry Densities*

Soil	lb/ft^3 (kg/m^3)
Gravel and Sand	120 – 140 (1,900 – 2,250)
Silts and Clay	90 – 110 (1,450 – 1,750)
Peat	~ 20 (300)

* Terzaghi, K. and Peck, R. B., "Soil Mechanics in Engineering Practice"

The density of the soil mass affects the strength of the soil. Generally, the strength of a soil increases as its dry density increases. Also the potential for the soil to take on water at later times is decreased by higher densities. This is due to the decreased presence of air space in the soil mass.

The in situ moisture content of a soil is often used, along with the soil classification, to determine the suitability of the material as a subgrade. Generally, as the moisture content of a soil increases its strength decreases and the potential for deformation and instability increases. For example, if the natural moisture content is near the liquid limit then the soil will quickly be disturbed by earth moving equipment and is unlikely to be suitable subgrade material. On the other hand, a natural moisture content below the plastic limit indicates a relatively firm material that could provide a suitable subgrade, provided that additional moisture is not added. The moisture content of a soil should be expected to vary seasonally.

5. FWD testing

A. MnDOT uses Dynatest FWDs that are each equipped with 10 pavement deflection sensors. One of the 10 sensors is located on a bracket behind the load plate and is used for PCC joint transfer testing. The following sensor positions (in distance to the center of the load plate are used):

Table 299.6 – FWD Sensor Positions

Sensor #	Distance
1	0
2	8 inches (203.2 mm)
3	12 inches (304.8 mm)
4	18 inches (457.2 mm)
5	24 inches (609.6 mm)
6	36 inches (914.4 mm)
7	48 inches (1219 mm)
8	60 inches (1524 mm)
9	72 inches (1829 mm)
10*	-12 inches (-304.8 mm)

* This sensor is placed in a bracket behind the load plate.

B. For FWD testing that will be analyzed with the TONN program or the ELMOD program, the following drop sequence is recorded:

- 2 drops at 9,000 pounds.
- 2 drops at 12,000 pounds.

C. For FWD testing of PCC joint load transfer, the following drop sequence is recorded:

- 2 drops at 9,000 pounds.
- 2 drops at 12,000 pounds.
- 2 drops at 15,000 pounds.

D. MnDOT standard FWD test locations are every tenth of a mile in the outside wheel path.